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The Causal Effect of Crisis Events on Health and Economic Outcomes

by

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Abstract

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In recent decades, an increasing number of crisis events, especially epidemics, economic crisis and natural disasters, have provoked socioeconomic upheaval and human suffering on an unprecedented scale, which emphasises the urgent need for crisis preparedness and management as well as raising public awareness of the potential risks of crisis events. In view of the importance of conducting cost-benefit analysis of crisis events which can inform evidence-based policy making associated with effectively coping with crisis, this thesis evaluates the causal effect of the Severe Acute Respiratory Syndrome (SARS) epidemic, fiscal austerity policies and wildfires on financial market performance, health outcomes of older people as well as adverse health conditions among the elderly and neonates respectively by using causal inference methods. Specifically, to assess the causal effect of SARS on Chinese A-share returns and systematic risk of each sector, the empirical analysis adopts the canonical difference-in-differences (DD) and difference-in-differences-in-differences (DDD). As for estimating health costs of fiscal austerity in Europe, the study employs extensions of DD and DDD with continuous treatment intensity at the country and individual level. In terms of assessing health consequences induced by wildfires in US, the research applies DD, two-way fixed effects approach as well as a $DID_{+, t}$ estimator suggested by de Chaisemartin and D'Haultfœuille (2020) which considers heterogeneity of treatment effects of wildfires across counties and over time. In terms of economic costs of epidemics, the empirical findings show that SARS epidemic had a negative effect on A-share returns in the entire stock market and in sectors including consumer discretionary, health care, industrials, and utilities. No sectors benefited from the SARS epidemic. There is also a significant increase in the systematic risk of the financials sector, whereas the systematic risk of the communication services and utilities is not influenced by SARS. As for health costs of fiscal austerity, the results indicate that fiscal austerity led to poorer self-perceived health and limited access to outpatient healthcare services indicating lack of diagnostic medical checks among the elderly, which may explain the null or positive impact of fiscal austerity on several indicators of physical and mental health since older people were not informed of their own physical or mental health issues while health indicators are self-reported. With respect to health impact of wildfires, results demonstrate that maternal exposure to large wildfires results in a slightly larger probability of developing other circulatory or respiratory anomalies among newborns, a higher likelihood of low birth weight, and a marginally increased probability of prematurity. When considering wildfires of different sizes, evidence show that wildfires induced a reduced risk of developing omphalocele and cleft lip for infants, a small rise in the length of gestation as well as a higher risk of macrosomia. Moreover, older people exposed to wildfires experienced asthma symptoms more often and suffered from a longer period of poor mental health. Wildfires also led to physical inactivity for senior citizens. In terms of the main contributions, this thesis investigates the effect of crisis events on a wider range of health outcomes of the elderly and neonates which receive scant attention in previous research. The thesis also studies the impact of epidemics on stock market performance of every sector, some of which are not considered in preceding literature. In addition, special attention is paid to vulnerable populations including the elderly and neonates. Methodologically, preceding research mainly adopts correlational methods, whereas in this thesis, the causal inference methods are used to more accurately identify the costs or benefits induced by crisis events and inform evidence-based policy making.

Table of Contents

Table of Tables

Table of Tables

Table of Figures

Research Thesis: Declaration of Authorship

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I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

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Chapter 1 Introduction

1.1 Aims and Objectives

1.1.1 The Effect of Crisis Events

Despite the creation and evolution of civilization and science, in an uncertain world full of unforeseen contingencies, human beings have been vulnerable both physically and psychologically in the face of interconnected crisis events, such as communicable diseases, economic crisis and climate change, which periodically caused enormous human suffering as well as social, political and economic disruption in human history. Public health crisis, financial crisis and natural disasters, happened more frequently across the globe in recent decades. Nevertheless, many countries remained unprepared to respond to crisis events and were incapable of managing each crisis efficiently leading to considerable economic loss and devastating health consequences. For instance, in terms of extreme weather events, there has been a rise of 53.7% in the death rate of the elderly aged 65 and above due to heatwaves around the world between 2000 and 2018, while 302 billion working hours were reduced in 2019 over the entire globe because of heat shocks (Watts *et al.*, 2021). As for the economic consequences of climate change crisis, the monetised costs of mortality Induced by exposure to extreme heat across the globe accounted for 0.37% of gross world product in 2018, whilst the income losses owing to a decline in working time related to heatwaves were estimated to be between 3.9% and 5.9% of GDP among the lower middle-income economies before 2015 (Watts *et al.*, 2021). In total, the financial losses caused by 236 extreme climate events amounted to $132 billion all over the world during 2019 (Watts *et al.*, 2021). In regard to economic crisis, as a result of the 2008 financial crisis, the average GDP growth of all European countries fell to -5.8% in 2009 (Baumbach and Gulis, 2014). Meanwhile, Slovakia and Poland respectively witnessed an extraordinarily large increase of 22.7% and 19.3% in suicide rates from 2007 to 2010 (Baumbach and Gulis, 2014). With respect to public health crises, the COVID-19 pandemic led to a decline of 13% and 12% in real GDP in China and India respectively during 2020 relative to the real GDP in the pre-COVID-19 period (Salisu, Adediran and Gupta, 2021). In addition, COVID-19 has resulted in 5,952,215 deaths and 435,626,514 confirmed cases across the globe as of 1 March 2022 (World Health Organization, 2022b).

Evaluating the causal effect of different types of crisis events on health and economic outcomes can play an important role in various contexts in an age of coronavirus, climate change, armed conflicts and economic crisis. First, quantifying the effect of disasters on economy is important for disaster management including disaster preparedness, assessment and monitoring of the consequences of disasters, as well as disaster relief operations during the post-disaster period (Yabe, Zhang and Ukkusuri, 2020). The relevant research also raises risk awareness among the general public, which influences resilience at the individual and community level (Wright, 2016). Second, the estimation of the causal effect of crisis events on financial market performance informs investors of the possible changes in returns and systematic risk of stocks in a certain industry, so that investors can adopt a profitable trading strategy. Third, natural and manmade disasters had a larger damaging impact on physical and psychological health of vulnerable populations including pregnant women, the elderly, families with children, the disabled, as well as individuals living in poverty, while vulnerable groups tend to take less precautionary measures throughout the disasters (Marshall *et al.*, 2020). Therefore, an investigation into the effect of crisis events on vulnerable populations can be used for understanding the consequences and degree of vulnerability for people susceptible to crisis events, so that policymakers can identify and address the needs of vulnerable population groups in case the crisis events happen.

Given the seriousness and urgency of crisis events humans are facing contemporaneously, this thesis focuses on three different categories of crisis events including epidemics, fiscal austerity and wildfires. Moreover, the dissertation pays special attention to vulnerable populations including the elderly and newborns. In particular, this thesis seeks to address the following empirical research questions based on causal inference methods: (1) How did Severe Acute Respiratory Syndrome (SARS) causally influence Chinese A-share stock market? (2) Did fiscal austerity measures have a negative causal impact on health outcomes of older people in Europe? (3) What is the causal effect of wildfire exposure on birth outcomes and older adults' health outcomes in US? Before looking into every single detail of each research question, this thesis gives a brief overview of existing literature in the field of the effect of crisis events on public health and economy, which alerts stakeholders to the consequences of past crisis events.

The effects of different types of crisis events on health and economic outcomes have invited the attention of researchers from economics, public health and crisis management. A number of studies have examined the impact of natural and man-made disasters on public health. The natural and man-made disasters[1] have directly resulted in more than 2 million deaths since 1980 while the mortality was mainly attributable to civil wars and famine (Sapir, 1993). Individuals, who were displaced by natural or man-made disasters, and lived in camps, suffered from lower nutritional levels and poorer health outcomes because of the higher possibility of infection in

[1] The man-made disasters include armed conflicts and the consequent famine (Sapir, 1993).

crowded camps (Ahmad *et al.*, 2017). In terms of how disasters affect psychological health, epidemics including Severe Acute Respiratory Syndrome (SARS), Middle East Respiratory Syndrome (MERS), Ebola and anthrax threat[2] are found to result in mental health problems[3] including depressive symptoms, anxiety, anger, aggression and stress, while natural disasters lead to psychological distress and health risk behaviours such as greater alcohol consumption (Esterwood and Saeed, 2020). In particular, the 2003 SARS epidemic resulted in an increase in suicide rates in Hong Kong and Taiwan possibly due to an economic slowdown and panic about being infected with SARS (Chang *et al.*, 2022).

Researchers have also attempted to evaluate the effect of natural and man-made disasters on economic outcomes. For example, the volatility of stock returns for airline companies around the world was increased by major crisis events including 1997 Asian financial crisis, 9/11 terrorist attacks, the outbreak of SARS in 2003 and 2008 global financial crisis (Wang, 2013). The Sichuan earthquake in China and 3.11 earthquake in Japan had stronger contagion effects on the stock markets of surrounding Asian nations, while the US stock market was influenced by the South Asian tsunami (Lee, Lu and Shih, 2018). Additionally, natural disasters[4] had a negative effect on bilateral trade flows, whereas technological disasters[5] and terrorist activities in developed nations positively influenced their trade with other developed economies (Oh, 2015). Nishiyama *et al.* (1991) show that in the short run, natural disasters had the greatest negative effect on per capita consumption, followed by wars and economic crises. In the long run, per capita GDP growth is positively affected by natural disasters and wars (Nishiyama *et al.*, 1991). The SARS epidemic had the largest negative effect on the number of inbound tourists in Taiwan tourism industry, followed by earthquake, 9/11 terrorist attacks and the Asian financial crisis (Wang, 2009). The COVID-19 gave rise to a larger reduction in employment of immigrants compared with natives in 2020, especially undocumented men (Borjas and Cassidy, 2020).

Moreover, several studies have explored the heterogeneity of the effect of crisis events on health and economic outcomes across different population groups. For instance, climate change is more likely to affect vulnerable population groups including children, the elderly, pregnant women, individuals from a less well-off background and people with chronic diseases (Balbus and Malina, 2009). According to Hoey *et al.* (2020), children aged between 0 and 18 were more likely

[2] After the 9/11 terrorist attack in 2001, political officers in US received anthrax-laced letters (Esterwood and Saeed, 2020).
[3] SARS also induced increased alcohol abuse among health staff (Esterwood and Saeed, 2020).
[4] The natural disasters in the literature include droughts, earthquakes, extreme temperatures, famines, floods, slides, volcanic activities, waves and surges, wild fires, wind storms, epidemics and insect infestations (Oh, 2015).
[5] The technological disasters refer to industrial, transport and miscellaneous accidents (Oh, 2015).

to develop diseases induced by climate change[6] as well as suffer from mental health problems during economic crises and epidemics. Specifically, extreme weather events lead to higher death rates due to diarrhoeal, respiratory diseases, malaria and malnutrition among children compared with other age groups (Bartlett, 2008). Furthermore, the malfunction of piped water supply system and sanitation as a result of extreme weather events such as rainstorms, as well as pollution of water caused by droughts can contribute to diarrhoeal (Bartlett, 2008). A shortage of food supplies as a consequence of weather hazards, such as droughts, is the cause of malnutrition among children (Bartlett, 2008). Meanwhile, changes in temperatures and rainfall gave rise to vector-borne illnesses, such as malaria, as well as respiratory diseases because increased wildfires trigger air pollution and flooding creates favourable environmental conditions for the rapid growth of pollen, fungi and moulds (Bartlett, 2008). Burke, Sanson and Van Hoorn (2018) review the literature regarding psychological effects of climate change on children and find evidence that extreme weather events including wildfires, floods, hurricanes and heatwaves directly result in mental health problems among children, such as sleep disorders, depression, anxiety, post-traumatic stress disorder (PTSD) and phobias.

For older people, extreme heat events and air pollution increase mortality rates due to cardiovascular and respiratory illnesses, while typhoons and flooding result in injuries, drowning as well as mental disorder such as PTSD, depression and anxiety (Aubrecht *et al.*, 2013). Natural disasters raise violence against women and enhance adverse pregnancy outcomes (Goodman, 2016). Parents who lost children during natural and man-made disasters tend to suffer from psychological disorder, especially mothers (Xu *et al.*, 2013). In terms of the economic consequences of crisis events, the COVID-19 had a greater negative effect on employment of women, Hispanics and Asians, individuals without a college degree as well as younger workers in April 2020, whereas the employment recovered by November 2020 (Lee, Park and Shin, 2021). In addition, government policies as a response to the crisis event can mitigate the negative economic impact on population groups susceptible to the event. The shutdown policy during COVID-19 in Demark lessened the decline in consumer spending among the elderly compared with younger cohorts because social distancing laws decreased the likelihood of spreading the infectious disease and enabled higher economic activities of older people (Sheridan *et al.*, 2020). Interestingly, individuals with complex heterogeneity, such as higher income combined with lower education, experience higher susceptibility to disasters (Shiba *et al.*, 2021a).

[6] Diseases caused by climate change include ozone-related respiratory illness, storm-related injury, diarrhoeal, etc. (Philipsborn and Chan, 2018).

This thesis aims to fill the following research gaps in existing literature. Overall, the estimation of causal effect of crisis events provides input into cost-benefit analyses of different types of crisis events. First, the current body of literature only analyses the impact of crisis events on a limited number of indicators of health and economic outcomes, so there is still much scope for examining the effect of crisis events on a broader range of health outcomes (Baumbach and Gulis, 2014) and economic indicators (Oh, 2015). In view of such a gap, this thesis investigates a wider range of health outcomes related to the elderly and neonates as well as economic indicators including stock returns and systematic risk of each sector. Second, lack of detailed data on measure of exposure to crisis events reduces the accuracy of estimates of the effect (Baumbach and Gulis, 2014). To address this issue, this thesis creates different measures of exposure to crisis by exploiting data from a timeline of crisis-related events, surveys, Eurostat and wildfire statistics. Third, in terms of economic effect of crisis events, some research is conducted at the industry or country level, while a firm level analysis can capture heterogeneity of companies in disaster management strategies (Oh, 2015). To cope with this issue, this thesis employs stock prices of all companies in each Chinese sector to evaluate how stock performance of a certain sector responded to SARS. Finally, research into disaster survivors generally obtains data regarding pre-disaster characteristics retrospectively, which contributes to recall bias (Shiba *et al.*, 2021a). To avoid this problem, this thesis analyses data obtained from health surveys and birth certificates, which were collected at a fixed interval. Furthermore, more specific contributions of each study in Chapter 2, Chapter 3 and Chapter 4 are described in Section 1.3.

1.1.2 Methodological Challenges

There are certain drawbacks in the previous literature associated with empirical methods applied to quantify the effect of crisis events on health and economic outcomes. First, some model specifications do not control for confounding variables (Baumbach and Gulis, 2014). Second, in terms of natural disasters, preceding research mostly used discrete outcome variables at a small number of time points rather than longitudinal and continuous variables about health and economic outcomes (Yabe, Zhang and Ukkusuri, 2020). To resolve these issues, data from health surveys and birth certificates employed in this thesis include detailed information for each respondent, such as demographic characteristics and public benefits received. In addition, both continuous and discrete outcome variables are available in the data where individuals or counties were followed in successive waves.

Third, the methods cannot establish a causal relationship between disasters and outcomes of interest (Yabe, Zhang and Ukkusuri, 2020). Most previous research on estimating the effect of crisis events on health and economic outcomes applied correlational methods, such as Anh and

Gan (2020), Baek, Mohanty and Glambosky (2020), Toffolutti and Suhrcke (2019), Loopstra *et al.* (2016a), Requia *et al.* (2021) and Heft-Neal *et al.* (2022), rather than causal inference approaches. The causal inference analysis in public health identifies the need for reducing exposure to hazardous factors and practitioners in public health can impose interventions based on results derived from causal inference analysis (Glass *et al.*, 2013). Despite the importance of causal inference analysis in evaluating the effect of crisis events, there remains a paucity of evidence on the causal impact of crisis events on health and economic outcomes. Given the drawbacks of methodology in previous research, a major contribution of this thesis is to use causal inference methods to establish the cause-and-effect relationship between crisis events and health or economic outcomes of interest.

This thesis adopts the standard difference-in-differences (DD), difference-in-difference-in-differences (DDD) and their extensions to estimate the treatment effect of crisis on health and economy.

The standard DD method assumes that the sample can be divided into the treated and control groups, which exist in two time periods: the pre-treatment and post-treatment periods. The treated group only receives treatment in the post-treatment period while the control group is not treated in both time periods. The DD estimator is calculated by comparing the difference in outcomes of interest during the pre-treatment and post-treatment periods for the treatment and control group. The key identifying assumption for the DD method is the parallel trend assumption, which presumes that the average outcomes for the treated and control group follow the same trend over time when the treatment does not exist. In particular, Chapter 2 employs two difference-in-differences model specifications. The first one is the country-specific DD model, in which the pre-SARS year is considered to be the control group while the SARS year is the treated group. The second one is the year-specific DD model, in which India serves as the control group while China is the treatment group.

As an extension of the standard DD method, the canonical DDD approach calculates the difference between two DD estimators (Olden and Møen, 2022). For example, the DDD method can compare the DD estimator for two groups in a treatment state with that in a control state (Olden and Møen, 2022). The identifying assumptions for the DDD method remain inconclusive (Olden and Møen, 2022).

Chapter 2 adopts an event study method which has been applied in empirical economics and health, such as Kleven, Landais and Søgaard (2019), Dobkin *et al.* (2018), Cotti, Gordanier and Ozturk (2018) and Dobkin, Nicosia and Weinberg (2014). Compared with DD and DDD methods, the event study can visually display a full dynamic pattern of the impact of an event over time

(Kleven, Landais and Søgaard, 2019) and consider changes in the impact of the event over multiple time periods. Based on Borusyak, Jaravel and Spiess (2021), a basic model specification of the event study takes the form below.

$$Y_{it} = \sum_{\substack{d=-n \\ d\neq -1}}^{m} \delta_d 1\{K_{it} = d\} + \alpha_i + \varepsilon_{it} \tag{1-1}$$

$$K_{it} = t - E_i \tag{1-2}$$

where K_{it} denotes the number of periods relative to the event date E_i; Y_{it} indicates the outcome of interest for unit i in period t; α_i is the individual fixed effect; n and m represent leads and lags of the event dummy respectively; ε_{it} is the disturbance term. The model omits the event dummy at $t = -1$, so that the coefficient δ_d measures the effect of the event relative to one period before the event date.

In the quasi-experimental study, if there are more than two time periods and the treatment began at different time points, the two-way fixed effects (TWFE) regression is preferred compared with the canonical DD or DDD. Nevertheless, most treatment effects in empirical problems are heterogeneous across groups or over time and a TWFE estimator of the average treatment effect on the treated (ATT) is biased (de Chaisemartin and D'Haultfœuille, 2020). In this case, the $DID_{+,t}$ estimator created by de Chaisemartin and D'Haultfœuille (2020) takes account of the heterogeneity in ATT.

1.2 Three Crisis Events

This section describes the three crisis events this thesis focuses on. As noted by Eastham, Coates and Allodi (1970), 'crisis' is a extensively used concept which is difficult to define specifically. The crisis event usually satisfies three criteria: the event is acute, severe and unexpected (Komlos and Kelly, 2016). Moreover, according to Eastham, Coates and Allodi (1970), there are five important characteristics of crisis: (1) The problem induced by the crisis event is unsolvable within a short period of time. (2) The problem cannot be solved via traditional methods. (3) The event is an obstacle to life goals of an individual. (4) The event can trigger physical tension due to anxiety. (5) The event indicates unsettled problems in the past. The crisis event is associated with clinical symptoms including behavioural changes; feelings of anxiety, panic, helplessness and ineffectiveness (Eastham, Coates and Allodi, 1970). Based on Mohamed

Shaluf (2007)[7], this thesis classifies crisis events into natural disasters, man-made crisis and hybrid crisis events. Natural disasters indicate calamitous events induced by natural causes, which include biological events[8] (such as epidemics), meteorological phenomena[9], natural phenomena underneath the Earth's surface[10] and topographical phenomena[11] (Mohamed Shaluf, 2007). Man-made crisis events are caused by human decisions[12], such as financial crisis and fiscal austerity, while the hybrid crisis events are triggered by both human behaviours and natural forces, such as floodplain disasters, deforestation (Mohamed Shaluf, 2007) and wildfires. Furthermore, disasters can lead to subsequent disasters, such as haze as a result of forest fires (Mohamed Shaluf, 2007).

This thesis concentrates on three crisis events: epidemics, fiscal austerity, and wildfires. Existing evidence has suggested that epidemics, fiscal austerity and natural disasters are interconnected events. Fiscal austerity policy can undermine the government's ability to cope with other crisis events including epidemics and natural disasters (Wright, 2016). Natural disasters can induce the spread of epidemics and fiscal austerity. For one thing, following natural disasters, the transmission of infectious diseases is facilitated by favourable conditions including pollution of drinking water, crowding among displaced people, an increase in vectors of communicable diseases, as well as disruption in healthcare services (Watson, Gayer and Connolly, 2007). For another, the direct economic cost due to natural disasters across the globe from 1980 to 2004 is calculated to be around $1 trillion (Strömberg, 2007) while the majority of damage is induced by climate-related events (Kousky, 2014). As a consequence, fiscal policies are inevitably affected by natural disasters and the associated economic damage. Governments in developed countries increased government expenditure and decreased taxes as a response to natural disasters, whereas developing countries tend to adopt pro-cyclical fiscal stance (Noy and Nualsri, 2011). Epidemics can influence fiscal policies. To manage COVID-19 crisis, most countries increased government spending on the healthcare sector, business sector, as well as households and individuals, while the amount of government expenditure depends on the seriousness of the pandemic and economic status in each nation (Chen *et al.*, 2021).

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[7] Mohamed Shaluf (2007) categorises disasters into three types: natural disasters, man-made disasters, and hybrid disasters. In particular, crisis and disaster share many common characteristics while the two terms are used interchangeably (Al-Dahash, Thayaparan and Kulatunga, 2016).
[8] Biological events include epidemics, infestations and locust swarms (Mohamed Shaluf, 2007).
[9] Meteorological phenomena include windstorms, tornados, floods, drought and heat waves (Mohamed Shaluf, 2007).
[10] Natural phenomena underneath the Earth's surface include earthquakes, tsunamis and volcanic eruptions (Mohamed Shaluf, 2007).
[11] Topographical phenomena refer to landslides and avalanches (Mohamed Shaluf, 2007).
[12] Mohamed Shaluf (2007) maintains that man-made disasters include socio-technical disasters (e.g., transport failures, production failures, plant failures, etc.) and wars.

The next section provides the background information on the three crisis events.

1.2.1 Severe Acute Respiratory Syndrome

An epidemic can be defined as the emergence of an unexpected rise in the number of cases of a communicable disease in a certain population that has never been infected with the disease before (Mohamed Shaluf, 2007). This thesis concentrates on Severe Acute Respiratory Syndrome (SARS), which was the first new infectious disease in the 21st century (World Health Organization, 2022a) and originated in Guangdong in late 2002 (Zhao *et al.*, 2003). At the beginning of the epidemic, the patients who developed SARS in Guangdong were associated with wildlife trade markets, where they might be infected with SARS via animals such as Himalayan palm civets and raccoon dogs, while the follow-up outbreak of the epidemic was triggered by rapid human-to-human transmission (Enserink, 2013). As shown by World Health Organization (2019), SARS was spread across 26 countries and the total number of SARS cases worldwide exceeds 8000 in 2003.

The causative agent of SARS is discovered to be a newly detected coronavirus (Kuiken *et al.*, 2003), which is highly infectious by close contact among humans (Zhao *et al.*, 2003). SARS can be transmitted through respiratory droplets and aerosol-generating processes (Peiris *et al.*, 2003). There are no apparent respiratory symptoms at the onset of the disease, but patients suffer from worsened shortness of breath and pulmonary infiltrates after 3 to 7 days (Zhao *et al.*, 2003). The SARS disease can develop into Acute Respiratory Distress Syndrome (ARDS) and lead to death if patients are not treated timely (Zhao *et al.*, 2003). The symptoms of SARS are similar to those of lower respiratory tract diseases, such as fever, malaise and lymphopenia, but other organs of patients may also be infected with the virus (Peiris, Guan and Yuen, 2004). The precautionary measures to control the spread of SARS include early identification and isolation of SARS patients, quarantine of close contacts of SARS patients, border screening and public education (Peiris *et al.*, 2003).

Hidden problems in public health system and disease control measures emerged during the SARS epidemic, which led to delayed and ineffective government response in the earlier phase of the epidemic. At the outset of the SARS epidemic, the local officials downplayed the epidemic situation and information about SARS was insufficient for the general public (Xu, 2003). The government publicised SARS related information to the society in a more accurate and prompt manner after 20 April 2003 when a press conference on SARS was hosted in Beijing and the executive vice Minister of Health revealed that the number of confirmed SARS cases in Beijing was higher than stated earlier (Xu, 2003). In addition, the failure to efficiently contain the spread of SARS can be attributable to the poor public health systems in China (Enserink, 2013). In April

2003, the health system in China improved its reporting system by using a web-based public health surveillance system and keeping record of patient profiles (Wang *et al.*, 2008). Furthermore, international collaboration and cooperation contributed to the successful containment of SARS (Mackenzie *et al.*, 2004). Global Outbreak Alert and Response Network (GOARN), which gathered laboratory scientists, clinicians and epidemiologists all over the world, played a vital role in investigating and identifying the SARS virus (Heymann and Rodier, 2004).

1.2.2 Fiscal Austerity

In 2008 financial crisis, the disruption in the US housing markets had a large influence on European Union (EU) countries, where many mortgage-backed securities were sold (Karanikolos *et al.*, 2013). As a consequence, many European nations experienced fiscal deficit because of reduced tax revenues and increased government expenditure, while there was a large decline in gross domestic product (GDP) across European economies in 2019 (Karanikolos *et al.*, 2013). Prior to the financial crisis, a number of European nations already accumulated high levels of debts and faced large fiscal deficits (Alesina *et al.*, 2015). To make matters worse, the aging population across Europe further increased government social spending (Alesina *et al.*, 2015). The high credit risk and volatile spreads on government bond yields among some EU countries led to sovereign debt crisis since 2010 (Lane, 2012). All these events led to the adoption of fiscal austerity policies in many European nations. Specifically, EU countries including Greece, Ireland and Portugal received bailouts from International Monetary Fund, European Central Bank and European Commission (termed troika), which implemented austerity measures as conditionality attached to financial support from troika (Stuckler and Basu, 2009; Lane, 2012; OECD, 2012). The second group of EU countries[13] experienced market pressure with an increase in long-term interest rates but could repay debts by themselves, so they had lower fiscal consolidation needs (OECD, 2012). The third group of EU nations[14] did not witness so much market pressure as the second group, but still faced a consolidation requirement due to entry into excessive deficit procedure (OECD, 2012). The fourth group of EU countries[15] had the lowest or no need for fiscal austerity because of smaller deficits and debt-to-GDP ratios (OECD, 2012).

Most public spending cuts happened to social protection, health and education (OECD, 2012). In particular, the financial crisis contributed to the structural reform in healthcare system, such as

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[13] The second group of countries include Belgium, Hungary, Italy, Poland, Slovenia, the Slovak Republic and Spain (OECD, 2012).
[14] The third group of nations consist of Finland, Austria, the Czech Republic, Denmark, France, Germany and the Netherlands (OECD, 2012).
[15] The fourth group of EU nations comprises Estonia, Luxembourg and Sweden (OECD, 2012).

merger and closure of healthcare providers as well as a shift towards outpatient and primary care (Quaglio *et al.*, 2013). The most widely implemented health system reform among EU countries is the introduction of extra user fees (Wenzl, Naci and Mossialos, 2017). Other health system reforms include cutting down on pharmaceutical prices, a decline in healthcare service coverage, a reduction in healthcare provider payment, the use of evidence-based prescriptions and e-health systems (Wenzl, Naci and Mossialos, 2017). As a consequence, the health system reforms limited the coverage of and access to healthcare services across Europe (Wenzl, Naci and Mossialos, 2017).

1.2.3 Wildfires

Wildfires have burned a larger amount of land in the United States during the last 40 years as a result of the accretion of combustible substances and increased aridity of fuels (Burke *et al.*, 2021). In addition, anthropogenic climate change including a rise in vapour pressure deficit and higher temperature has promoted fuel aridity in western US forests, which doubled the western US forest areas burned by wildfires between 1984 and 2015 and is expected to enhance the risk of wildfires in western US forests in the future (Abatzoglou and Williams, 2016). Moreover, the accelerated growth of US wildland-urban interface from 1990 to 2010 tend to ignite more wildfires (Radeloff *et al.*, 2018). Active wildfires mostly occurred along the coast of western US between 2018 and 2019, where the burned areas were smaller and the burning lasted for a shorter period of time compared with Australia and Brazil (Kganyago and Shikwambana, 2020). Wildfires have a remarkable influence on ecosystem. California and Southern Area are expected to suffer from the highest losses to highly valued resources[16] because of moderate or high density built structure and municipal watersheds in these regions, followed by Southwest area; meanwhile, wildfires are predicted to have a positive effect on fire-adapted ecosystems[17] in the western US, especially Northwest (Thompson *et al.*, 2011). Air pollution caused by wildfires is a matter of serious concern. The $PM_{2.5}$ concentrations caused by wildfire smoke in US have increased considerably since the mid-2000s and have made up half of the total $PM_{2.5}$ concentrations in western US recently, which was transported to other US regions (Burke *et al.*, 2021).

[16]The high valued resources is made up of residential structure, municipal watersheds, air quality, energy and critical infrastructure, federal recreation and recreation infrastructure, species vulnerable to wildfires and fire-adapted ecosystems (Thompson *et al.*, 2011).
[17] The fire-adapted ecosystems indicate places where fires are exploited to preserve the ecosystem in a non-deadly manner (Thompson *et al.*, 2011).

Wildfires could incur huge costs and losses if managed inappropriately. The total annualized costs and losses of wildfires in US are estimated to range between $71.1 and $347.8 billion (Thomas *et al.*, 2017). The costs of wildfires consist of prevention, mitigation, suppression and cross-cutting, while the losses are made up of direct[18] and indirect losses[19] (Thomas *et al.*, 2017). The longer wildfire season as well as increased frequency, size and intensity of wildfires have given rise to higher costs of wildfire suppression in last few decades (United States Forest Service, 2015). Notably, aggressive wildfire suppression under the current protocol for wildfire management could enhance the intensity, losses and coverage areas related to several large-scale wildfires which are difficult to cope with (Calkin, Thompson and Finney, 2015).

1.3 Chapter-by-Chapter Outline

1.3.1 The Causal Effect of SARS on the Performance of Chinese Stock Market

1.3.1.1 Research Question and Contribution

Chapter 2 seeks to analyse the causal effect of 2003 SARS epidemic on stock returns and systematic risk of different sectors in Chinese A-share[20] stock market. During the SARS epidemic, A-shares were mainly available to mainland Chinese investors while B-shares were targeted at investors outside mainland China. Therefore, this chapter focuses on A-shares because the impact of SARS on Chinese economy can be more precisely reflected by behavioural response of Chinese investors directly influenced by the SARS epidemic. In areas most seriously hit by the SARS epidemic, including mainland China, Hong Kong, Canada and Singapore, the economic losses appear to be the largest; additionally, SARS had a devastating effect on the following sectors in which close human-to-human contact frequently happened: exports, tourism, hotels, restaurants, airline, investment (inward and outward) and retail sales (Keogh-Brown and Smith, 2008). Previous research has shown that SARS had a damaging impact on stock indices in mainland China and Vietnam (Nippani * and Washer, 2004), the cumulative abnormal returns of Taiwan hotel companies (Chen, Jang and Kim, 2007), China tourism sector (Chong, Lu and Wong, 2010) as well

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[18] The direct losses is comprised of deaths and injuries, psychological effects, agricultural loss, infrastructure loss, etc (Thomas *et al.*, 2017).

[19] The indirect losses include economic effect, utility disruption, transportation interruption, housing market effect, evacuation costs, etc (Thomas *et al.*, 2017).

[20] In mainland China, stocks are categorised into A-shares and B-shares on Shanghai Stock Exchange and Shenzhen Stock Exchange. A-shares denote common shares which are denominated and traded in Chinese Yuan, while B-shares are denominated in Chinese Yuan, but are traded in U.S. dollars and Hong Kong dollars on Shanghai Stock Exchange and Shenzhen Stock Exchange respectively. We refer to section 2.2.3 for an introduction of Chinese stock market.

as Taiwan tourism, wholesale and retail industry (Chun-Da *et al.*, 2009). However, specific sectors benefited from the SARS epidemic with a marked rise in stock returns, such as the Taiwan biotechnology sector (Chun-Da *et al.*, 2009) and the Mainland China pharmaceutical industry (Chong, Lu and Wong, 2010). SARS also enhanced the financial risk of airline firms in mainland China, Hong Kong, Singapore, Thailand and Canada (Loh, 2006).

Chapter 2 aims to make the following contributions to the existing literature. First, it would be helpful to offer investors advice on whether a certain sector is a stock market winner or loser during the epidemic, but there have been few empirical investigations into the causal effect of the SARS epidemic on stock returns of all the sectors in China. As a result, Chapter 2 attempts to fill this research gap by studying the causal impact of the SARS epidemic on A-share returns of every Chinese sector, so that the study pays attention to sectors which have received scant attention in existing literature. Second, no studies have analysed the influence of epidemics on systematic risk of each sector and Chapter 2 looks into how systematic risk of each Chinese sector responded to SARS. Furthermore, from a priority setting perspective, Chapter 2 expands our understanding of the size of the effect of epidemics on stock market performance. The presence of the damaging effect of SARS on stock returns informs governments about preventing future epidemics or mitigating the adverse impact of epidemics on economy.

Methodologically, preceding empirical studies in this field mostly use a shorter time window, such as several days surrounding the date of an important SARS related event. Nevertheless, a narrow time window does not capture changes in stock returns over different stages of an epidemic. To fix this issue, Chapter 2 adopts a one-year time span from the occurrence of the first SARS patient in Guangdong to the WHO's announcement of the successful control of SARS. Additionally, most previous research has applied the event study method to calculate the cumulative average abnormal returns (CAAR), which does not account for the issue that the determinants of normal stock returns may change with various phases of the SARS epidemic. The event study also fails to control for other confounding factors including the global economic recession and the Iraq war. In light of these problems, Chapter 2 not only estimates the dynamic effect of SARS using the event study, but also for the first time, evaluates the ATT of SARS through causal inference methods including difference-in-differences (DD) and difference-in-difference-in-differences (DDD). Moreover, a proper causal inference analysis provides input into cost-benefit analysis of the SARS epidemic.

1.3.1.2 Empirical Method and Main Results

To estimate the causal effect of the SARS epidemic on stock returns and systematic risk of different sectors in China, Chapter 2 uses data from Bloomberg about closing prices of A-shares at the daily level for each sector on Shanghai Stock Exchange and Shenzhen Stock Exchange from 18 November 2002 to 10 November 2003. Companies are categorised into different sectors based on the Global Industry Classification Standard (GICS) system. The timeline of SARS related events was obtained from World Health Organization (2003), Enserink (2013) as well as Lee and McKibbin (2012). The empirical analysis of Chapter 2 first conducts the event study to estimate the dynamic effect of the key SARS related event (on 17 March 2003[21]) on stock prices over one year. Second, to evaluate the effect of SARS on stock returns, the analysis uses event study based on market model to estimate the cumulative average abnormal returns (CAAR). Finally, the SARS epidemic is a natural experiment. The DDD and DD methods are employed to estimate the ATT of SARS on stock returns. For the DD method, Chapter 2 exploits the country-specific DD method, which uses the pre-SARS year as the control group, as well as the year-specific DD method, which regards India as the control group. The country-specific DD controls for the stock market seasonality while the year-specific DD captures the effect of other confounding factors including international crisis events. The country-specific DD also checks the validity of the control group used in DDD. The year-specific DD for the pre-SARS year is intended for a placebo test for the parallel trend assumption underlying the year specific DD as well as the DDD in the absence of stock market seasonality. The DDD approach compares the changes in stock returns of Chinese A-shares in different sectors to variation in stock returns in the control countries between the pre-treatment and the post-treatment period during the SARS year, relative to the pre-SARS year. The DDD method accounts for both the stock market seasonality and the effect of other contemporaneous confounding events on Chinese stock market. In risk analysis, inspired by Ramiah, Martin and Moosa (2013), Chapter 2 adjusts the CAPM (termed modified CAPM) based on DD and DDD to estimate the effect of SARS on systematic risk of different Chinese sectors. Additionally, the post-treatment period is split into two sub-periods to assess whether the DD and DDD estimates change prior to and following the Chinese stock market closure in May 2003.

The results demonstrate that the SARS epidemic had a negative effect on A-share returns in the entire stock market and sectors including consumer discretionary, healthcare, industrials, and utilities. No sectors gained from the SARS epidemic. Moreover, there is a significant increase in the systematic risk of the financial sector, whereas the systematic risk of the communication services and utilities was not influenced by SARS.

[21] The event date (termed Day 0) is defined as 17 March 2003, which is the first trading day (Monday) after WHO named the contagious disease ‘Severe Acute Respiratory Syndrome (SARS)’ and claimed it to be ‘a worldwide health threat’ on Saturday, 15 March 2003 (World Health Organization, 2003).

1.3.2 The Causal Effect of Fiscal Austerity on Older People's Health Outcomes

1.3.2.1 Research Question and Contribution

The purpose of Chapter 3 is to evaluate how fiscal austerity policies causally influence the health outcomes of the elderly across EU nations. Overall, the mechanism underlying the impact of fiscal austerity on health outcomes includes a 'social risk effect' and a 'healthcare effect' (Stuckler *et al.*, 2017). The social risk effect indicates the impact of higher unemployment rates, homelessness, food insecurity, poverty and other socioeconomic risk factors, while the healthcare effect denotes mediators related to health system reform, such as a reduction in medical services, cuts in healthcare coverage and limiting healthcare access (Stuckler *et al.*, 2017). The existing evidence suggests that fiscal austerity is associated with a rise in the following health related outcomes: mortality (Loopstra *et al.*, 2016a), mortality due to cirrhosis and chronic liver diseases (Toffolutti and Suhrcke, 2019), death owing to external causes (Borra, Pons-Pons and Vilar-Rodriguez, 2020), death caused by circulatory diseases (Borra, Pons-Pons and Vilar-Rodriguez, 2020),.suicide rates (Antonakakis and Collins, 2015) as well as mental health problems (Barr, Kinderman and Whitehead, 2015). Chapter 3 aims to contribute to a number of studies that examine the impact of fiscal austerity on older people's health. In the context of Europe, higher suicide rates among older people are found to be related to government spending cuts in Greece (Antonakakis and Collins, 2014) and fiscal austerity in the Eurozone periphery, including Greece, Ireland, Italy, Portugal and Spain (Antonakakis and Collins, 2015). A relevant study has found that the spending cuts in Pension Credit and social care in the UK significantly increased the mortality rates of older people aged 85 and over (Loopstra *et al.*, 2016a). The rise in old-age mortality can be explained by psychological problems due to the relatively large size of decrease in older people's income levels, as well as poor living conditions, less intake of nutrition and social isolation because of poverty (Loopstra *et al.*, 2016a).

Moreover, Chapter 3 corroborates and complements the ideas of the preceding literature which has explored whether the fiscal austerity policies influenced the elderly's healthcare utilisation. Several lines of evidence suggest that the elderly encountered barriers to healthcare access due to fiscal austerity policies across EU countries. One study by Tavares and Zantomio (2017) finds a pro-poor inequity in GP visits among older people aged 50 and above in Italy and Spain after a reduction in public healthcare expenditure, whereas Portugal witnessed a pro-rich inequity in primary care visits. These results imply that in Italy and Spain, the elderly with more disadvantaged socioeconomic status tend to choose free primary healthcare services, whereas since GP visits also charge medical costs in Portugal, older people with lower socioeconomic background are more likely to restrict primary care utilisation (Tavares and Zantomio, 2017).

Additionally, Tavares and Zantomio (2017) discover evidence of significant pro-rich inequity in access to specialist healthcare services for all the three countries, which suggests that underprivileged senior citizens encountered difficulties in accessing the medical care they need. In an analysis of the impact of fiscal austerity on older people in rural areas, Milbourne (2015) points out that the closure of public services due to fiscal austerity had a geographical effect on the elderly living in rural places because of the barriers to travelling to the alternative public service facilities. A qualitative study by Doetsch *et al.* (2017) reveals potential difficulties that limit healthcare use among older people after the healthcare spending cuts in Portugal. In particular, financial status and decreased pensions are the most important factors which restrict the elderly's access to medical care services (Doetsch *et al.*, 2017). Costa-Font, Jimenez-Martin and Vilaplana (2018) suggest that in 2012 fiscal austerity policy in Spain, the reduction in long-term care subsidization significantly increased hospital admissions of senior citizens, which can be explained by reduced outpatient visits, worse mental health conditions and heightened loneliness.

Several limitations remain in the preceding literature. Chapter 3 aims to fill the following research gaps. This chapter contributes to empirical literature in terms of the relationship between fiscal austerity and mortality or suicide rates of older people, which aims to address the question of how fiscal austerity influenced older people's health conditions. Therefore, Chapter 3 informs evidence-based policy making by providing input into cost-benefit analysis of fiscal austerity. However, there has been a relatively small body of literature that is concerned with the effect of fiscal austerity on health status of vulnerable population, such as older people. Research to date have only focused on how fiscal austerity could influence younger adults or the working-age population. Moreover, most previous research has mainly focused on the effect of austerity on mortality, suicides and healthcare inequity of the elderly, but little attention has been paid to other health outcomes of older people, such as chronic diseases, mobility, mental health, and self-perceived health. Chapter 3 aims to investigate the influence of fiscal austerity on a broader range of health outcomes among older people. In addition, existing literature on the effect of fiscal austerity on older people's health has only examined the 'healthcare effect' of fiscal austerity. However, fiscal austerity can influence the elderly's health outcomes through other channels besides utilisation of healthcare services. There has been little analysis of the overall effect of fiscal austerity policies on senior citizens' health outcomes, and Chapter 3 attempts to fill this gap.

From a methodological perspective, the methods applied in past literature linking fiscal austerity to mortality have been correlational in nature, but there is lack of evidence based on causal inference methods. Chapter 3 employs an extension of difference-in-differences and difference-in-difference-in-differences methods to estimate the causal effect of fiscal austerity on older people's health outcomes. In particular, the methodological approach in this study attempts to resolve the endogeneity issue of measures of fiscal austerity as a result of self-selection into or out of public benefits prompted by fiscal austerity. The identification strategy takes account of different levels of exposure to fiscal austerity policies at the country and individual level, which are represented by the country and individual level treatment intensity.

1.3.2.2 Empirical Method and Main Results

The purpose of Chapter 3 is to obtain empirical evidence on the causal effect of fiscal austerity on the elderly's health outcomes across EU nations. The empirical analysis employs micro level panel data from Survey of Health, Ageing and Retirement in Europe (SHARE) and the sample is made up of older people aged 50 and above from 11 European countries which implemented fiscal austerity. As suggested by Fetzer (2019), a major threat to identification strategy is that people may self-select in or out of receiving welfare benefits due to fiscal austerity. The empirical analysis creates continuous individual and country level treatment intensity, which are respectively based on the number of public benefits each person received before years of fiscal austerity and the Blanchard Fiscal Impulse denoting fiscal stance. The empirical method uses an extension of the standard difference-in-difference (DD) with country-level treatment intensity, as well as difference-in-difference-in-differences (DDD) with both individual and country level treatment intensity. Compared with a binary treatment variable, the advantage of using continuous treatment intensity is that it exploits changes in exposure to fiscal austerity across countries and individuals. In addition, the study carries out a placebo test for common time trend assumption for both DD and DDD, which expects that unobserved factors do not differentially determine the trends in outcomes of interest among countries with different treatment intensity so that the treatment effects are not caused by these unobservable determinants.

The findings indicate that fiscal austerity worsened self-perceived health, but appears to reduce the probability of developing chronic diseases including cancer, cataracts, stroke, hypertension, high cholesterol and gastric ulcers. In addition, fiscal austerity had a null impact on having depression symptoms, functional capacity, the probability of getting other chronic conditions including chronic lung diseases and diabetes, as well as mortality caused by accident. Notably, fiscal austerity limited access to outpatient healthcare utilisation indicating lack of diagnostic checks among the elderly, which may explain the null and positive impact of fiscal austerity on several indicators of health outcomes in addition to poorer self-perceived health. Specifically, older people were not aware of their own physical or mental health problems while health indicators are self-reported by respondents.

1.3.3 The Causal Effect of Wildfire Exposure on Health Outcomes of the Elderly and Newborns

1.3.3.1 Research Question and Contribution

Chapter 4 investigates whether exposure to wildfires leads to adverse birth outcomes and poorer health conditions among older people aged 65 and older across US counties. Maternal exposure to wildfires has been found to be related to adverse pregnancy outcomes through exposure to air pollutants released from wildfires and psychological problems of mothers induced by traumatic experiences during wildfires (Amjad *et al.*, 2021). The evidence in preceding research with regard to the effect of wildfires on birth outcomes appears to be inconclusive. The existing literature has established that maternal exposure to wildfires is related to prematurity (Holstius *et al.*, 2012; Abdo *et al.*, 2019; Amjad *et al.*, 2021); reduced birth weight (Holstius *et al.*, 2012; Abdo *et al.*, 2019; Amjad *et al.*, 2021) or low birth weight (Jones and McDermott, 2021); fetal, infant and child deaths (Jayachandran, 2009); as well as birth defects including cleft lip, congenital respiratory diseases and nervous system abnormalities (Requia *et al.*, 2021). In contrast, O'Donnell and Behie (2015) have argued that wildfires result in macrosomia and increased birth weight. Furthermore, it remains inconclusive during which trimester of gestation pregnant women are more vulnerable to wildfires (Jayachandran, 2009; Holstius *et al.*, 2012; Abdo *et al.*, 2019; Jones and McDermott, 2021; Requia *et al.*, 2021).

Existing research into the health effect of wildfire exposure on adults have paid attention to all age cohorts as a whole. There is much less evidence about the effect of wildfires on health outcomes of vulnerable populations, such as older people who are more susceptible to wildfire smoke than any other age cohorts (DeFlorio-Barker *et al.*, 2019; Masri *et al.*, 2021). Previous studies on the influence of wildfires on adults' health have found that wildfires are correlated with a higher possibility of developing respiratory diseases (Frankenberg, McKee and Thomas, 2005; Chen, Verrall and Tong, 2006; Moore *et al.*, 2006; Liu *et al.*, 2015; Reid *et al.*, 2016; Sheldon and Sankaran, 2017; Walter *et al.*, 2020; Aguilera *et al.*, 2021), worsened general health status (Kim *et al.*, 2017), greater difficulties with activities of daily living (Frankenberg, McKee and Thomas, 2005; Kim *et al.*, 2017) as well as suffering from mental health problems including post-traumatic stress disorder, major depressive disorder and generalized anxiety disorder (To, Eboreime and Agyapong, 2021). However, wildfire exposure has a null effect on developing cardiovascular diseases (Moore *et al.*, 2006; DeFlorio-Barker *et al.*, 2019).

To study the causal effect of wildfire exposure on both birth outcomes and older adults' health outcomes, Chapter 4 examines three sub-questions for each health outcome of interest. The first sub-question studies the causal effect of each of the five most sizeable wildfires on neonatal health and older people's health status at individual level, which avoids attenuating the treatment effect of wildfires on health due to wildfires of small size. The second sub-question examines how multiple massive wildfires jointly affect health outcomes of the newborns and the elderly based on the micro-level data[22]. The third sub-question evaluates the aggregate effect of multiple wildfires of different sizes on average health outcomes of infants and older people at the county level.

Chapter 4 makes the following contributions to the existing empirical research on the health impact of wildfires. Essentially, the first contribution is that the research identifies health costs of wildfires for vulnerable populations, which is of assistance to cost-benefit analysis of wildfire exposure. According to empirical findings, the absence of a significant effect of wildfires on several health outcomes implies that when allocating resources to cope with the consequences of wildfires, health effect may not be a priority concern. Thus, stakeholders may consider developing targeted interventions aimed at mitigating economic and environmental impact of wildfires in the first instance. The second contribution is that the preceding literature only focuses on the impact of air pollutants emitted from wildfires on birth outcomes and health conditions of adults, but fails to account for the effect of wildfires on health through mental health problems induced by traumatic wildfire events. Chapter 4 investigates the health impact of wildfires through both exposure to air pollution and mental health, which estimates the health consequences of wildland fires in a holistic way. Third, existing research about the health effect of wildfires in US only focuses on a single state or several areas in one state, such as Colorado (Abdo *et al.*, 2019), California (Heft-Neal *et al.*, 2022) and California's South Coast Air Basin (Holstius *et al.*, 2012). Chapter 4 uses data including a larger number of US counties to assign the treatment and control groups in causal inference. Moreover, Chapter 4 focuses on the impact of wildfires on health outcomes of the elderly, which is another group vulnerable to wildfires but receives scant attention in existing literature. Finally, Chapter 4 investigates the impact of wildfires on a broader category of health outcomes including birth weight and the length of gestation for birth outcomes as well as general physical and mental health, physical activities and asthma symptoms for the elderly. Chapter 4 also studies the effect of wildfires on birth defects, for which there has been insufficient evidence in previous research.

As for contribution to methodology, the empirical analyses in the existing literature are correlational in nature, so there has been little causal inference analysis of the health impact of

[22] For birth outcomes, 5 large wildfires are employed, which burned more than 5000 acres and whose distance to each county is less than 20 km. For older people's health outcomes, the analysis exploits 63 wildfires, which induced more than 50 burned acres and whose distance to each county is smaller than 20 km.

wildfire exposure. Chapter 4 carries out causal inference analysis including difference-in-differences method for event-specific analysis; two-way fixed effects regression to estimate the health effect of multiple large wildfires as well as $DID_{+,t}$ estimates suggested by de Chaisemartin and D'Haultfœuille (2020) for the county-level analysis. As mentioned by de Chaisemartin and D'Haultfœuille (2020), a major advantage of $DID_{+,t}$ estimates is that it considers the heterogeneity of the treatment effects of wildfires across counties or over time.

1.3.3.2 Empirical Method and Main Results

Chapter 4 studies how exposure to wildfires causally influence birth outcomes as well as the health outcomes of older people. The wildfire data were obtained from Fire Statistics System (FIRESTAT) created by United States Department of Agriculture (USDA) Forest Service (2021), which includes information about the geographic locations and the start date of wildfires. The dataset with respect to pregnancy outcomes from 1998 to 2004 were collected from the public use birth data files provided by National Vital Statistics System (NVSS), but only access to data in terms of counties with a population size no fewer than 100,000 is permitted. The health-related data for the elderly were obtained from Behavioural Risk Factor Surveillance System (BRFSS) data between 2001 and 2010. All three datasets include information about county and monthly date, which is considered as location and time index.

Specifically, Chapter 4 first estimates the causal effect of wildfire exposure on birth outcomes including birth weight, premature birth and congenital anomalies. Then, Chapter 4 examines the impact of wildfires on health conditions of older people with respect to general physical and mental health, physical activities as well as asthma symptoms. There are three sub-questions for each outcome of interest.

The first sub-question studies the causal effect of each of the five most sizeable wildfires on neonatal health and older people's health status at individual level. A difference-in-differences (DD) model is adopted in which the distance from wildfires to each county is used as a continuous treatment intensity. The second sub-question examines how multiple large wildfires affect health outcomes of the newborns and the elderly. The two-way fixed effects (TWFE) regression is used because there are more than two time periods and treatment began at different time in different counties. The canonical DD method can no longer be applied because treatment timing changes across counties and the post-treatment period cannot be defined in control groups (Goodman-Bacon, 2021). The third sub-question evaluates the aggregate impact of multiple wildfires of different sizes on average health outcomes at the county level. Since treatment effects are heterogeneous across counties or over time, TWFE estimator of the average treatment effect on the treated (ATT) is biased based on the common trend assumption (de Chaisemartin and

D'Haultfœuille, 2020). Given the disadvantages of TWFE and the heterogeneity of the treatment effects across counties throughout the time window, Chapter 4 adopts $DID_{+,t}$ estimator proposed by de Chaisemartin and D'Haultfœuille (2020), which accounts for heterogeneity in treatment effects among groups or over time.

The empirical evidence shows that for birth outcomes, the largest wildfire results in a slightly higher probability of developing other circulatory or respiratory anomalies among newborns. Moreover, the second largest wildfire marginally increased the likelihood of low birth weight. However, both effects are close to zero. As for the health impact of wildfires on older people, the elderly experienced asthma symptoms more often following the second largest wildfire. Second, the impact of multiple large wildfires which burned more than 5000 acres slightly increased the probability of prematurity. Multiple wildfires also enhanced the frequency of showing asthma symptoms and extended the period of poorer mental health for older people. For the third sub-question, maternal exposure to wildfires modestly reduced the risk of developing omphalocele and cleft lip whilst there is a slight increase in the length of gestation due to being exposed to wildfires. As for the elderly, wildfire exposure resulted in physical inactivity.

Chapter 5 discusses the limitations in this thesis and provides recommendation for practitioners and further work.

Chapter 2 The Sectoral Effects of Severe Acute Respiratory Syndrome: Evidence from the Chinese Stock Market

2.1 Introduction

Infectious diseases constitute an unavoidable component of human world and have impeded economic prosperity increasingly (Lewis, 2001). From 1980 onwards, the population across the globe has witnessed an unexpected surge in the number of communicable disease cases and the appearance of novel contagious diseases (Smith *et al.*, 2014). In an analysis of 12102 outbreaks of 215 human communicable diseases between 1980 and 2013 by Smith *et al.* (2014), 88 percent of infectious disease outbreaks were caused by bacteria and viruses while non-vector borne pathogens induced 87 percent of outbreaks relative to vector transmitted diseases. Moreover, relative to 44 percent of outbreaks due to anthroponoses, 56 percent of the spread of contagious diseases was triggered by zoonotic diseases (Smith *et al.*, 2014). The globe has experienced a rise in the number and novelty of infectious disease outbreaks caused by zoonoses compared with human-specific diseases (Smith *et al.*, 2014). Recently, the COVID-19 pandemic has led to catastrophic socioeconomic consequences in the globe. In addition to causing 4,871,841 deaths and 239,007,759 confirmed cases as of 14 October 2021 (World Health Organization, 2021), COVID-19 also resulted in considerable unexpected health risks, such as mental health problems (Pfefferbaum and North, 2020), suicidal behaviour (Sher, 2020) and cancer deaths because of a postponement of diagnosis (Maringe *et al.*, 2020). Given the calamitous effect of epidemics or pandemics on public health, one of the major challenges caused by an epidemic or a pandemic is the consequent economic costs. Meanwhile, several different strands of economic literature have investigated the impact of epidemics on economic outcomes, such as economic growth (Boucekkine, Diene and Azomahou, 2008; Fogli and Veldkamp, 2021), property values (Ambrus, Field and Gonzalez, 2020), labour market outcomes (Lee and Cho, 2016), household income and expenditures (Celik, Ozden and Dane, 2020), corporate performance (Shen *et al.*, 2020), as well as the long-term impact on socioeconomic outcomes for birth cohorts exposed to epidemics in utero (Almond, 2006).

As the first epidemic in the 21st century, Severe Acute Respiratory Syndrome (SARS) had a devastating impact on local economies and challenged public health system in China. The etiological agent of SARS was detected to be a novel coronavirus, which can be spread from human to human (World Health Organization, 2019) while its clinical symptoms include pyrexia, myalgia, cough, dyspnoea and acute respiratory distress syndrome (Zhao *et al.*, 2003). More than 8000 people were infected with SARS among 26 countries in 2003 (World Health Organization, 2019). Research findings estimate the worldwide macroeconomic cost of SARS to be 30-100 billion US dollars in total and 3-10 million US dollars per SARS case (Smith, 2006). Although SARS lasted for a shorter time span and a smaller number of patients were infected compared with other major epidemics, such as HIV and malaria (Bloom and Canning, 2006; Lee and McKibbin, 2012), SARS induced a tremendous economic upheaval in China possibly due to public fear of SARS (Fan, 2003; Xu, 2003; Siu and Wong, 2004; Bloom and Canning, 2006; Lee and McKibbin, 2012). The public panic and economic turmoil could be attributed to the poor disease surveillance and reporting systems (Xu, 2003; Lee and McKibbin, 2012; Cao, Fang and Xiao, 2019), the delay in the government response (Xu, 2003) as well as a paucity of SARS-related information available to the public (Fan, 2003).

To date, researchers have already examined the effect of SARS on stock returns in various sectors within different regions and countries. The existing evidence suggests that SARS had a negative impact on the following economic variables: stock indices in mainland China and Vietnam (Nippani * and Washer, 2004), the cumulative abnormal returns of hotel firms in Taiwan (Chen, Jang and Kim, 2007), tourism sector in China (Chong, Lu and Wong, 2010) as well as tourism, wholesale and retail industry in Taiwan (Chun-Da *et al.*, 2009). By contrast, there were stock market winners during the epidemic, which experienced an increase in stock returns: the biotechnology sector in Taiwan (Chun-Da *et al.*, 2009) and the pharmaceutical industry in China (Chong, Lu and Wong, 2010). Moreover, SARS significantly increased the financial risk of airline stocks across mainland China, Hong Kong, Singapore, Thailand and Canada (Loh, 2006).

This chapter investigates the causal effect of Severe Acute Respiratory Syndrome (SARS) epidemic on Chinese A-share[23] returns and systematic risk for every sector. The empirical analysis uses data about closing prices of A-shares at the daily level for each sector on Shanghai Stock Exchange and Shenzhen Stock Exchange between 18 November 2002 and 10 November 2003, which is drawn from Bloomberg. The sectors are classified according to the Global Industry Classification Standard (GICS) system. Data for the timeline of SARS related events were collected from World Health Organization (2003), Enserink (2013) as well as Lee and McKibbin (2012).

[23] In mainland China, stocks are classified as A-shares and B-shares on Shanghai Stock Exchange and Shenzhen Stock Exchange. A-shares are common shares denominated and traded in Chinese Yuan while B-shares are denominated in Chinese Yuan but are traded in U.S. dollars and Hong Kong dollars on Shanghai Stock Exchange and Shenzhen Stock Exchange respectively. See section 2.2.3 for more details.

The following empirical strategy is adopted for this study. To begin with, the event study evaluates the dynamic impact of the key SARS related event (on 17 March 2003) on stock prices over a one-year time horizon. Compared with difference-in-differences and difference-in-difference-in-differences, the event study explores the changes in the effect of an event over multiple time periods. Next, cumulative average abnormal returns for the entire stock market are estimated to show how stock returns responded to SARS. Furthermore, the SARS epidemic can be considered as a natural experiment to conduct causal inference analysis. Thus, a combination of the DDD and DD methods is adopted to calculate the average treatment effect on the treated (ATT) of SARS on stock returns. In particular, to control for the stock market seasonality, the analysis adopts the country-specific DD, which uses one year before the core sampling period[24] as the control group. In order to capture the influence of other confounding factors including international crisis events, the year-specific DD method is employed, which regards India as the control group. Another purpose of using the country-specific DD is to check the validity of the control group used in DDD, while the year-specific DD for the pre-SARS year is intended for a placebo test for the parallel trend assumption underlying the main year specific DD as well as DDD in the absence of stock market seasonality. Furthermore, for the purpose of controlling for the stock market seasonality and the effect of other contemporaneous confounding events on Chinese stock market in a single framework, the DDD approach is a preferred choice. This chapter also evaluates the causal impact of SARS on systematic risk of each sector. Motivated by Ramiah, Martin and Moosa (2013), this chapter adjusts the CAPM (termed modified CAPM) based on DD and DDD to estimate the effect of SARS on systematic risk of different Chinese sectors. In addition, to assess whether the DD and DDD estimates change prior to and following the Chinese stock market closure in May 2003, the post-treatment period is split into two sub-periods.

The empirical findings show that the cumulative average abnormal returns for the entire A-share market are negative and decreasing during the SARS epidemic, which indicates that the Chinese A-share stock market as a whole experienced a steady decline in stock returns. Specifically, the SARS epidemic had a negative effect on A-share returns in the entire stock market and the following sectors: consumer discretionary, healthcare, industrials, and utilities. Unexpectedly, no stock market winners are discovered over the SARS epidemic. Moreover, there is a significant surge in the systematic risk of the financial sector, whereas the systematic risk of the communication services and utilities is not influenced by SARS. Furthermore, the magnitude of the decrease in A-share returns of stock market losers is found to be higher following the resumption of the stock market activities relative to the earlier phase of the SARS epidemic. A

[24] The core sampling period runs from 18 November 2002 to 10 November 2003.

possible explanation for these results may be public panic over the SARS epidemic and self-protection behaviours. Due to data unavailability, it is beyond the scope of this study to empirically investigate the effect of public fear on stock market response.

As for contribution, this chapter extends the existing literature in the following directions. First, despite the importance of identifying stock market winners and losers during the epidemic, there remains a paucity of findings on the effect of SARS on stock returns of all the sectors in China. Therefore, this chapter aims to fill this research gap by studying the causal impact of SARS on A-share returns of each sector in China, so that the analysis takes into account the effect of SARS on Chinese sectors which have received scant attention in current literature. Second, there has been little discussion about the influence of epidemics on systematic risk of each sector so far. This study offers some insights into the changes in systematic risk of each Chinese industry induced by SARS. Moreover, from a priority setting perspective, there is a need to investigate the size of the effect of an epidemic on stock market performance. The negative effect of SARS on stock returns of most sectors incentivises the government to prevent future epidemics or minimise the devastating effect of existing epidemics.

From a methodological perspective, most previous research has tended to focus on a short time horizon such as several days around the date of a key SARS related event, whereas studies to date using a narrow time window such as these do not necessarily consider subtle changes in stock returns over time during the entire period of SARS epidemic. For the purpose of more precisely capturing the effect of SARS over the complete time span, the present research extends the shorter time span to one year, which runs from the emergence of the first case of SARS in Guangdong until the WHO's announcement of the successful containment of SARS. Furthermore, this chapter not only evaluates the dynamic effect of SARS on a daily basis using the event study, but also for the first time, assesses the ATT of SARS by employing methods for causal inference. Much of the research up to now has adopted the event study to estimate the cumulative average abnormal returns (CAAR), such as Chun-Da *et al.* (2009), Chen, Jang and Kim (2007) and Chong, Lu and Wong (2010), which is also applied in this paper to calculate the CAAR of all sectors combined during the SARS epidemic. Such an approach, nevertheless, has failed to address the problem that in the longer event window, the determinants of normal stock returns may vary with the SARS situation, public health policies and other confounding factors including the worldwide economic recession and the Iraq war. This chapter aims to contribute to the methodology and resolve these issues by using another form of event study as well as causal inference methods including difference-in-differences (DD) and difference-in-difference-in-differences (DDD). Finally, the appropriate causal estimation of the effect of SARS on stock market performance can be used as input into cost-benefit analysis of the SARS epidemic.

This chapter is organised as follows. Section 2.2 gives a brief overview of SARS epidemiology, SARS-related events, and public health response, as well as the Chinese stock market. Section 2.3 reviews existing literature regarding the effect of SARS on economy and the stock market. Section 2.4 describes the data while Section 2.5 explains the methods. Section 2.6 and 2.7 presents the empirical results and discussions respectively. The conclusions are shown in Section 2.8.

2.2 Background

2.2.1 SARS Epidemiology

According to Porta (2008), an epidemic is defined as the appearance of a certain unanticipated and abnormal disease, health-relevant behaviour or health-related incidents in a society. The specific number of infected patients signifying an outbreak of an epidemic depends on several factors, such as the characteristics of the infected groups, the time and location of the emergence of the epidemic as well as the history of the epidemics (Porta, 2008). The outbreak of SARS was a severe public health emergency originating from Guangdong Province in China in November 2002. The SARS epidemic situation became grave in the second quarter of 2003 and the epidemic was controlled in July 2003 (Keogh-Brown and Smith, 2008). The spread of SARS chiefly happened within the healthcare environment, but the transmission sometimes occurred in a taxi, in the workplace or on an aeroplane where people were likely to interact with SARS patients (Peiris *et al.*, 2003). Nearly one-fifth of SARS patients consisted of physicians and nurses (Enserink, 2013). Furthermore, according to Peiris *et al.* (2003), people of all ages were infected with SARS and females constituted a larger proportion of SARS patients possibly because nurses were more likely to contract SARS. It is noteworthy that the occurrence of “super-spreading” phenomenon, when a small fraction of SARS patients infected a large group of contacts, may be attributed to environmental, behavioural and biologic characteristics (Peiris, Guan and Yuen, 2004).

A number of suspected SARS patients at the beginning of the epidemic in Guangdong were associated with wildlife trade markets and they were believed to have contracted the SARS virus via the animals in the markets, whereas almost all the succeeding SARS infections can be attributable to contact between susceptible individuals and infected patients (Enserink, 2013). The causative agent of SARS is an unusual coronavirus, which is thought to pose no threat to humans, although it can damage animals’ health (Enserink, 2013). However, the spike of the coronavirus mutated into forms that strengthened the virus’s ability to infect people and to transmit among the public, which subsequently caused severe symptoms (Enserink, 2013). Specifically, the coronavirus originated from either a variation in the virus discovered in the horseshoe bats or an unknown progenitor virus (Enserink, 2013). The new coronavirus was then transmitted to wild animals, including Himalayan palm civets and raccoon dogs, in wildlife trade markets which facilitated the transmission of the virus among animals and humans (Enserink, 2013).

The symptoms of SARS are similar to those of lower respiratory tract diseases, including fever and malaise, but SARS can also damage other organs and induce additional ailments, for example, diarrhoea (Peiris, Guan and Yuen, 2004). At the outset, the infected patients often suffer from fever, malaise, cough, chills or myalgia while gradually, the patients develop symptoms such as tachypnoea, pleurisy and breathing difficulty (Peiris *et al.*, 2003). A small fraction of patients need intensive care or assisted ventilation (Peiris *et al.*, 2003). Moreover, SARS patients suffer from post-traumatic stress disorder as well as depression whilst the disorder plagued them even after discharge from the hospital (Peiris *et al.*, 2003). Peiris *et al.* (2003) observe that the symptoms of SARS during the early stage of the disease, such as lower respiratory disease, cannot distinguish SARS itself from other acute pneumonia, so the symptoms cannot be used as unique diagnostic criteria. In fact, SARS cases were identified by tracing the contact history of diagnosed SARS patients (Peiris *et al.*, 2003). Peiris *et al.* (2003) also note that SARS was spread by means of respiratory droplets or aerosol-generating processes while the latter could speed up the transmission of SARS especially in the hospitals. The SARS patients can spread the coronavirus at least five days after they are infected (Peiris *et al.*, 2003).

In terms of prevention and treatment of SARS, the hospitals at first used general antibacterial drugs, such as ribavirin which could cure acute pneumonia, as a therapy for the suspected SARS patients, but treatment efficacy was understudied (Peiris *et al.*, 2003). In addition, since no vaccines were developed, epidemic prevention measures include early identification and isolation of SARS patients, quarantine of close contacts of SARS patients, border screening and public education (Peiris *et al.*, 2003). Peiris *et al.* (2003) also describe other precautionary measures to avoid infection via respiratory droplets or contact with SARS patients, for instance, hand cleanliness. It is important to raise the public awareness of the threat of SARS to ease public concerns and stabilise social order when enforcing public health measures (Peiris *et al.*, 2003).

2.2.2 SARS-related Events and Public Health Response

During the detection, prevention and treatment of SARS, a series of prominent SARS-related events attracted people’s attention. In the initial stages of the SARS outbreak, the WHO mistook SARS for H5N1 avian influenza or another different epidemic and the severity of the epidemic was undervalued by the local government (Enserink, 2013). Several exceptional “super-spreading” incidents become a key attribute of SARS. The first such event happened in Hong Kong when a

Guangdong physician infected with SARS stayed in the Metropole Hotel in Hong Kong and SARS was subsequently spread to other hotel guests from different regions and countries, which led to the outbreak of SARS in Canada, Hong Kong, Singapore and Vietnam (World Health Organization, 2003). Another super-spreading event occurred in the Amoy Gardens, an apartment complex in Hong Kong, which originated from a renal disease patient infected with SARS when hospitalised in the Prince of Wales hospital (Lee, 2003). The patient called on his brother in Amoy Gardens and used the toilet in the flat, which resulted in the transmission of SARS through the sewage system in the community and more than 300 SARS cases were linked to the Amoy Gardens (Lee, 2003).

In order to deal with the pressing public health events, the WHO and governments in different countries or regions took a sequence of measures to stem the rapid spread of SARS. For example, the WHO issued a series of urgent travel warnings for travellers who had planned to travel to countries and regions where the epidemic situation was exacerbated (World Health Organization, 2003). In March 2003, the WHO suggested screening departing passengers for SARS-related symptoms at several airports of the affected regions or countries (World Health Organization, 2003). In addition, schools were closed for several days in Hong Kong and Beijing (World Health Organization, 2003). The China Securities Regulatory Commission enforced a policy on closing the stock markets and futures markets in Shanghai and Shenzhen from 1 May until 12 May while on April 28th, the Beijing municipal government required the closure of movie theatres, Internet cafes and other entertainment venues (Xu, 2003). The daily reporting and updates in terms of SARS-related facts and figures were launched in China since April 2003 (World Health Organization, 2003; Xu, 2003).

The battle against SARS revealed the weaknesses of the local government and the public health systems in the surveillance and reporting of the epidemic situation, which resulted in excessive economic and societal response to SARS. According to Xu (2003), in the early stages of SARS epidemic, the local officials' response to the epidemic situation was negligent and the media coverage in regard to the relevant SARS information was sparse. Thus, the general public lacked sufficient knowledge about SARS. The local authorities attached little importance to the epidemic and announced that the epidemic was brought under control at the beginning of the SARS outbreak (Xu, 2003). Until the second half of April 2003, the government of China began to pay full attention to the seriousness of the epidemic situation and required that all the workplaces update on suspected or confirmed SARS cases promptly and meticulously (Xu, 2003), while the government started cooperating with the WHO since then (Enserink, 2013). Bloom and Canning (2006) emphasize the important role of international collaboration in containing the transmission of epidemics, such as using the international media to propagate information about the virus and prophylactic measures as well as to issue travel recommendations for the affected countries. In addition, the central and local governments failed to cooperate effectively to respond to the SARS epidemic and the government expenditure on the investigation into SARS was insufficient (Lee and McKibbin, 2012).

The public health systems play an important part in identifying and isolating disease cases and their related contacts in the initial stages of the epidemic, but during the SARS outbreak, the poor public health systems in the affected countries failed to effectively stop the spread of SARS (Enserink, 2013). Firstly, the main culprit of the disproportionate transmission of SARS among healthcare workers is lack of dissemination of SARS-related information while a shortage of knowledge about SARS could be ascribed to the absence of an epidemic surveillance system and the out-of-date reporting scheme, which would postpone the response from the local government and health authorities (Cao, Fang and Xiao, 2019). Secondly, under the traditional and inefficient surveillance scheme, people reported SARS-related data by filling in the reporting forms manually and sending the forms via fax or post (Cao, Fang and Xiao, 2019). However, the reports sent by hospitals were often inaccurate and deferred (Wang *et al.*, 2008). Notably,until after 24 April, 2003, the local health authorities and hospitals began providing SARS-related figures using a web-based system, which facilitated the dissemination of the latest SARS-related facts and figures (Wang *et al.*, 2008). Another enhancement to the reporting system was that more detailed information with respect to each individual patient rather than aggregate information was provided so that the health authorities could keep track of patient profiles, such as the demographic characteristics, geographic location and the household the patient belongs to (Wang *et al.*, 2008). Wang *et al.* (2008) commented that this new and real-time reporting system helped diminish the possibility of underreporting the SARS cases to some extent.

2.2.3 Introduction of Chinese Stock Market

Following the 3rd Plenary Session of the 11th Central Committee in 1978, the Reform and Opening-up policy promoted the development of the Chinese stock markets and since 1980, China gradually reformed its securities market (Shanghai Stock Exchange, 2001). Some state-owned companies were corporatized and began selling stocks to outside investors (Chen, Firth and Gao, 2002). Moreover, two main stock exchanges were established in mainland China: Shanghai Stock Exchange (SSE), which was founded in November 1990 and Shenzhen Stock Exchange (SZSE), which was set up in December 1990. The Shanghai Composite Index was initiated in July 1991 while the Shenzhen Composite Index was introduced in April 1991 (Huo and Ahmed, 2018).

The stock market segmentation is a major characteristic of the Chinese stock market. In mainland China, stocks are classified as A-shares and B-shares on Shanghai Stock Exchange and Shenzhen Stock Exchange. A-shares are common shares denominated and traded in Chinese Yuan while B-shares are denominated in Chinese Yuan but are traded in U.S. dollars and Hong Kong dollars on Shanghai Stock Exchange and Shenzhen Stock Exchange respectively. In addition, before December 2002, exclusively Chinese investors were eligible to buy A-shares while earlier than February 2001, B-shares were purely available to foreign investors (Luo, Brooks and Silvapulle, 2011). The segmented structure was designed to maintain financial stability in China (Luo, Brooks and Silvapulle, 2011). However, after joining the World Trade Organisation, China introduced some new policies in order to ease restrictions on the stock market (Huo and Ahmed, 2018). For example, foreign investors could invest in A-shares through Qualified Foreign Institution Investment (QFII) scheme since 2002, which had positive effects on the Chinese stock market, such as promoting the management of the listed corporations and augmenting the investment strategies (Huo and Ahmed, 2018). Fung, Lee and Leung (2000) suggest that A-shares and B-shares are weakly correlated and the stock prices of the two types of stocks display different characteristics. In China, the A-share prices are higher than B-shares while in other countries, the situation is reversed (Wo, 1997, Bailey, 1994, cited in Fung, Lee and Leung, 2000). The distinction between the prices of A-shares and B-shares can be explained by the market liquidity and the segmented stock market structure (Poon et al., 1998, Wo, 1997, cited in Fung, Lee and Leung, 2000). During the sample period of this study, A-shares were primarily available to mainland Chinese investors while B-shares were mainly targeted at investors outside mainland China. Therefore, this chapter focuses on A-shares because the impact of SARS on Chinese economy can be more accurately reflected by behavioural response of Chinese investors, who were directly affected by SARS.

2.3 Literature Review

2.3.1 The Effect of SARS on Stock Market

Since the outbreak of SARS, several lines of evidence suggests that SARS influenced the stock market performance of several industries within the affected countries. Nippani * and Washer (2004) demonstrate that the stock indices in mainland China and Vietnam were negatively influenced by SARS whereas there is no evidence of SARS effect on stock indices in Canada, Hong Kong, Indonesia, the Philippines, Singapore and Thailand. Loh (2006) studies the impact of SARS on both the returns and the volatility of individual stocks in the airline industry in mainland China, Canada, Hong Kong, Thailand, Singapore and Taiwan. The results show that SARS had no significant influence on the mean returns of market indices and airline stocks in all the regions (Loh, 2006). SARS also did not significantly affect the volatility of market indices in all the countries except Singapore, but the volatility of airline stocks was significantly increased in all the areas, which implies higher financial risk of airline stocks (Loh, 2006). Furthermore, no structural breaks in the systematic risk of airline stocks are discovered in all countries excluding Singapore and Thailand, so the effect of SARS on the risk of airline stocks was temporary (Loh, 2006). In addition, the systematic risk of airline stocks in Thailand, Singapore, Taiwan and Hong Kong increased significantly during the SARS period (Loh, 2006). Chen, Jang and Kim (2007) find that SARS had a negative effect on the cumulative abnormal returns of Taiwan hotel firms 10 days after the event day when the first case of SARS was reported in Taiwan while the magnitude of the negative abnormal returns was larger 20 days following the event day, which probably resulted from more reported SARS cases.

SARS is also found to have a positive impact on stock returns of specific industries. Chong, Lu and Wong (2010) reveal that in China, the stock returns of pharmaceutical companies stayed positive seven weeks after the official announcement of SARS outbreak by the Chinese government on 20 April 2003, whereas the stock returns of tourism firms decreased drastically and kept negative over a long period following 20 April, 2003. Chun-Da *et al.* (2009) conclude that in Taiwan, compared with the negative effect of SARS on stock returns of tourism, wholesale and retail sectors, the returns for biotechnology sector were positively influenced by SARS after 22 April 2003 when the first case of SARS was reported in Taiwan.

2.3.2 The Effect of COVID-19 on Stock Market Performance

Following 2020, the COVID-19 pandemic has severely influenced financial markets all around the globe and there has been an increasing amount of literature on the effect of COVID-19 on stock market performance. Given the similarity between SARS epidemic and COVID-19 pandemic, this section reviews literature regarding the influence of COVID-19 on stock market.

Baker *et al.* (2020) find that due to the influence of COVID-19 pandemic, the stock market volatility in the U.S. have exceeded that during Great Depression, 1987 Black Monday and 2008 Global Financial Crisis as well as other infectious disease outbreaks including 2003 SARS epidemic and 2015 Ebola epidemic which caused much more moderate and short-run changes in stock market volatility. Such an extraordinary U.S. stock market volatility can be mainly attributed to policy and behavioural changes, such as travel restrictions and voluntary social distancing behaviour (Baker *et al.*, 2020). Griffith, Levell and Stroud (2020) point out that COVID-19 had a large and negative effect on the stock prices of the following sectors in the UK: tourism and leisure, retailers, insurance, fossil fuels production and distribution as well as large manufacturing industries, whereas the sectors below have witnessed an increase in stock prices: food and drug manufacturers and retailers, utilities, tobacco and high tech manufacturing as well as medical and biotech research. Ramelli and Wagner (2020a) report that the industry averages of cumulative raw returns in several Chinese industries were positively affected by COVID-19, such as food, beverage and tobacco, materials, media and entertainment, healthcare as well as semiconductors, whereas some industries in China suffered significant losses in raw returns including telecom services, energy, retailing, utilities, real estate, consumer services and transportation. In another study, Ramelli and Wagner (2020b) propose that in US, the telecommunications industry performed well during the entire pandemic period because of an increasing demand for telecommunication services to work at home, while the stock returns of the utilities industry outperformed during the Incubation and Outbreak stages because the goods in the utilities industry are essential for domestic use and the demand for these goods was not affected by the pandemic. The following industries suffered the biggest loss during the whole period of pandemic: energy, automobiles and consumer services (Ramelli and Wagner, 2020b). In particular, the stock returns in the healthcare industry increased in the initial stages, but such benefits diminished during the Fever period (Ramelli and Wagner, 2020b).

Similarly, other researchers, who have looked at whether sectors benefit from the pandemic or made a loss, have found that COVID-19 had a positive effect on stock returns of the following Chinese sectors: information technology (Al-Awadhi *et al.*, 2020; He *et al.*, 2020), medicine manufacturing (Al-Awadhi *et al.*, 2020), manufacturing, education, and health industries (He *et al.*, 2020). In US, sectors which benefit from the pandemic include electronic entertainment, diversified retailers, nondurable household goods, biotechnology, computer hardware (Thorbecke, 2020), healthcare, food, natural gas (Mazur, Dang and Vega, 2021) and software (Thorbecke, 2020; Mazur, Dang and Vega, 2021). In Australia, food, pharmaceuticals, telecommunications and healthcare show an increase in returns following the pandemic (Alam, Wei and Wahid, 2020).

By contrast, the following Chinese industries witnessed a decline in stock returns: beverages, air transportation, water transportation, highway transportation (Al-Awadhi *et al.*, 2020), agriculture and forestry, real estate, retail (Cheng, Cui and Li, 2020), transportation, mining, electric and heating, as well as environmental industries (He *et al.*, 2020). In US, the sectors with a reduction in stock returns include airlines, aerospace, tourism, oil, brewers, retail apparel, funerals, production equipment, machinery, electronic and electrical equipment (Thorbecke, 2020), crude petroleum, entertainment, hospitality (Mazur, Dang and Vega, 2021) and real estate (Thorbecke, 2020; Mazur, Dang and Vega, 2021). In addition, the pandemic negatively affected the stock returns of the following sectors in Vietnam: financial, industrial and consumer goods sectors (Anh and Gan, 2020), while in Australia, the sectors worst hit by the pandemic include transportation and energy (Alam, Wei and Wahid, 2020).

Moreover, some researchers have mainly been interested in the characteristics of sectors or companies which experienced a gain or loss over the pandemic. At the sector level, Smales (2020) suggests that the US sectors which supply essential goods and services (such as food and healthcare) tend to benefit from the steady demand during COVID-19. Cheng, Cui and Li (2020) point out that the Chinese labour-intensive industries characterised by larger population movement, such as agriculture and forestry, real estate, and retail, experienced a larger loss, whereas sectors associated with medical care and contactless communication gain from the market because of their vital contributions to the society. At the firm level, Ding *et al.* (2021) identify the following five features of companies in different countries with a positive reaction of stock returns during the pandemic: strong financial health before 2020, greater international exposure, involvement in more corporate social responsibility activities before the pandemic, less entrenched executives as well as ownership taken by families, large enterprises and governments.

Furthermore, some research has attempted to explore factors that drive the changes in stock market performance. Haroon and Rizvi (2020) find that the panic incurred by news about COVID-19 is linked to an increase in volatilities in some US industrial sectors, such as transportation, automobiles and components, energy as well as travel and leisure industries. Choi (2020) concludes that the economic policy uncertainty produced by COVID-19 escalates the volatility in all the US sectors. Smales (2020) shows that the enhanced investor attention to COVID-19 either increased or decreased US stock returns in different sectors. Thorbecke (2020) maintains that the macroeconomic environment and idiosyncratic factors can explain changes in US stock returns across various sectors. Anh and Gan (2020) propose that the lockdown in Vietnam led to an increase in stock returns for all the industries, which can be explained by the public trust in the abilities of the government to contain the spread of COVID-19.

2.3.3 The Economic Effect of SARS

Since the outbreak of SARS, a strand of literature related to this paper has become available on the impact of SARS on the overall economic conditions and business performance of various industries in China and other affected countries. Bloom and Canning (2006) maintain that imposing travel restrictions in order to prevent the spread of SARS strongly hit the tourism and trade industries while compared with agricultural countries, the negative effect on these industries is larger in the industrialized or industrializing nations where more travel is necessary.

Xu (2003) argues that the most negatively influenced industries include travel and tourism as well as retail businesses (including restaurants and hotels) in Asia because customers avoided crowded indoor spaces, which is in line with Fan (2003), while the Chinese service sector experienced a heavy loss induced by a sense of insecurity and fear of infection among consumers. The precautionary measures, such as shortening the 'Golden Week' holidays, the stock market closures and the shutdown of entertainment venues, further aggravated the economic slowdown (Xu, 2003). However, the economic disturbance in the manufacturing sector was minimal owing to its cost advantage, large scale and investment from governments and transnational corporations, whereas the small share of the service sector in Chinese economy lessened the negative influence of SARS on Chinese economy (Xu, 2003). Other factors, such as China's entry into the World Trade Organisation and the government policy on stimulating the domestic demand, also abated the negative economic outcomes of SARS (Xu, 2003).

Empirical research has highlighted the economic loss to China and other affected nations caused by SARS, especially to the service sector. Keogh-Brown and Smith (2008) find that the regions where the most severe SARS outbreak occurred, including mainland China, Hong Kong, Canada and Singapore, suffered the largest loss while the following sectors which involve close contact between people were likewise most negatively affected: exports, tourism, hotels, restaurants, airline, investment (inward and outward) and retail sales. Keogh-Brown and Smith (2008) also reveal that the effect of SARS on GDP and economic losses in several sectors appeared to be short-term and lasted for one month, followed by subsequent gains in the following period. Likewise, Beutels *et al.* (2009) suggest that SARS had a negative impact on leisure activities (including bars and restaurants), transportation and tourism in the third quarter of 2003 in Beijing, but the consumption in these sectors recovered in the fourth quarter of 2003 after the containment of SARS.

Given that the economic effect of the epidemic involves income loss caused by absenteeism or death, O. M. Lee and Warner (2006) propose that the Chinese business performance and the employment of entertainment, retail, +hotel and catering were seriously and negatively affected by SARS while although the GDP growth rate was barely weakened, the microeconomic outcomes were severe in the short term through the labour market effect of SARS, such as layoffs or redundancy in the service sector.

In Hong Kong, studies have indicated that SARS resulted in a negative economic effect on consumption, tourism and travel (Siu and Wong, 2004) as well as real estate (Wong, 2008).

2.4 Data

The research focuses on A-shares traded on Shanghai Stock Exchange and Shenzhen Stock Exchange. This paper retrieves data regarding closing prices of all common stocks at the daily level across 11 sectors on trading days between Monday and Friday obtained from Bloomberg Applications Program Interface (API). The core sample period runs from 18 November 2002 to 10 November 2003. The stocks are categorised by the sub-industry each company belongs to, the location of domicile of the companies and the stock exchange each company was listed on. The stock prices over the weekends are excluded from the dataset while the prices on public holidays during the weekdays are obtained as missing values. A total of 1080 Chinese companies with non-missing closing prices are included in the sample between 18 November 2002 and 10 November 2003. In addition, the total number of Chinese firms with non-missing last prices in each of the 11 sectors in the sample is listed as follows: 31 in communication services, 150 in consumer discretionary, 76 in consumer staples, 28 in energy, 25 in financials, 78 in healthcare, 223 in industrials, 87 in information technology, 204 in materials, 117 in real estate and 61 in utilities.

In the modified CAPM as specified in section 2.5, this paper uses the repo rate as a measure of the risk-free rate in each country for the following reasons. Fan and Zhang (2006) suggest that before 2006, the short-term bonds were not issued in China and the repo rate is the best surrogate for the risk-free rates in China. The repo rates could reflect the supply and demand in the financial markets to a large extent (Fan and Zhang, 2006). They investigate the characteristics of repo rates in China and their term premiums. Fan and Zhang (2006) find that the term premiums of the repo rates in China are relatively small compared with the U.S. Treasury market, so the repo rates could reveal the market participants' belief about future fluctuations in interest rates. Specifically, this study employs the interbank repo rate in China, Reserve Bank of India repo rate policy announcement, The Bank of Korea base rate and Japanese Yen Overnight General Collateral Government Repo as the risk-free rate in China, India, South Korea and Japan respectively.

In order to evaluate market returns, the research employs data in terms of the following market indices of each country from Bloomberg: Shanghai Stock Exchange A-share Index, Shenzhen Stock Exchange A-share Index, S&P BSE SENSEX (for Bombay Stock Exchange), NSE NIFTY 50 Index (for National Stock Exchange of India), KOSPI Index (for Korea Stock Exchange) and Nikkei 225 (for Tokyo Stock Exchange).

In addition, to identify the categories of sectors, this paper adopts the Global Industry Classification Standard (GICS) system, which was created by MSCI (Morgan Stanley Capital International) and Standard & Poor's Dow Jones Indices in 1999 (MSCI Inc., 2018). In particular, the GICS system classifies enterprises into 11 sectors, 24 industry groups, 69 industries and 158 sub-industries (MSCI Inc., 2018). The 11 sectors under the GICS system include communication services, consumer discretionary, consumer staples, energy, financials, healthcare, industrials, information technology, materials, real estate and utilities (MSCI Inc., 2018). Moreover, this classification system is chosen due to its following merits. After comparing GICS system with three widely used classification systems including Standard Industry Classification (SIC), North American Industry Classification System (NAICS) and Fama-French (FF) classification codes, Bhojraj, Lee and Oler (2003) find that GICS has better performance based on several metrics of homogeneity of companies within each industry, such as explaining the contemporaneous correlation of stock returns as well as cross-sectional variations in R&D costs and sales growth in each industry. They also suggest that GICS scheme is mainly established for financial professionals based on the financial characteristics of companies instead of on production technology of firms (Bhojraj, Lee and Oler, 2003). Moreover, the classification codes are consistent over time (Bhojraj, Lee and Oler, 2003). Kahle and Walkling (1996) examine the valuation errors using the multiples approach under different classification codes including SIC, NAICS, FF as well as GICS, and discover that the valuation errors are the smallest using the GICS system, which indicates that GICS can classify more homogeneous companies into the same industry.

With respect to the event data, the timeline of key daily events relevant to SARS is listed in Appendix A.1, which is mainly collected from World Health Organization (2003) and complemented by Enserink (2013) as well as Lee and McKibbin (2012). The major event of interest happened on 15 March, 2003 when the contagious disease was named ‘Severe Acute Respiratory Syndrome (SARS)’ by WHO according to its symptoms and WHO announced that it is ‘a worldwide health threat’ (World Health Organization, 2003). Thus, in the empirical analysis, both the event day in the event study and the starting date of the post-treatment period in differences-in-differences and triple-differences models are identified as 17 March 2003, which is the first Monday following Saturday, 15 March when the stock market suspended trading over the weekend.

2.5 Methodology

2.5.1 Event Study of Stock Prices

The stock price can be employed to detect the immediate impact of an event on the market value of companies under efficient market hypothesis (MacKinlay, 1997). A string of critical events caused by SARS can arguably be considered as exogenous and trigger off stock price movements uncorrelated with unobserved factors that affect stock prices. The focus of the first analysis is to investigate the dynamic effect of SARS on last prices of enterprises in different Chinese sectors by adopting the event study method. A major advantage of the event study is that it discovers the dynamic path of the effect of events while provides a more accurate estimate of the impact of events by capturing changes in outcomes of interest at the individual level (Kleven, Landais and Søgaard, 2019). Event study is based on the assumption that the event is uncorrelated with the outcomes of interest, which holds true when no evidence shows that the outcomes change significantly before the date of the event (Kleven, Landais and Søgaard, 2019).

In order to estimate the dynamic effect of SARS on stock prices, the study is carried out at the daily horizon, which allows the analysis to capture the immediate effect of SARS on stock prices following the event. The event date (denoted by Day 0) is defined as 17 March 2003, which is the first trading day (Monday) after WHO named the infectious disease 'Severe Acute Respiratory Syndrome (SARS)' and claimed it to be 'a worldwide health threat' on Saturday, 15 March 2003 (World Health Organization, 2003). Although the initial known SARS case can be traceable back to a patient in Guangdong on 16 November 2002, who was identified until a later date, it is assumed that economic agents are unaware of the menace of a novel infectious disease in advance of the event. As a result, stock prices are not expected to be influenced by SARS before the date of the event. All other days are indexed relative to the date of the event. In particular, the event study specification considers the time window starting from Monday, 18 November 2002 and ending on 10 November 2003, which is 128 days following the WHO's announcement that SARS was completely controlled globally on 5 July 2003. Therefore, the specification can identify pre-existing trends in the outcomes of interest as well.

The baseline event study regression model can be specified as follows:

$$y_{its} = \sum_{k \neq -1} \beta_k \, 1(d_t = k) + \alpha_i + u_{its} \quad (2\text{-}1)$$

where y_{its} denotes the closing price of stock i on day t in sector s. The time variable d_t is a dummy for each trading day and k indicates the number of trading days relative to the date of the event. The time dummy at $t = -1$ is omitted from the regression, so β_k evaluates the impact of SARS on stock prices relative to the day before the event. If stocks suspended trading on a certain day due to public holidays, firm-specific events or any other unknown reasons, the values of closing prices are set to missing. The firm fixed effects α_i's soak up the impact of company-specific characteristics on stock prices. u_{its} denotes the error term satisfying

$$u_{its} \sim \text{IID } (0, \sigma_u^2). \quad (2\text{-}2)$$

The estimator of interest, β_k, assesses the effect of the event on outcomes of interest on day k. When $k < -1$, β_k's show the placebo effect of SARS on stock prices In the pre-event period. The impact of SARS on stock prices over the entire period is visualised in graphs. The standard errors are clustered at the firm level to allow for the autocorrelation of stock prices for each company over time.

2.5.2 Event Study of Stock Returns

The second analysis involves evaluating the influence of SARS on stock returns in China by applying the event study approach proposed by MacKinlay (1997). This method has been extensively applied to assess the impact on the value of companies of various events, such as mergers and acquisitions, the issuance of new equity and regulatory changes (MacKinlay, 1997). The event study is based on the efficient market hypothesis, which presumes that stock prices can efficiently reflect new information shocks (Malkiel, 2003; Oberndorfer *et al.*, 2013). Similar to the aforementioned method, the date of event (Day 0) of interest is 17 March 2003. The event window covers the time period from Day -1 (which is one trading day before Day 0) to Day 270 (which is 270 business days after the date of the event). In order to calculate the normal returns, an estimation window of 269 trading days before the event window is chosen. Three models currently exist for estimating the normal returns: market model, mean-adjusted returns model and market-adjusted returns model (Dyckman, Philbrick and Stephan, 1984). The market model is preferred because it increases the power of the test in discovering abnormal returns compared with other models (Dyckman, Philbrick and Stephan, 1984). In addition, compared with Capital Asset Pricing Model (CAMP) and Arbitrage Pricing Theory (APT), the market model can eliminate biases in these models and imposes fewer restrictions on the statistical model (MacKinlay, 1997).

Specifically, at the first step, the market model specified below is used to estimate the normal returns using data over the estimation window (MacKinlay, 1997).

$$r_{it} = \alpha_i + \beta_i r_{mt} + \varepsilon_{it} \tag{2-3}$$

$$E(\varepsilon_{it}) = 0 \tag{2-4}$$

where r_{it} is the observed stock logarithmic returns of firm i on day t while r_{mt} is the market return on day t, which is calculated as logarithmic returns on stock market indices. α_i denotes the variation in stock returns which cannot be explained by market risk factors. ε_{it} is the zero mean idiosyncratic error term.

After evaluating the parameters of interest α_i and β_i in the market model, the event study employs the sample within the event window and calculates the abnormal returns ($\widehat{AR}_{it}$) of firm i on day t as the deviation of actual stock returns from the expected returns, which is specified as follows (MacKinlay, 1997).

$$\widehat{AR}_{it} = r_{it} - \hat{\alpha}_i - \hat{\beta}_i r_{mt} \tag{2-5}$$

where $\hat{\alpha}_i$ and $\hat{\beta}_i$ are the estimates of α_i and β_i respectively. The abnormal returns reflect the variation in returns caused by SARS and are supposed to be negative if investors believe that SARS will decrease the companies' value.

Then, the cumulative average abnormal returns (CAAR) since the event day are calculated in order to assess the causal effect of SARS on the aggregate loss of stock returns for shareholders. CAAR also evaluates the lasting response of stock returns in the entire time frame within which firms are likely to be affected by SARS (Chen, Jang and Kim, 2007). More specifically, the CAAR as specified below is defined as the aggregation of average abnormal returns (AAR) throughout the event window, where AAR is the arithmetic average of all securities' abnormal returns on each day (MacKinlay, 1997).

$$CAAR = \sum_{t=t_0}^{t_1} AAR_t \tag{2-6}$$

$$AAR_t = \frac{1}{N}\sum_{i=1}^{N} \widehat{AR}_{it} \tag{2-7}$$

where AAR_t is the cross-sectional average of abnormal returns on day t. t_0 and t_1 are respectively the beginning and the ending date in the event window. N is the total number of firms in the sample. If SARS had a significant effect on stock returns, CAAR is expected to be significantly different from zero.

2.5.3 Causal Inference Methods

This section focuses on estimating the ATT of SARS on A-share returns and systematic risk in different sectors using the difference-in-difference-in-differences (DDD) method and difference-in-differences (DD) methods underlying DDD. Given that SARS was caused by a new coronavirus overlooked by the public in the initial stage of the epidemic (Cao, Fang and Xiao, 2019), the epidemic can be regarded as a natural experiment.

The pre-treatment and post-treatment periods along with the SARS year and the pre-SARS year are defined as follows. The SARS year begins on 18 November 2002 and ends on 10 November 2003, whereas the pre-SARS year or the placebo year, which is the corresponding year-ago period before the SARS year, starts from 19 November 2001 and finishes until 11 November 2002. In addition, in the SARS year, the pre-treatment period is the time window from 18 November 2002 to 14 March 2003, while the post-event period is defined as the time interval between 17 March

2003 and 10 November 2003. The beginning date of the post-SARS period in the SARS year is consistent with the date of the event in the event study. Correspondingly, during the pre-SARS year, the pre-event period is the time frame between 19 November 2001 and 15 March 2002 while the post-period happens from 18 March 2002 to 11 November 2002.

The Chinese stocks belong to the treatment group while India, South Korea and Japan are assigned to control groups. The use of control groups could capture the influence of other global events and eliminate changes in outcomes induced by events irrelevant to SARS. It can be assumed that all the three control countries were not affected by SARS. According to World Health Organization (n.d.), only three SARS cases in total emerged in India and South Korea respectively while the first SARS case was discovered at the end of April 2003 in both countries. In Japan, no SARS cases were detected during the SARS year. In particular, India is used as the main control country for the following reasons. Firstly, according to Bloomberg News on the Bloomberg Terminal, during the SARS year, the stock markets in India were less influenced by SARS, but mainly affected by key global events, such as the Iraq War and the U.S. economic recession, as well as events in other Asian counties, including the fluctuations in market indices of Japanese stock markets. The same holds true for the Indian stock markets during the pre-SARS year. Other events in India during the SARS year, such as the bomb attack in Mumbai on 25 August 2003, were expected to have a short-term effect on the Indian stock market and the stock market could recover soon (Thakur, 2003). Thus, the impact of other events in India on the stock market could be ignored in the longer run. Secondly, Figure A-1 and Figure A-2 show that the overall trends in the major stock market indices and market returns in India were similar to those in China during the pre-SARS year.

2.5.3.1 Difference-in-Differences

2.5.3.1.1 Country-Specific DD

The country-specific DD is used to check the validity of control groups in the DDD method. In the country-specific DD, the pre-SARS year is employed as the control group to control for the Chinese stock market seasonality. The DD model specification for China and each control country is specified as follows.

$$r_{ijt} = \alpha + \beta_1 Post_t + \beta_2 SARS_j + \gamma(Post_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \qquad (2\text{-}8)$$

where r_{ijt} indicates the stock i's logarithmic return on Day t in Year j; j denotes whether the sample belongs to the SARS year or the pre-SARS year; $SARS_j$ is an indicator which equals one for the SARS year and zero for the pre-SARS year. $Post_t$ is a dummy variable which takes the value of one in the post-treatment period and zero during the pre-treatment period. The variable λ_i is the time-invariant company-specific fixed effect, which represents the stable characteristics of the company. The term ε_{ijt} is the error term and $\mathrm{E}(\varepsilon_{ijt} \mid j, t) = 0$. In all model specifications in this paper, the standard errors are clustered at the firm level to allow for correlations in daily stock returns within each company and independence of returns across different firms. Furthermore, all the DD models in this chapter are estimated by each of the 11 sectors as well as for the whole economy. The estimator of interest is γ, which represents the changes in stock returns in the countries of interest during the post-SARS period relative to the pre-SARS period, in the SARS year, compared with the returns during the same period in the pre-SARS year. The DD estimates for the control countries are used as a placebo test for parallel trend assumption. In addition, the DD estimator β_1 controls for variation in stock returns in the countries of interest during the post-SARS period compared with the pre-SARS period. β_2 denotes changes in stock returns in the relevant countries throughout the SARS year in comparison with the pre-SARS year. The country-specific DD applied to the control countries examines whether India, Japan or South Korea can act as a valid control group after controlling for the stock market seasonality. Thus, the DD estimator γ for well-defined control countries are expected to be zero.

In order to differentiate the effect of SARS in the early stage of the post-period from that in the later phase of the post-period and identify changes in the impact of SARS on stock returns in different stages of the post-treatment period, this research additionally splits the post-treatment period into two time windows, with the period of Chinese stock market closure from 1 May 2003 to 12 May 2003 as a dividing line. That is, the first post-treatment period runs from 17 March 2003 to 30 April 2003 while the second post-SARS period starts from 12 May 2003 and ends on 10 November 2003. In this case, the model is specified below.

$$r_{ijt} = \alpha + \beta_1 Post1_t + \beta_2 Post2_t + \beta_3 SARS_j + \gamma_1 (Post1_t \times SARS_j) + \gamma_2 (Post2_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \quad \text{(2-9)}$$

where $Post1_t$ and $Post2_t$ are indicator variables. for the first and second post-treatment period respectively. The definitions of other variables are identical to those in equation (2-8). The coefficients β_1 and β_2 indicate changes in stock returns during the first and second post-treatment period compared with the pre-treatment period. The coefficients of interest, γ_1 and γ_2, represent the DD estimators of the impact of SARS on stock returns in the first and second post-SARS period separately. The error terms are clustered by firm.

2.5.3.1.2 Modified CAPM (Country-Specific Model)

Besides evaluating the impact of SARS on Chinese A-share returns in different sectors, CAPM is introduced in DD to study the uncertainty in the stock market induced by SARS. Inspired by

Ramiah, Martin and Moosa (2013), the following modified form of the CAPM is used in order to estimate the changes in the systematic risk of A-shares in different sectors caused by SARS.

$$\begin{aligned} r_{ijt} - r_{fjt} = \theta_0 + \theta_1(r_{mjt} - r_{fjt}) + \theta_2(r_{mjt} - r_{fjt}) \times Post_t \\ + \theta_3(r_{mjt} - r_{fjt}) \times SARS_j + \theta_4(r_{mjt} - r_{fjt}) \times Post_t \times SARS_j \\ + \theta_5 Post_t + \theta_6 SARS_j + \theta_7(Post_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \end{aligned} \quad (2\text{-}10)$$

where r_{mjt} and r_{fjt} respectively denote the market returns and the risk-free rate on Day t in Year j in each country. Other variables have the same meaning as those in equation (2-8). The term θ_0 is the non-market premium and $\mathrm{E}(\theta_0)$=0. The coefficient θ_1 is the average systematic risk; θ_2 is the changes in the systematic risk during the post-treatment period relative to the pre-treatment period; θ_3 means a shift in the systematic risk in the SARS year compared with the pre-SARS year; θ_4 is the DD estimator of the changes in the systematic risk due to SARS, which is the parameter of interest; θ_7 denotes variation in the non-market premium caused by SARS; θ_5 is the changes in the intercept in the post-period in comparison with the pre-period; θ_6 denotes variation in the intercept during the SARS year relative to the pre-SARS year. In this chapter, all the modified CAPM are estimated by each of the 11 sectors. Likewise, θ_4 is assumed to be zero when DD is applied to valid control countries.

The model which divides the post-treatment period into two sub-periods is specified below.

$$\begin{aligned} r_{ijt} - r_{fjt} = \theta_0 + \theta_1(r_{mjt} - r_{fjt}) + \theta_2(r_{mjt} - r_{fjt}) \times Post1_t \\ + \theta_3(r_{mjt} - r_{fjt}) \times Post2_t + \theta_4(r_{mjt} - r_{fjt}) \times SARS_j \\ + \theta_5(r_{mjt} - r_{fjt}) \times Post1_t \times SARS_j \\ + \theta_6(r_{mjt} - r_{fjt}) \times Post2_t \times SARS_j + \theta_7 Post1_t + \theta_8 Post2_t \\ + \theta_9 SARS_j + \theta_{10}(Post1_t \times SARS_j) + \theta_{11}(Post2_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \end{aligned} \quad (2\text{-}11)$$

where θ_5 and θ_6 are the DD estimators of the influence of SARS on the systematic risk over the earlier and later post-treatment time respectively.

2.5.3.1.3 Year-Specific DD

In the year-specific DD, the control country is used as a control group to capture the effect of other confounding events on stock returns during the SARS year, such as the Iraq War in 2003 and the global economic slowdown. The year-specific DD model is specified as follows.

$$r_{ijt} = \alpha + \beta_1 Post_t + \beta_2 Treat_i + \gamma(Post_t \times Treat_i) + \lambda_i + \varepsilon_{ijt} \quad (2\text{-}12)$$

where $Treat_i$ is equal to one if the returns belonged to China and zero otherwise. The model uses the sample of the treated and control countries during the SARS year. γ represents the DD estimator of the impact of SARS on Chinese A-share returns during either the SARS year or the pre-SARS year. Other variables are defined in the same way as those in the equation (2-8). The year-specific DD relies on the parallel trend assumption that in the absence of the SARS epidemic, the expectation of the stock returns in the treatment and control groups follows the same trend over time. When the year-specific DD is applied to the pre-SARS year when no epidemics occurred, it is used as a test for parallel trend assumption underlying year-specific DD and DDD without capturing the stock market seasonality.

The following model specification that splits the post-treatment period into two sub-periods is then adopted.

$$r_{ijt} = \alpha + \beta_1 Post1_t + \beta_2 Post2_t + \beta_3 Treat_i + \gamma_1 (Post1_t \times Treat_i) + \gamma_2 (Post2_t \times Treat_i) + \lambda_i + \varepsilon_{ijt} \quad \text{(2-13)}$$

where γ_1 and γ_2 represent the DD estimators of the impact of SARS on stock returns during the first and second post-treatment period separately.

2.5.3.1.4 Modified CAPM (Year-Specific Model)

Similar to 2.5.3.1.2, the adjusted CAPM based on year-specific DD can be formulated as follows.

$$r_{ijt} - r_{fjt} = \theta_0 + \theta_1 (r_{mjt} - r_{fjt}) + \theta_2 (r_{mjt} - r_{fjt}) \times Post_t + \theta_3 (r_{mjt} - r_{fjt}) \times Treat_i + \theta_4 (r_{mjt} - r_{fjt}) \times Post_t \times Treat_i + \theta_5 Post_t + \theta_6 Treat_i + \theta_7 (Post_t \times Treat_i) + \lambda_i + \varepsilon_{ijt} \quad \text{(2-14)}$$

where the definitions of all the variables in this model are the same as those in equations (2-10) and (2-12). The coefficient θ_4 is the DD estimator of the changes in the systematic risk induced by SARS; θ_7 represents the variation in the non-market premium caused by SARS. The placebo test for common trend assumption is applied to the sample from the pre-SARS year.

The following regression breaks down the post-treatment phase into two time intervals for the purpose of examining the dynamic changes in the systematic risk over time.

$$\begin{aligned} r_{ijt} - r_{fjt} = \theta_0 &+ \theta_1 (r_{mjt} - r_{fjt}) + \theta_2 (r_{mjt} - r_{fjt}) \times Post1_t \\ &+ \theta_3 (r_{mjt} - r_{fjt}) \times Post2_t + \theta_4 (r_{mjt} - r_{fjt}) \times Treat_i \\ &+ \theta_5 (r_{mjt} - r_{fjt}) \times Post1_t \times Treat_i \\ &+ \theta_6 (r_{mjt} - r_{fjt}) \times Post2_t \times Treat_i + \theta_7 Post1_t + \theta_8 Post2_t \\ &+ \theta_9 Treat_i + \theta_{10} (Post1_t \times Treat_i) + \theta_{11} (Post2_t \times Treat_i) + \lambda_i \\ &+ \varepsilon_{ijt} \end{aligned} \quad \text{(2-15)}$$

where all variables in the model are identical to those in equations (2-11) and (2-14). θ_{10} and θ_{11} represent the variation in the non-market premium caused by the SARS epidemic. θ_5 and θ_6 represent the DD estimators of interest about the changes in the systematic risk induced by SARS in each sub-period. Likewise, the placebo test for parallel trend assumption is conducted using the sample from the pre-SARS year.

2.5.3.2 DDD

The DDD method compares the changes in stock returns of Chinese A-shares in different sectors to variation in stock returns in the control countries between the pre-treatment and the post-treatment period during the SARS year, relative to the pre-SARS year. The use of the sample from the pre-SARS year captures the seasonal effect on stock market, whereas the adoption of the control country accounts for the potential impact of other international or Asia-specific events on the Chinese stock market performance, both of which cannot be controlled for in a single DD method. The parallel trend assumption invoked by DDD is that in the absence of SARS, the expectation of stock returns in the treatment and control countries evolves in the same path and that SARS had no effect on the control country. The former is tested via year-specific DD for the pre-SARS year while the latter is examined by employing country-specific DD for the control country.

The study utilises the following DDD model specification to estimate changes in stock returns caused by SARS.

$$\begin{aligned} r_{ijt} = \alpha + \beta_1 Treat_i + \beta_2 Post_t + \beta_3 SARS_j + \gamma_1 (Treat_i \times Post_t) \\ + \gamma_2 (Treat_i \times SARS_j) + \gamma_3 (Post_t \times SARS_j) \\ + \delta (Treat_i \times Post_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \end{aligned} \tag{2-16}$$

where the definitions of all the variables are the same as those in equations (2-8) and (2-12). The standard errors clustered by firm are calculated to consider the dependence of stock returns within each company. This model is applied to each of the 11 sectors and all sectors combined. The DDD estimator of interest is δ, which represents the changes in A-share returns caused by SARS. The coefficient β_1 controls for the invariant characteristics of A-share returns; β_2 denotes the variation in stock returns in the post-treatment period relative to the pre-treatment period in the SARS and pre-SARS year; β_3 shows the changes in stock returns in the SARS year in comparison with the pre-SARS year. In addition, γ_1 captures changes in A-share returns over time in all years; γ_3 indicates changes in stock returns over the post-treatment period in contrast with the pre-treatment period in the SARS year relative to the pre-SARS year; γ_2 represents the variation in A-share returns in the SARS year relative to the pre-SARS year.

To detect any time variation in the impact of SARS, the post-treatment period is subsequently partitioned into two subdivisions and the associated model is constructed below.

$$
\begin{aligned}
r_{ijt} = \alpha + \beta_1 Treat_i + \beta_2 Post1_t + \beta_3 Post2_t + \beta_4 SARS_j + \gamma_1 (Treat_i \times Post1_t) \\
+ \gamma_2 (Treat_i \times Post2_t) + \gamma_3 (Treat_i \times SARS_j) + \gamma_4 (Post1_t \times SARS_j) \\
+ \gamma_5 (Post2_t \times SARS_j) + \delta_1 (Treat_i \times Post1_t \times SARS_j) \\
+ \delta_2 (Treat_i \times Post2_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \qquad (2\text{-}17)
\end{aligned}
$$

where δ_1 and δ_2 represent the DDD estimators of interest during the first and second post-period.

2.5.3.3 Modified CAPM

To examine the influence of SARS on systematic risk of Chinese A-shares in various sectors, the adjusted CAPM including the interaction variables in DDD is formulated as follows.

$$
\begin{aligned}
r_{ijt} - r_{fjt} = \theta_0 + \theta_1 (r_{mjt} - r_{fjt}) + \theta_2 (r_{mjt} - r_{fjt}) \times Post_t \\
+ \theta_3 (r_{mjt} - r_{fjt}) \times Treat_i + \theta_4 (r_{mjt} - r_{fjt}) \times SARS_j \\
+ \theta_5 (r_{mjt} - r_{fjt}) \times Post_t \times Treat_i \\
+ \theta_6 (r_{mjt} - r_{fjt}) \times SARS_j \times Treat_i \\
+ \theta_7 (r_{mjt} - r_{fjt}) \times Post_t \times SARS_j \\
+ \theta_8 (r_{mjt} - r_{fjt}) \times Treat_i \times Post_t \times SARS_j + \theta_9 Post_t + \theta_{10} Treat_i \\
+ \theta_{11} SARS_j + \theta_{12} (Post_t \times Treat_i) + \theta_{13} (Treat_i \times SARS_j) \\
+ \theta_{14} (Post_t \times SARS_j) + \theta_{15} (Treat_i \times Post_t \times SARS_j) + \lambda_i + \varepsilon_{ijt} \qquad (2\text{-}18)
\end{aligned}
$$

where θ_{15} denotes the changes in the non-market premium induced by SARS. The parameter of interest is indicated by θ_8.

Besides, the following model is employed after splitting the post-treatment period into two sub-periods to consider temporal changes in SARS effect on risk.

$$
\begin{aligned}
r_{ijt} - r_{fjt} = \theta_0 &+ \theta_1(r_{mjt} - r_{fjt}) + \theta_2(r_{mjt} - r_{fjt}) \times Post1_t \\
&+ \theta_3(r_{mjt} - r_{fjt}) \times Post2_t + \theta_4(r_{mjt} - r_{fjt}) \times Treat_i \\
&+ +\theta_5(r_{mjt} - r_{fjt}) \times SARS_j + \theta_6(r_{mjt} - r_{fjt}) \times Post1_t \times Treat_i \\
&+ \theta_7(r_{mjt} - r_{fjt}) \times Post2_t \times Treat_i \\
&+ \theta_8(r_{mjt} - r_{fjt}) \times SARS_j \times Treat_i \\
&+ \theta_9(r_{mjt} - r_{fjt}) \times Post1_t \times SARS_j \\
&+ \theta_{10}(r_{mjt} - r_{fjt}) \times Post2_t \times SARS_j \\
&+ \theta_{11}(r_{mjt} - r_{fjt}) \times Treat_i \times Post1_t \times SARS_j \\
&+ \theta_{12}(r_{mjt} - r_{fjt}) \times Treat_i \times Post2_t \times SARS_j + \theta_{13}Post1_t \\
&+ \theta_{14}Post2_t + \theta_{15}Treat_i + \theta_{16}SARS_j + \theta_{17}(Post1_t \times Treat_i) \\
&+ \theta_{18}(Post2_t \times Treat_i) + \theta_{19}(Treat_i \times SARS_j) \\
&+ \theta_{20}(Post1_t \times SARS_j) + \theta_{21}(Post2_t \times SARS_j) \\
&+ \theta_{22}(Treat_i \times Post1_t \times SARS_j) \ + \theta_{23}(Treat_i \times Post2_t \times SARS_j) \\
&+ \lambda_i + \varepsilon_{ijt} \qquad (2\text{-}19)
\end{aligned}
$$

where θ_{11} and θ_{12} represent the changes in the systematic risk of Chinese A-shares induced by SARS in the first and second post-treatment period; θ_{22} and θ_{23} denote the variation in the non-market premium attributable to SARS.

2.5.3.4 Robustness Check

As a robustness analysis, the causal inference methods employ Japan and South Korea as control countries for the same reasons as using India as a control group[25]. However, some Japan or South Korea specific events occurred during the SARS year, which influenced the stock markets in the two control countries to some degree. For example, on 12 March 2003, the Japanese stock returns increased due to the investors’ expectation that the Japanese government would prompt the Bank of Japan to purchase stocks from banks (Tsang and Kumar, 2003). In South Korea, a series of strikes in different industries happened during the SARS year, which had a large impact on the South Korean stock markets. For instance, on 13 May 2003, a strike launched by truck drivers and dockworkers occurred at the largest port in South Korea and interrupted the shipments, which induced a decline in the KOSPI index for five days (Hong and Kumar, 2003). These are the limitations when using Japan or South Korea as control countries.

[25] The empirical results using Japan and South Korea as control groups are discussed in Appendix A.8 and A.9.

2.6 Empirical Results

2.6.1 The Dynamic Effect of SARS on Stock Prices

As a first step, this analysis focuses on A-share daily price changes in each sector induced by SARS using event study. Figure 2-1 as well as all the figures between Figure A-3 and Figure A-12 show event study results for each of the 11 sectors. A-share prices of all the sectors do not show any pre-event trends at least three days before the event, which satisfy the fundamental assumption of the event study. Between Day 15 (7 April 2003) and Day 22 (16 April 2003), the following sectors witnessed a significant surge in A-share prices: communication services, consumer discretionary, consumer staples, financials, healthcare, information technology, materials, real estate and utilities, which is likely to be driven by the presence of Chinese Minister of Health on the national TV to deal with SARS-related problems on Day 13 (3 April 2003) as well as the commencement of providing updated information online about the SARS situation on Day 14 (4 April 2003), such as the number of SARS cases and the death toll in each province. The price increase implies the importance of information transparency and the timely reporting of the latest SARS-related information, which can soothe fear among the general public and prompt people to make rational decisions in the face of a public health emergency. Contrary to expectations, after Day 22 (16 April 2003) when the WHO laboratory network declared the discovery of the pathogen of SARS, the A-share prices of companies in the sectors listed below decreased significantly: communication services, consumer discretionary, consumer staples, financials, industrials, information technology, materials, real estate and utilities. This suggests that despite advances in the knowledge of SARS, most investors appear to be still gloomy about prospects for business performance of these sectors, which might result from the anxiety over the increasingly severe SARS situation during this period. By contrast, the stock prices in the healthcare sector increased slightly after Day 22, which may reflect a boost to the public's confidence in the capability of healthcare system to carry out investigation into SARS following the major breakthrough in SARS related research. Notably, before the stock market closure, there is a statistically significant decreasing trend in stock prices across most sectors including communication services, consumer discretionary, healthcare, industrials, information technology, materials, real estate and utilities, which is likely to be related to the rising number of SARS cases and deaths in China, public health restrictions such as closures

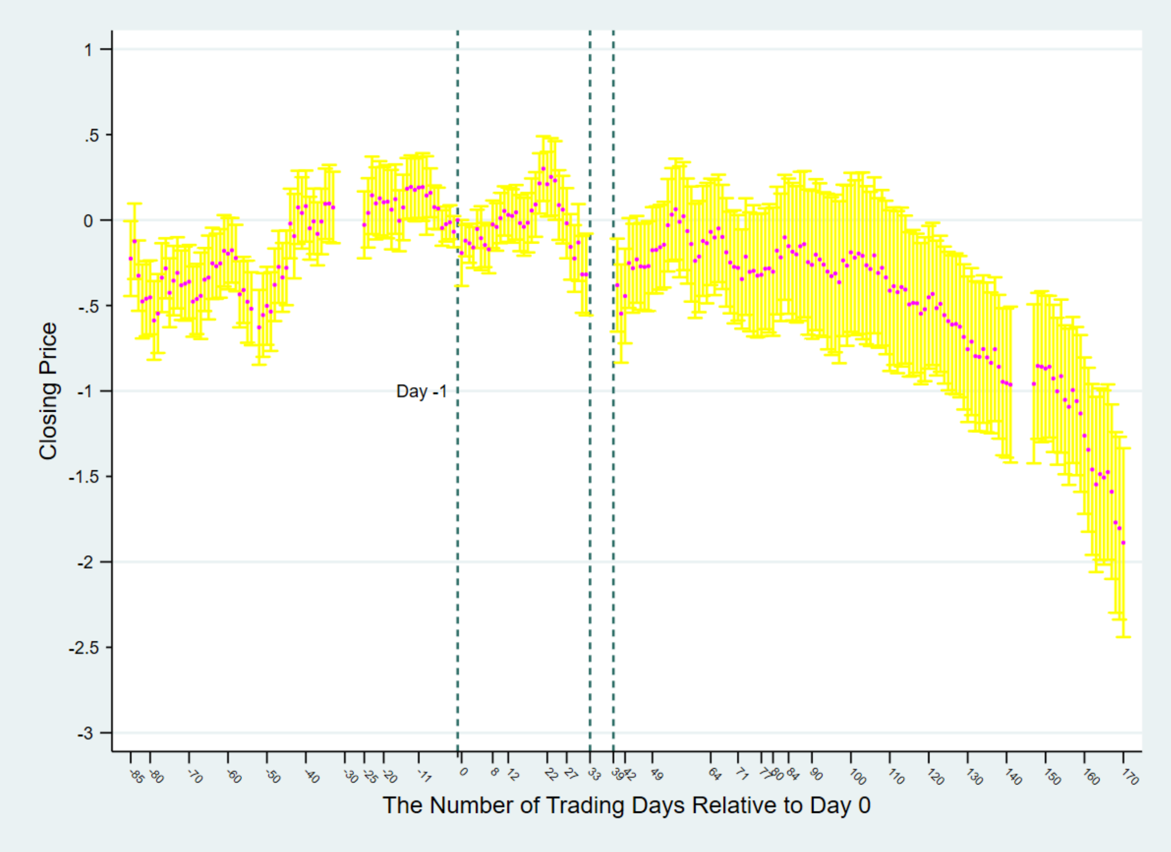

Figure 2-1. The impact of SARS on A-share prices in communication services.

Notes: The figure shows the dynamic effect of the SARS-related event on the A-share closing prices of communication services. The spikes around estimates indicate the 95% confidence intervals. In addition to the event of interest on Day zero, the time interval between Day 33 and Day 39 denotes the period of Chinese stock and futures market closure in Shanghai and Shenzhen from 1 May 2003 to 11 May 2003, which was mandated by the China Securities Regulatory Commission to prevent the transmission of SARS in the trading floors. The effect of SARS on stock prices is calculated relative to Day -1. The date of event (i.e., Day 0) represents 17 March 2003, which is the first trading day (Monday) after WHO named the infectious disease ‘Severe Acute Respiratory Syndrome (SARS)’ and claimed it to be ‘a worldwide health threat’ on Saturday, 15 March 2003.

of certain venues and schools in Beijing, political chaos in China[26], as well as WHO travel warnings for China over the second half of April.

When the stock market reopened after Day 39 (9 May 2003), all the sectors witnessed a dramatic plunge in share prices over the subsequent two days, which implies pessimism about economic conditions in China and a grave national concern over the serious epidemic situation. After Day 42 (14 May 2003) when Toronto was reported to have contained the local transmission of SARS, the A-share prices of most sectors listed below displayed a significant rally over the next few days: consumer discretionary, consumer staples, industrials, information technology, materials, real estate and utilities, which could be attributed to good news about improved

[26] The mayor of Beijing and the minister of health were dismissed for their negligence in the handling of SARS on 20 April (World Health Organization, 2003). Before 8 May 2003, 120 government officials had been discharged or reprimanded due to failure to cope with SARS epidemic (Tak-ho, 2003).

epidemic situation. Following Day 49 (23 May 2003) when a SARS-like virus was discovered in the masked palm civet and racoon-dog in Hong Kong and mainland China, the sectors, including consumer staples, industrials, information technology, materials, real estate and utilities, experienced a recovery of stock prices, which suggests investor confidence in health research, disease control and prospects for economic performance. Although travel warnings for several provinces in mainland China were lifted and many areas were removed from the list of regions with recent local spread of SARS on Day 64 (13 June 2003), the A-share prices in several sectors dropped significantly afterwards: consumer discretionary, consumer staples, healthcare, industrials, information technology, materials and real estate, which implies persistent pessimism over stock market. After Day 76 (1 July 2003) when the WHO announced the successful control of SARS around the world, the A-share prices in the following several sectors showed a trend of reversion indicating positive investor sentiment and a resumption of economic activities: consumer discretionary, consumer staples, energy, healthcare, industrials, information technology and materials.

If we look at the results by sector, there has been a significant rise in the A-share last prices of the utilities following the event until Day 64, after which SARS had a null impact on A-share prices of the utilities. The result may be explained by the fact that the utilities sector was attractive to investors because it provides people with essential utilities services required for daily life and is characterised by stability. In addition, most people stayed at home for the purpose of self-protection, which increased domestic demand for water and energy. Meanwhile, the stock prices of communication services, financials and energy remained stable between the date of event and Day 76. The unchanged stock prices of financials and energy sectors could respectively be attributed to the stable household and government investment between 1990 and 2003 (Kuijs, 2005) as well as stable energy production (Ahmed *et al.*, 2016). The communication services sector is composed of telecommunication services as well as media and entertainment. Although a reduction in face-to-face contact increased the usage of telecommunication services, such as bandwidth cable network and wireless telecommunication services, and had a positive impact on share prices, movies and entertainment industries, which expanded drastically after China's entry into WTO in 2001 (Xu and Yang, 2021), may make a loss due to a drop in visits to entertainment venues and cancelled out the positive effect. We observe a downward trend of A-share prices of consumer staples and real estate from the date of event to Day 76. Although the consumer staples sector offers essential goods and is expected to benefit from the epidemic, panic buying and stockpiling are unlikely to occur in China because local government guaranteed adequate supply of goods (Liu, 2021). There are several possible explanations for the price decline in the consumer staples sector: a fear of spread of SARS through food packages and food; a decline in consumption of beverages and food induced by avoiding dining venues; fewer visits to food retail stores, hypermarkets and super centres. As for the real estate sector, individual self-protection behaviour including social distancing measures reduced business activities and resulted in lower income leading to a decline in commercial and residential property sales as well as an increased incidence of rent arrears (Balemi, Fuss and Weigand, 2021). The stock prices of the following sectors experienced fluctuations from the date of event to Day 76 indicating higher uncertainty possibly induced by investors' fear sentiment on SARS (Chen, Liu and Zhao, 2020): consumer discretionary, industrials, information technology and materials, which were negatively affected by SARS after the stock market closure period. In particular, stock prices of the healthcare witnessed a significant rise prior to the stock market shutdown, followed by a plateau from the reopening of stock market to Day 71 (24 June 2003), before a gradual decrease subsequently. The healthcare sector played a key role in providing medical treatment, developing vaccines, and addressing research needs since the onset of SARS. Furthermore, there is a steady decline in the A-share prices of all sectors towards a lower level in the aftermath of the successful containment of SARS relative to the previous period indicating long-lasting and lagged negative impact of SARS on all sectors, which may be attributable to a fear of recurrence of SARS.

In order to investigate whether the stock prices recovered from the SARS effect, the event study results over a longer time horizon from 18 November 2002 (Day -85) to 12 April 2004 (Day 280) are presented in all graphs between Figure A-12 and Figure A-23. The graphs show that the negative SARS effect persisted until Day 175 (17 November 2003) and reverted towards zero afterwards. Specifically, the rally reached its highest point at a level of near zero after Day 250 (1 March 2004) for all the sectors. However, the impact of SARS on stock prices of consumer discretionary, healthcare and real estate remains negative even at the maximum of recovery implying the persistence of the negative SARS effect on these sectors in the long run which might be due to panic over reoccurrence of SARS. Furthermore, the recovery of prices stopped after Day 240 (16 February 2004) or 250. After Day 280, the prices in all sectors plunged drastically possibly driven by the stock market seasonality or other events.

2.6.2 Cumulative Average Abnormal Returns

This section examines the cumulative average abnormal returns (CAARs) of the entire Chinese stock market[27] caused by SARS using event study. We compare CAARs of Chinese stock market with those of Indian stock market which is used as the main control group in causal inference

[27] Given that the changes in stock prices show a similar trend across different sectors, the CAARs for each sector are not estimated.

discussed in the following sections[28]. Figure 2-2 displays cumulative average abnormal returns (CAARs) from Day -1 (14 March 2003) to Day 270 (29 March 2004) for China and India, while Figure A-24 shows CAARs in the pre-SARS year as a placebo test. The CAARs are calculated based on the market model[29]. Figure 2-2 shows a significant and gradual fall in CAARs for Chinese A-shares following the event, which may be induced by economic slowdown due to social distancing measures as well as investors' panic and anxiety over SARS epidemic situation. Following Day 210 (5 January 2004), which is 131 trading days after the WHO's announcement of the successful control of SARS, the CAARs of A-shares show a reversion to zero signifying economic recovery in the post-SARS era. In stark contrast to CAARs of A-shares, the Indian CAARs display fluctuations at the level of around 0.2 and reverted towards zero after Day 240 (16 February 2004).

[28] As a robustness check, we also use South Korea and Japan as alternative control groups. The CAARs for South Korea and Japan during the SARS year and pre-SARS year are displayed in Appendix A.4. In stark contrast to CAARs of A-shares, CAARs in Japanese and South Korean stock markets experienced a moderate increase after the SARS event.

[29] In order to check the robustness of CAAR estimates to model specifications, we also calculate expected returns using CAPM. The CAAR estimates based on CAPM are similar to those obtained from the market model.

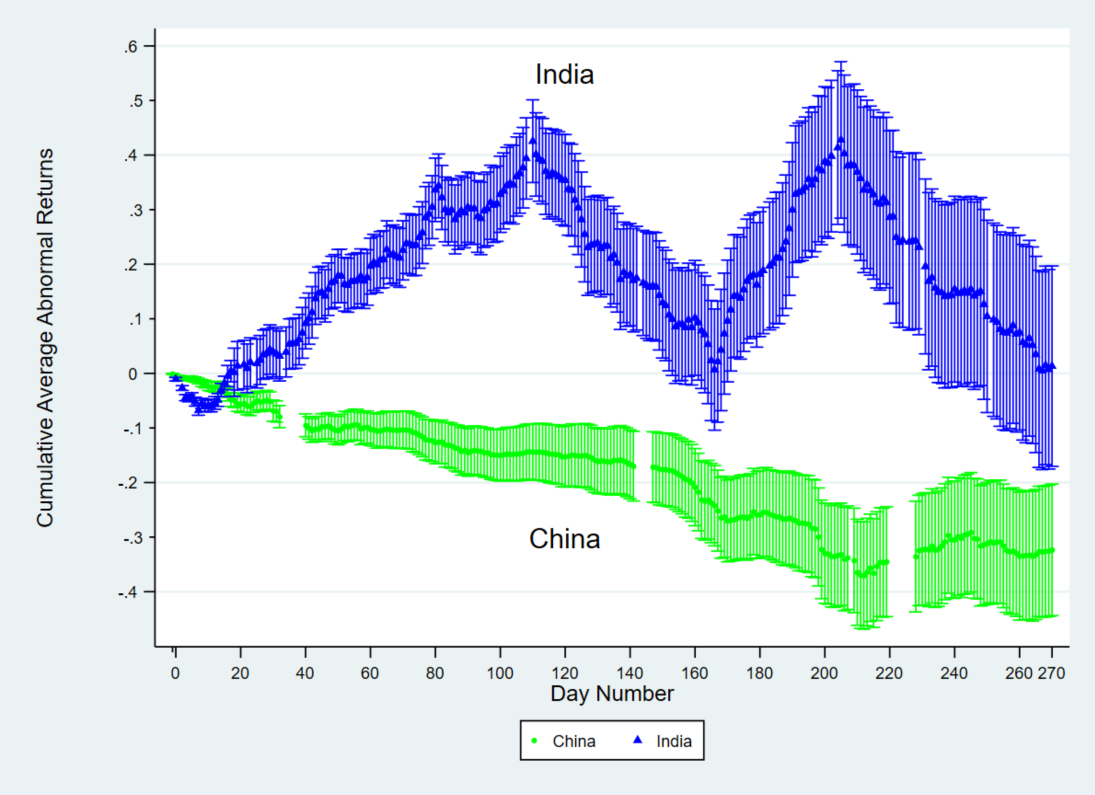

Figure 2-2. Cumulative average abnormal returns from Day -1 (14/03/2003) to Day 270 (29/03/2004) in the SARS year for China and India.

Notes: The CAARs are calculated based on the market model.

2.6.3 The Effect of SARS on A-share Returns

This section examines findings on how A-share returns responded to SARS, which are obtained from DDD and DD methods. Unless otherwise stated, only DD and DDD results which do not violate the parallel trend assumption are presented below.

The first set of analyses are concerned with the effect of SARS on A-share returns employing the DDD method. Table 2-1 reveals that during the entire post-SARS period, the A-share returns significantly dropped for the entire stock market and all sectors excluding real estate which was not influenced by SARS. Surprisingly, no sectors gained from the epidemic. Overall, some sectors are expected to benefit from the epidemic, such as healthcare, consumer staples and information technology, so it seems possible that these results are driven by investors' pessimism about future economic performance of all sectors (Liu *et al.*, 2020a; Liu *et al.*, 2020b; Su, Liu and Fang, 2021). In particular, the reduction in returns is the smallest for consumer staples possibly due to its key role in supplying daily essentials, while the communication services sector is the worst performing one, which is likely to be related to lower revenues in movies and entertainment sub-industry induced by social distancing. Turning now to the evidence based on the two sub-periods, over the earlier sub-period, only returns in communication services and energy decreased significantly while for all sectors combined and other sectors, no evidence of significant variation in A-share returns is detected. After the stock market closure period, the overall economy and all the sectors underwent a significant fall in A-share returns. Moreover, the largest and smallest decline in returns is observed for the communication services and real estate respectively during the second post-period. Such a delayed impact of SARS on stock returns may be explained by the fact that the information in terms of SARS was not disclosed efficiently in earlier phase of the epidemic (Qiu *et al.*, 2018; Lee and Jung, 2019).

Next, Table 2-2 shows the China-specific DD results regarding the effect of SARS on A-share returns[30]. Panel A in Table 2-2 shows that the overall A-share returns significantly decreased by 0.13 percent following the SARS event. In addition, SARS resulted in a significant reduction in A-share returns of the following sectors over the post-treatment period: consumer discretionary, financials, healthcare, industrials, information technology, materials and real estate. These findings are in agreement with those obtained from the DDD approach. Returns in other sectors including consumer staples, communication services, energy and utilities were not significantly influenced by SARS. No sectors benefited from the epidemic, which further supports DDD estimates. According to Panel B in Table 2-2, the A-share returns in financials, healthcare and utilities were not significantly affected by the SARS event during the first half of the post-period. During the second sub-period, financials and healthcare sectors witnessed a significant decline in stock returns, which are in accord with DDD estimates. The sectors below were significantly negatively influenced by SARS in both periods, but were more seriously affected before the stock market closure time: consumer discretionary, industrials, information technology, materials and real estate.

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[30] The India-specific DD estimates are displayed in Table A-1 to check which sectors in India are well-founded control groups. See Appendix A.5 for more discussion.

Notably, SARS had a null impact on stock returns of the utilities in both sub-periods. These results have not been observed in DDD results, because the China-specific DD approach only accounts for the seasonal effects but ignores the impact of other confounding events on stock market performance.

Finally, Table 2-3 summarises the empirical evidence on the causal effect of SARS on A-share returns based on the year-specific DD, which uses India as the control group. The placebo test for the parallel trend assumption estimates the year-specific DD for the pre-SARS year as shown in Table A-3. From Table 2-3, it can be seen that the sectors, including consumer discretionary, healthcare, industrials, real estate and utilities, as well as the entire stock market experienced a significant reduction in stock returns. There are no stock market winners during the epidemic. All these results match those obtained from the DDD method. Additionally, during the earlier post-period, the SARS event had a null impact on stock returns of real estate and utilities sectors, while in the second phase of the post-period, stock returns in these sectors decreased significantly, which corroborates findings from DDD.

Table 2-1 The Effect of SARS on A-share Returns (Using Modified CAPM Based on DDD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Healthcare	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DDD estimates for the entire post-period												
DDD estimate (%)	-.690*** (.0279)	-1.294*** (.180)	-.672*** (.0619)	-.496*** (.0916)	-.894*** (.137)	-.696*** (.128)	-.783*** (.0976)	-.720*** (.0560)	-1.002*** (.0976)	-.553*** (.0571)	-.0817 (.234)	-.551** (.198)
Panel B: DDD estimates for two post-periods												
Post-period 1 (%)	-.0401 (.0510)	-.781* (.299)	.101 (.117)	-.273 (.177)	-.464* (.226)	.0647 (.233)	.211 (.146)	-.0174 (.106)	-.130 (.177)	-.0407 (.109)	.806 (.482)	-.294 (.522)
Post-period 2 (%)	-.943*** (.0280)	-1.495*** (.180)	-.929*** (.0604)	-.673*** (.0978)	-.980*** (.140)	-.898*** (.134)	-1.094*** (.0980)	-.982*** (.0601)	-1.396*** (.0945)	-.805*** (.0563)	-.531* (.236)	-.590* (.263)
N	1307348	42672	230502	95784	29459	87459	94764	242538	111282	268845	71328	32715

Notes: The dependent variable is the daily log returns. The DDD compares return changes in China relative to India during the SARS year compared with the pre-SARS year. Panel A and B show results for the entire post-period and two sub-periods respectively. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table 2-2 The Impact of SARS on A-Share Returns (using the China-Specific DD)

	(1) Economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financials	(7) Healthcare	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	-.127*** (.0117)	-.185 (.114)	-.170*** (.0210)	-.0826 (.0494)	-.0878 (.0816)	-.203*** (.0516)	-.159*** (.0378)	-.0986** (.0323)	-.164*** (.0431)	-.112*** (.0269)	-.163*** (.0273)	-.0161 (.0441)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.256*** (.0193)	-.333* (.151)	-.314*** (.0376)	-.134* (.0631)	-.278* (.109)	-.0817 (.113)	-.0806 (.0645)	-.239*** (.0476)	-.340*** (.0611)	-.284*** (.0510)	-.427*** (.0566)	-.0402 (.0711)
Post-period 2 (%)	-.130*** (.0120)	-.201 (.115)	-.168*** (.0210)	-.0814 (.0544)	-.0807 (.0772)	-.230** (.0758)	-.227*** (.0405)	-.108** (.0328)	-.152*** (.0421)	-.109*** (.0254)	-.135*** (.0258)	-.0152 (.0533)
N	447139	13066	64109	31472	11187	10345	32935	89867	34532	82639	50944	26043

Notes: The dependent variable is the daily log returns. The DD compares return changes in the SARS year relative to the pre-SARS year. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table 2-3 The Impact of SARS on A-Share Returns (using The Year-Specific DD for the SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Healthcare	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	-.657*** (.0189)	-.765*** (.0967)	-.671*** (.0379)	-.631*** (.0640)	-.659*** (.0914)	-.367*** (.0958)	-.714*** (.0711)	-.705*** (.0410)	-.591*** (.0649)	-.751*** (.0413)	-.382* (.189)	-.570*** (.0999)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.104** (.0327)	-.608*** (.162)	-.0981 (.0646)	-.270* (.121)	-.157 (.153)	.414** (.159)	.0870 (.0993)	-.102 (.0757)	-.184 (.113)	-.225*** (.0681)	.716 (.395)	-.190 (.463)
Post-period 2 (%)	-.680*** (.0196)	-.761*** (.0958)	-.655*** (.0394)	-.669*** (.0704)	-.647*** (.0990)	-.466*** (.0992)	-.857*** (.0746)	-.699*** (.0428)	-.678*** (.0677)	-.743*** (.0430)	-.523** (.179)	-.525* (.212)
N	701497	22070	124868	51905	15552	47868	50770	130970	57738	145997	37033	16726

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to India. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

2.6.4 Risk Analysis (Modified CAPM)

In addition to stock returns, SARS is expected to affect volatility of returns, which may be due to investors' sentiment (Lee, Jiang and Indro, 2002; Escobari and Jafarinejad, 2019). The outbreak of SARS is assumed to increase systematic risk of the stock market due to public panic. This section only pays attention to results which satisfy the common trend assumption underlying DD and DDD approaches.

The results in Table 2-4 based on DDD demonstrate that the following sectors experienced a significant increase in systematic risk: consumer discretionary, energy, financials, industrials, information technology, materials and real estate, which was possibly influenced by depressed macroeconomic conditions and negative news regarding the SARS situation (Baek, Mohanty and Glambosky, 2020). On the other hand, SARS had a null effect on systematic risk of communication services, consumer staples, healthcare and utilities, which is consistent with Uyar and Uyar (2022). A possible explanation is that the consumer staples and utilities sectors provide goods and services essential to everyday life, so consumer demand for products from these sectors remained steady during the epidemic. In addition, the demand for goods and services from the healthcare sector was higher than usual and this sector was a potential beneficiary during SARS. Moreover, due to social distancing measures, individuals relied on communication services to communicate remotely. Specifically, although the stock returns in the real estate did not show significant changes throughout the whole post-treatment period, the real estate sector witnessed the largest increase in systematic risk. On the one hand, the economic fallout induced by SARS was likely to decrease the demand for commercial and residential property as well as people's ability to pay rent. On the other hand, during the period of real estate boom in China, speculative investors may increase their demand for stocks in the real estate sector and expect to make a profit when SARS was brought under control. Furthermore, in the earlier post-treatment time period, the systematic risk of most sectors was significantly reduced: communication services, healthcare, information technology and materials, while there is no evidence that SARS significantly influenced the systematic risk of consumer discretionary, consumer staples, energy, financials, industrials, real estate and utilities. The magnitude of the decline in systematic risk is the largest for the communication services. Nevertheless, during the second half of the post-period, the systematic risk of consumer staples and utilities is not significantly affected by SARS whereas the systematic risk of all other sectors is shown to have increased significantly, among which the real estate witnessed the greatest rise in systematic risk. Such a phenomenon might be explained in the following way. In the earlier stage of SARS, no sufficient information and knowledge about SARS was disclosed while the government downplayed the seriousness of SARS (Xu, 2003). Therefore, the investors were unaware of the potential risk caused by SARS. In the later phase, the increase in systematic risk may be due to public health interventions, public fear as well as exposure to negative news regarding the increasing number of SARS cases and deaths.

Table 2-5 shows the impact of SARS on systematic risk of each Chinese sector based on China-specific DD[31]. It can be seen from Panel A of Table 2-5 that in the post-period, what appears to be robust compared with adjusted CAPM based on DDD is that there is no evidence of significant changes in systematic risk of sectors including communication services, consumer staples and utilities. In the first sub-period following the SARS event, the findings support the above-mentioned results that the systematic risk was significantly reduced for sectors including communication services, healthcare, information technology and materials sectors. After the reopening of the stock market, only utilities experienced a significant increase in systematic risk while SARS had a null impact on the systematic risk of any other sectors, which differs from the results derived from adjusted CAPM based on DDD, because this method fails to control for the effect of other contemporaneous events on systematic risk.

The findings regarding risk valuation based on the year-specific DD are summarised in Table 2-6[32]. During the entire post-period, the finding in agreement with other methods is that the systematic risk of communication services and utilities sectors is not significantly influenced by SARS. Furthermore, the results similar to those derived from adjusted CAPM based on DDD demonstrate that there is no evidence of significant changes in systematic risk of consumer discretionary, consumer staples, energy, industrials, real estate and utilities before the suspension of trading in May, whilst in the second part of the post-treatment time period, the systematic risk of the utilities sector is not significantly influenced by SARS.

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[31] Table A-2 displays results of Indian-specific DD to check whether each Indian sector can function as a valid control group. For more details, see Appendix A.5.

[32] The placebo test results for the parallel trend assumption are set out in Table A-4, which is based on based on the year-specific DD for the pre-SARS year.

Table 2-4 The Effect of SARS on Systematic Risk (using Modified CAPM based on DDD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Healthcare	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
Risk Changes	.251	.512***	.0223	.383*	.494***	.116	.567***	.762***	.703***	1.106***	.242
	(.252)	(.0746)	(.125)	(.158)	(.140)	(.111)	(.0860)	(.132)	(.0810)	(.302)	(.380)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-1.176***	-.219	-.351	-.0489	.116	-.476**	-.138	-.630***	-.273*	-.408	.148
	(.264)	(.112)	(.195)	(.201)	(.223)	(.161)	(.120)	(.185)	(.117)	(.550)	(.269)
Post-period 2	.595*	.657***	.00523	.540**	.572***	.335**	.694***	1.055***	.833***	1.307***	.223
	(.262)	(.0782)	(.129)	(.186)	(.141)	(.118)	(.0904)	(.133)	(.0836)	(.306)	(.404)
N	42652	230385	95739	29444	87405	94712	242426	111229	268695	71314	32708

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to India in the SARS year compared to the pre-SARS year. It includes interaction terms of 3 dummies for China, post-period and SARS year respectively based on DDD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table 2-5 The Impact of SARS on Systematic Risk (Using Modified CAPM Based on China-specific DD)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Healthcare	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
Risk Changes	.0227 (.0734)	-.0402 (.0277)	-.00558 (.0422)	.0550 (.0616)	.00159 (.0639)	-.119** (.0440)	-.000614 (.0308)	.0182 (.0481)	-.0329 (.0297)	-.0537 (.0365)	.0760 (.0387)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.191* (.0913)	-.196*** (.0403)	-.105 (.0722)	-.118 (.130)	-.0576 (.127)	-.288*** (.0581)	-.115** (.0410)	-.185** (.0592)	-.176*** (.0412)	-.180** (.0547)	.0127 (.0611)
Post-period 2	.114 (.0780)	.0303 (.0292)	.0260 (.0471)	.117 (.0734)	.0145 (.0613)	-.0507 (.0490)	.0518 (.0324)	.102 (.0514)	.0192 (.0315)	.0151 (.0383)	.0995* (.0436)
N	13066	64109	31472	11187	10345	32935	89867	34532	82639	50944	26043

Notes: The adjusted CAPM compares changes in systematic risk in the SARS year relative to the pre-SARS year. It includes interaction terms between a dummy for SARS year and a dummy for post-period based on country-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table 2-6 The Impact of SARS on Systematic Risk (Using the Modified CAPM Based on the Year-Specific DD for the SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Healthcare	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	.246 (.237)	-.0196 (.0547)	-.286** (.0894)	.133 (.109)	.335** (.115)	-.115 (.0830)	.0880 (.0581)	.581*** (.100)	.0697 (.0558)	.331 (.220)	.0631 (.259)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.557* (.249)	-.113 (.0765)	-.238 (.127)	.245 (.131)	.419** (.148)	-.232* (.103)	.0383 (.0796)	-.339* (.133)	.0523 (.0783)	-.135 (.319)	.517 (.319)
Post-period 2	.454 (.241)	.0183 (.0559)	-.288** (.0919)	.155 (.122)	.343** (.116)	-.0366 (.0849)	.133* (.0593)	.803*** (.103)	.106 (.0573)	.440 (.233)	-.0899 (.233)
N	22070	124868	51905	15552	47868	50770	130970	57738	145997	37033	16726

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to India. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

2.6.5 Robustness Test[33]

This paper checks the robustness of results by using South Korea and Japan as alternative control countries in both DD and DDD methods, the findings of which are shown in appendices A.8 and A.9. The first set of robustness analyses examine whether sectors in South Korea and Japan can be good control groups compared with India. According to the results with respect to stock returns, the utilities sector in the second half of the post-period for all three control countries can be a credible control group for the Chinese counterpart. Nonetheless, in the first sub-period, there are more sectors in India which can serve as valid control groups compared with South Korea and Japan. As for risk analysis, we conclude that there are more Indian sectors which can be employed as credible control groups in the entire post-period.

The second robustness check studies whether the year-specific DD estimates are robust to using South Korea and Japan as control groups. The following results are robust to the choice of control groups and only estimates which satisfy the parallel trend assumption are presented. The A-share stock market as a whole as well as all the sectors experienced a significant drop in stock returns during the whole post-period, while the decline in returns mostly occurred after the stock market reopening. As for risk valuation, the systematic risk of the energy sector prior to the stock market closure was not significantly affected by SARS.

Finally, this paper checks whether DDD results are robust to using either South Korea or Japan as a control group. The results which are consistent when using different control countries show that the impact of SARS on A-share returns of the entire stock market and all sectors excluding the utilities sector was significantly negative during the whole post-period, especially during the sub-period following the reopening of the stock market. As for the risk analysis, the following sectors experienced an upsurge in systematic risk independent of the choice of control groups: consumer discretionary, energy, financials, industrials, information technology and materials, while the increase in market risk mainly happened following the trade resumption.

2.7 Discussion

Compared with other major epidemics including AIDS and malaria, the number of probable SARS cases (Fan, 2003; Bloom and Canning, 2006; Lee and McKibbin, 2012) and the associated

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[33] See Appendix A.7 for more detailed discussion. Given that the impact of SARS on A-share returns using South Korea as a control country is much larger than expected, another robustness check is conducted by winsorizing data to examine whether the extreme outliers could influence the DD and DDD results.

medical expenses appear to be lower while the human capital effect of SARS was also minimal (Lee and McKibbin, 2012). Besides, the death toll of SARS is relatively smaller compared with the preceding pandemics (Fan, 2003; Peiris, Guan and Yuen, 2004) while the duration of SARS is relatively short (Bloom and Canning, 2006). However, the economic impact of SARS appears to be larger than expected (Bloom and Canning, 2006).

The first question in this research is to investigate the dynamic impact of SARS on A-share prices at daily level by using the event study. The current study finds that the stock price of the utilities sector was positively affected by SARS following the SARS event (on 17 March 2003) most of the time, while the stock prices of communication services, financials and energy appear to be unaffected by SARS. SARS had a negative effect on A-share prices of consumer staples and real estate following the event. The stock prices of healthcare increased significantly in the earlier stage of the epidemic and remained unchanged afterwards.

The second question seeks to use event study to examine how A-share returns respond to SARS and evidence suggests that the cumulative average abnormal returns of A-shares declined gradually after the event.

The third question aims to determine the causal effect of SARS on stock returns and systematic risk across various Chinese sectors by using DD and DDD methods. The results robust to model specifications find that during the entire post-period, the A-share returns decreased significantly for the following Chinese sectors: consumer discretionary, healthcare, industrials, utilities as well as all sectors combined. SARS had the least impact on stock returns of the real estate when using different methods. Moreover, before the Chinese stock market closure, there has been a sharp drop in stock returns of the communication services, whereas SARS had a null effect on stock returns of sectors listed below: consumer discretionary, healthcare, industrials, information technology, real estate and utilities. After the reopening of the stock market, there is a significant decline in stock returns of the following sectors: consumer staples, materials, real estate and utilities, among which the real estate experienced the smallest fall in stock returns. No increase in stock returns is detected for any sectors.

The findings with respect to risk valuation show that during the SARS epidemic, the systematic risk of the financials surged whilst that of the communication services and utilities remained steady. Additionally, before the shutdown of the stock market, SARS did not significantly affect the systematic risk of consumer discretionary, consumer staples, energy, industrials, real estate and utilities. In the later phase of the post-treatment period, the systematic risk of the utilities was not significantly influenced by SARS.

It is striking to note that for some sectors including utilities and real estate, the stock returns were not affected before the stock market closure, but experienced a significant reduction following the reopening of the stock market. In addition, there is a larger drop in stock returns of several sectors including consumer staples in the earlier stage of the epidemic compared with the later phase after the trade resumption. One likely interpretation of this discrepancy is that prior to the stock market shutdown, the public was unaware of the risk of SARS in the initial phase of the epidemic due to lack of transparency, imprecise information and a delay in government response (Lee and McKibbin, 2012). In late April and May, the cumulative number of SARS cases climbed considerably while the public began to realise the threat of SARS as more mitigation strategies were implemented by the government, which induced public panic and had a larger impact on business performance of different sectors.

2.7.1 A Sectoral Analysis

One interesting finding is that for the utilities sector, the average stock price was positively affected by SARS, which is in line with the findings about the COVID-19 effect on stock prices of the utilities in the UK by Griffith, Levell and Stroud (2020) and in US by Ramelli and Wagner (2020b). Besides, the systematic risk of the utilities sector remained unchanged during the SARS epidemic. The investors appeared to maintain a positive attitude towards the business performance of the utilities sector for the following reasons. Firstly, water, electricity and gas are necessities in daily life, so the consumption in the utilities sector is less volatile during the epidemic (Ramelli and Wagner, 2020b; Szczygielski *et al.*, 2022). Secondly, most people kept away from the public places and stayed at home most of the time, which increased the domestic demand for utility services, such as electricity, water, gas and solar power. Thirdly, the water consumption was greatly increased because of self-protection behaviour. For example, a large amount of water was used for cleaning and disinfection to prevent infection. Thus, water utilities could profit from the increasing water consumption. By contrast, the demand for utility services in industries, such as hotels, restaurants and entertainment, was reduced due to the decreasing consumption in these public spaces.

The null impact on stock prices of financials contradicts the outcomes of Anh and Gan (2020), who discover a negative effect of COVID-19 on financials in Vietnam, although a notable finding is that the financials experienced a rise in systematic risk, which can be explained by a larger possibility of nonperforming loans, bank runs, higher costs of capital, changes in firm financing as well a decline in consumption expenditures and consumer demand (Goodell, 2020).

The results in terms of an increase in stock prices of healthcare in the earlier stage of the epidemic corroborate the earlier findings by Chun-Da *et al.* (2009); Chong, Lu and Wong (2010); Ramelli and Wagner (2020a); Ramelli and Wagner (2020b) while the plateau in the later phase is in agreement with the evidence obtained by Ramelli and Wagner (2020b). The result can be explained by the fact that the SARS epidemic gave prominence to the important role of healthcare providers and services, pharmaceuticals and biotechnology in containing the spread of SARS and providing medical treatment.

One unanticipated finding is that the SARS had the least impact on stock returns of the real estate when different methods are applied, although it reflects that of Wong (2008), who suggests that SARS did not cause an overreaction in Hong Kong housing prices as expected by behavioural economics due to a "wait-and-see" and cautious attitude.

Consistent with the previous literature by Haroon and Rizvi (2020) and Anh and Gan (2020) about the COVID-19 impact on US and Vietnam sectors respectively, this research finds evidence of a significant fall in the stock returns of the industrials sector. The observed drop in stock returns of the industrials sector could be attributed to a tremendous disruption to the supply of factors of production, a decrease in consumer demand for offline services as well as an interruption in international trade (Tan *et al.*, 2022).

Contrary to expectations, this study does not find any Chinese sectors which benefit from the epidemic, whereas all sectors witnessed a decline in stock returns. The next section offers one possible explanation for these findings. Nevertheless, due to unavailability of data about panic among the general public, it is not possible to assess empirically whether the psychological impact of SARS induced a decrease in stock returns across most sectors. Further research with more focus on the effect of public panic on stock market performance is therefore suggested.

2.7.2 Explanation for the Negative SARS Impact on Stock Returns

This section discusses possible explanations for the negative effect of SARS on stock returns across most sectors from the perspective of fear and uncertainty among the public. Prior studies have noticed the importance of the psychological impact of SARS on the public, which in turn exacerbated the economic effect of SARS. A state of panic about infection with SARS and uncertainty about SARS among the public is a major factor which influenced the economic performance (Fan, 2003; Xu, 2003; Siu and Wong, 2004; Bloom and Canning, 2006; Lee and McKibbin, 2012). As a result of panic and uncertainty, the general public were unduly sensitive to the epidemic and some researchers have argued that the world has overreacted to SARS (Fan, 2003; Bloom and Canning, 2006). For example, WHO issued the travel warnings which restrained the flow of travellers and hit tourism and trade (Bloom and Canning, 2006). In addition, in order to avoid social interactions, there was a large reduction in demand for goods (Fan, 2003; Xu, 2003; Lee and McKibbin, 2012), especially in service-related industries which mainly depend on consumers' emotions (Xu, 2003), while SARS undermined investors' confidence in the prospects of China, leading to a slump in the inflow of foreign investment (Lee and McKibbin, 2012). What's more, considerable expenditure on precautionary measures was incurred in the affected industries (Lee and McKibbin, 2012).

Some studies have highlighted the reasons for the psychological and behavioural impact of SARS on the public, which include the large-scale media coverage (Peiris, Guan and Yuen, 2004; Bloom and Canning, 2006; Lee and Warner, 2006) as well as lack of transparent and detailed medical information about SARS (Fan, 2003; Bloom and Canning, 2006; Lee and Warner, 2006). In addition, the cultural beliefs could influence people's perceptions of SARS and how individuals dealt with the epidemic situation (Cheng and Tang, 2004). People who felt panic and took more precautionary measures during SARS believed in Chinese cultural values including cautiousness, diligence and harmony (Chang and Sivam, 2004, cited in Cheng and Tang, 2004) as well as Chinese dialectical thinking that despite the negative effects of SARS, the positive factors which would improve the epidemic situation also existed (Ji et al., 2004, cited in Cheng and Tang, 2004). A higher level of social panic could result in individuals' excessive demand for self-protection behaviour (Bhattacharya, Hyde and Tu, 2013) including cancelling travel arrangements and avoiding indoor places (Xu, 2003), which ultimately resulted in negative economic outcomes in China.

Some empirical research has found evidence of the public panic over SARS epidemic in the affected regions. Lau *et al.* (2005) demonstrate that in Hong Kong, more than sixty percent of people would avoid visiting hospitals or mainland China while a large number of interviewees felt uneasy, scared and helpless because they were worried that they or their families would be infected with SARS. Additionally, about 20 percent of people were in a state of panic and almost half of the interviewees reported that SARS had a negative impact on their mental health (Lau *et al.*, 2005). Likewise, Leung *et al.* (2003) find that in Hong Kong, thirty percent of the interviewees thought that they were highly likely or somewhat likely to get infected with SARS and tended to take more preventive measures against SARS.

Furthermore, preceding literature has reported magnified behaviour response to SARS due to anxiety and panic. Bennett, Chiang and Malani (2015) indicate that in Taiwan, a steep reduction in outpatient visits can be attributed to public information measured by reported SARS cases and social learning behaviour which denotes how people learned about risk information on epidemics from the reactions and opinions on SARS of their peers in the community. A relevant study by Chang *et al.* (2004) finds that people refrain from seeking healthcare services during the SARS epidemic while there was a sharp decrease in healthcare utilisation and healthcare expenditure in Taiwan, which can be explained by public concern about the rapid transmission of SARS among healthcare workers and patients in the hospitals.

2.8 Conclusion

The aim of the present research is to investigate the impact of Severe Acute Respiratory Syndrome (SARS) on Chinese A-share returns and systematic risk across different sectors. The preceding relevant research has studied the influence of SARS on stock returns of a selected number of sectors, such as airlines, biotechnology, hotels, tourism and pharmaceutics in various countries or regions over a short time horizon. This chapter aims to carry out further research into the dynamic and average effect of SARS on all the sectors over a longer time window. Moreover, most previous research mainly applies event study, but the model parameters and the determinants of the normal returns may change over time because of the effect of event or other confounding factors while this method also fails to consider the contemporaneous confounding events. Given the limitations of event study, this chapter further adopts another type of event study used in applied economics to study the daily dynamic effect of SARS on A-share prices. In addition, the difference-in-differences and difference-in-difference-in-differences are employed to examine the average causal effect of SARS on Chinese A-share returns and systematic risk.

Although the duration of SARS was shorter and the number of SARS cases was smaller compared with other major epidemics, such as AIDS, this study has shown that in general, there has been a gradual fall in the cumulative average abnormal returns of A-shares during the epidemic. The empirical results demonstrate that the impact of SARS on A-share returns in the following sectors was significantly negative: consumer discretionary, healthcare, industrials, utilities as well as all sectors combined. No sectors witnessed any increase in A-share returns. Moreover, SARS increased the systematic risk of the financials sector, whereas SARS had a null impact on the systematic risk of the communication services and utilities. In addition, the reduction in stock returns appears to be larger after the reopening of the stock market compared with the initial stage of the epidemic.

Given the fact that no sectors benefited from the epidemic and most sectors were severely hit, an implication of these results is the possibility that SARS can result in individual behavioural changes because of panic over infection and increased demand for self-protection, which led to widespread economic disruption across different industries. The findings of this study provide some support for a number of practical implications. The early identification and containment as well as information transparency are essential to mitigate the negative economic impact of epidemics, which can help the general public understand the true risk of epidemics without causing panic (Fan, 2003; Lau *et al.*, 2005; Keogh-Brown and Smith, 2008). This demonstrates the important role of local government and the public health system in containing the transmission of epidemics and controlling public panic. Global cooperation to resolve the risk of the epidemic (Bloom and Canning, 2006) as well as coordinating response to the epidemic between central and local governments (Lee and McKibbin, 2012) also contribute to mitigating the health and economic effects of SARS.

The limitation of this chapter is that it fails to obtain the measurement of the degree of public fear to evaluate the relationship between panic and stock market response due to data unavailability. Further research is required to assess the impact of public panic on economic responses during the epidemic. In addition, future empirical studies regarding the impact of public health policies on mitigating the negative economic effect of epidemics would be worthwhile. All the work on these questions would be an essential next step in informing how public health policies can make a trade-off between control of epidemics and minimizing economic disruption.

Chapter 3 Human Costs of Fiscal Austerity: Unexpected Effect on the Elderly's Health in Europe

3.1 Introduction

Fiscal austerity policy has unleashed a lot of controversy surrounding its negative economic and health impact. In recent years, researchers have shown a renewed interest in the relationship between fiscal austerity policies and public health. Previous research has shown that fiscal policies have a pivotal role in affecting population health. For instance, higher government health spending is found to be correlated with an improvement in population health outcomes, such as lower mortality (Bokhari, Gai and Gottret, 2007; Martin, Rice and Smith, 2008; Golinelli *et al.*, 2017). Nevertheless, as a response to economic recession or negative economic shocks, the introduction of fiscal austerity and the associated structural adjustment programs can have an unexpected and harmful influence on health outcomes of vulnerable population groups despite its aim of rehabilitating public finance. In particular, the existing body of research suggests that fiscal austerity is related to an increase in the following health outcomes: mortality (Loopstra *et al.*, 2016a), mortality due to cirrhosis and chronic liver diseases (Toffolutti and Suhrcke, 2019), death owing to external causes (Borra, Pons-Pons and Vilar-Rodriguez, 2020), death caused by circulatory diseases (Borra, Pons-Pons and Vilar-Rodriguez, 2020),.suicide rates (Antonakakis and Collins, 2015) and mental health problems (Barr, Kinderman and Whitehead, 2015).

Tracing back to the origin of fiscal austerity, the financial crisis and Eurozone sovereign debt crisis posed one of the greatest challenges to governments across European Union (EU) member countries. In their efforts to reduce the elevated government budget deficits and debts, governments in some EU member states implemented fiscal consolidation strategies, most of which involved slashing government expenditures especially in public sectors. Specifically, Greece, Spain, Portugal and Ireland took tighter fiscal austerity than any other EU nations (McKee *et al.*, 2012). Greece, Ireland and Portugal received financial aids from the joint structural adjustment programs organised by International Monetary Fund, European Central Bank and European Commission (termed troika), which was accompanied by accepting stabilization, liberalization, deregulation and privatization as a conditionality. Meanwhile, Iceland refused to adopt austerity policies following a referendum (McKee *et al.*, 2012). The consequence of the 'austerity experiment' is that Iceland had better economic conditions, whereas the economy in nations which adopted fiscal austerity recovered slowly and the austerity policies unexpectedly gave rise to unnoticed human cost, such as higher suicide rates and greater prevalence of psychological disorders (McKee *et al.*, 2012; Quaglio *et al.*, 2013). Fiscal austerity can influence health through both a 'social risk effect' and a 'healthcare effect' (Stuckler *et al.*, 2017). The former refers to the mechanism underlying the health effects of austerity including higher unemployment rates, homelessness, food insecurity, poverty and other socioeconomic risk factors, while the latter indicates mediators of health impact regarding healthcare system reforms, such as a rise in user charges (Stuckler *et al.*, 2017).

Different from young people whose health conditions improved during economic recessions (Ruhm, 2000), evidence has shown that the health status of the ageing population deteriorated following the financial crisis (Bucher-Koenen and Mazzonna, 2013). Moreover, there has been an increase in the mortality rate of the elderly across Europe following the introduction of fiscal austerity (Stuckler *et al.*, 2017). Therefore, the impact of economic shocks on health outcomes of older people appears to differ considerably from that of younger population. Most existing literature regarding the impact of fiscal austerity on health outcomes is limited to younger adults (Barr, Kinderman and Whitehead, 2015; Stuckler *et al.*, 2017; Toffolutti and Suhrcke, 2019) or all age groups as a whole (Arca, Principe and Van Doorslaer, 2020; Borra, Pons-Pons and Vilar-Rodriguez, 2020). Despite the seriousness of the population ageing across Europe, there remains a paucity of evidence on the health consequences of fiscal austerity for older adults in EU countries. This paper pays attention to the elderly across EU nations.

Population ageing is growing at a fast pace in Europe and the median age of European population is the largest in the world (World Health Organization, 2020b). The fraction of older people aged 65 and above is expected to grow from 14% in 2010 to 25% in 2050 (World Health Organization, 2020b). Meanwhile, the proportion of working-age population is predicted to decrease resulting in a likely rise in the old-age dependency ratio (World Health Organization, 2020a). The elderly constitutes a vulnerable population group because older people suffer from poorer health conditions and multimorbidity compared with younger age cohorts, which is more likely to incur catastrophic medical expenses (Tavares and Zantomio, 2017). Besides increasing physical and mental multimorbidity, older people pose challenges to health and social care systems which require huge funding and human resources (The Lancet Public, 2017). In order to improve the elderly's health and well-being regardless of their socioeconomic background and country of residence, the World Health Organization (WHO) has been developing healthy ageing policies in EU member states, such as promoting informal care, averting social exclusion, enhancing medical care qualities and preventing communicable diseases (World Health Organization, 2020c).

The aim of this paper is to provide empirical evidence on the causal effect of fiscal austerity on the elderly's health outcomes across EU nations. The study uses micro level panel data from Survey of Health, Ageing and Retirement in Europe (SHARE) and the sample consists of older people aged 50 and above across 11 EU countries which adopted fiscal austerity. As for empirical strategy, the causal inference analysis employs an extension of the standard difference-in-differences (DD) and difference-in-difference-in-differences (DDD) methods with continuous individual and country level treatment intensity, which are respectively based on the number of public benefits each individual received prior to the introduction of fiscal austerity, and the Blanchard Fiscal Impulse indicating fiscal stance. Compared with a binary treatment variable, the advantage of using continuous treatment intensity is that it exploits variation in exposure to fiscal austerity across nations and individuals.

Most importantly, in line with the expectation that fiscal austerity had a negative influence on health conditions of the aged, the empirical findings of this study demonstrate that older people's self-perceived health (SPH), a measure of general health with high reliability and validity for the elderly (Maddox and Douglass, 1973; Lundberg and Manderbacka, 1996; Miilunpalo *et al.*, 1997), was reported to deteriorate following the implementation of fiscal austerity policies across EU countries. Next, the analysis investigates whether fiscal austerity led to physical and mental health problems in support of the poorer self-assessed health. Surprisingly, the research finds no evidence of showing depression symptoms or worsened functional capacity among respondents. Moreover, the results show that the total number of chronic conditions was not affected by fiscal austerity. Specifically, older people exposed to fiscal austerity were less likely to develop chronic diseases including cancer, cataracts, stroke, hypertension, high cholesterol and gastric ulcers, while the evidence suggests no effect of austerity measures on the likelihood of having other chronic conditions including chronic lung diseases and diabetes. As for cause-specific deaths, difference-in-differences estimates reveal that the probability of death caused by digestive disorders increased with the enforcement of fiscal consolidation, which supports the hypothesis that fiscal austerity damaged physical health conditions. The results obtained from both DD and DDD show that austerity measures had a null impact on the probability of mortality caused by accident, whereas the triple difference estimates of causal effect indicate that fiscal austerity resulted in a fall in mortality due to other cardiovascular related illnesses. Since fiscal austerity worsened self-perceived health, but appears to either ameliorate or have no effect on most health outcomes, the results are somewhat perplexing and difficult to interpret.

In the last part of the analysis, the current research looks into possible mediating factors including behavioural risk factors and healthcare utilisation underlying the causal effect of fiscal austerity policies on health outcomes. The empirical evidence demonstrates that fiscal austerity caused unhealthy behaviours including heavier drinking, an increased smoking and physical inactivity, which may explain the worsened self-assessed health and a rise in mortality due to digestive diseases following fiscal austerity. Interestingly, the results also highlight that senior citizens affected by fiscal austerity policies experienced a reduction in outpatient care utilisation, which indicates inadequate access to diagnostic tests and other healthcare services in line with the health system reforms associated with fiscal austerity policies in Europe. Specifically, a decline in outpatient care use combined with the impact of austerity measures on health outcomes imply that older people may experience unmet medical need for medical examination and diagnoses because of barriers to access to medical services induced by fiscal austerity, so that they were not aware of their physical and mental health problems. Since health outcomes are self-reported during the survey, most elderly people failed to report the presence of health problems in the interview, although they subjectively rated their overall health status as being poor because of feelings of illness or lower mental well-being. Due to data unavailability, this paper cannot empirically estimate how fiscal austerity causally affected unmet medical need for diagnoses of diseases. Notwithstanding these limitations, the existing research has confirmed that the elderly people in Europe indeed encountered unmet medical need for medical examination after the implementation of fiscal austerity policies because of financial difficulty, long waiting time or long distance to hospital (Petmesidou, Pavolini and Guillén, 2014; Doetsch *et al.*, 2017). However, the results need to be interpreted with caution given that self-perceived health cannot represent all aspects of health and can be determined by the particular element of health people are thinking about when judging their overall health (Au and Johnston, 2014).

This paper aims to fill the following research gaps identified in existing research. Research to date has mostly focused on how fiscal austerity could influence the health outcomes of working-age population or all age groups combined. This study contributes to a relatively small body of empirical literature that is concerned with the relationship between fiscal austerity and mortality or suicide rates of older people. The research resolves the problem with respect to how fiscal austerity causally affected health status of the elderly and enables evidence-based policy making by providing input into cost-benefit analysis of fiscal austerity.

Several other limitations remain in the relevant literature. Most previous research has mainly focused on the effect of austerity on mortality, suicides and healthcare inequity of the elderly, but far too little attention has been paid to other health outcomes of interest for older people, such as self-perceived health, chronic diseases, mobility levels and mental health. This work aims to generate a fresh insight into the influence of fiscal austerity on a more comprehensive set of health outcomes among older people in addition to all-cause and cause-specific mortality.

Besides, much of the current literature has only explored how health system reforms driven by fiscal austerity influenced health outcomes (the 'healthcare effect' of fiscal austerity). However, fiscal austerity can influence the elderly's health outcomes through other mediating mechanisms besides utilisation of healthcare services. What is not yet clear is the overall effect of fiscal austerity policies on senior citizens' health outcomes, which is the main focus of this paper.

With regard to methodology, much of the research linking fiscal austerity to mortality up to now has been correlational in nature and has failed to apply causal inference methods to empirical analysis. This research employs the extension of difference-in-differences and difference-in-difference-in-differences methods with continuous country- and individual-level treatment intensity to causally link fiscal austerity to older people's health outcomes. In order to resolve the endogeneity issue of measures of fiscal austerity as a result of self-selection into or out of public benefits prompted by fiscal austerity, the identification strategy considers the differing stringency of fiscal austerity policies across EU nations and differences in individual exposure to fiscal austerity by creating treatment intensity at the country and individual level respectively.

The remaining part of this paper is organised in the following way. This paper begins by introducing the background information about fiscal consolidation and population ageing in Europe. It will then go on to literature review. Section 3.4 describes data while section 3.5 is concerned with methodology. Next, section 3.6 and section 3.7 respectively present empirical findings and discuss results. The last section 3.8 draws a conclusion.

3.2 Fiscal Austerity, Health System Reform and Population Ageing

3.2.1 Financial Crisis and Fiscal Consolidation

Similar to the United States, Europe was severely affected by the financial crisis during late 2008 and early 2009 while the European Central Bank implemented a set of monetary policies including reducing short-term interest rates and supplying liquidity (Lane, 2012). In late 2009, several EU countries, such as Ireland, Spain and Greece, revealed an extraordinary surge in deficit/GDP ratios due to reasons such as increased fiscal risks, a reduction in tax revenues caused by reduced construction activities and lower asset prices, as well as other financial and macroeconomic imbalances (Lane, 2012). In addition, the Greek government reported that the predicted fiscal deficit would be 12.7 percent of GDP in 2009 rather than 6 percent estimated before (Lane, 2012). These adverse events increased perceived credit risks leading to larger government bond yield spreads among some EU countries such as Portugal, Italy, Greece, Spain and Ireland compared with Germany, which ultimately resulted in sovereign debt crisis since 2010 (Lane, 2012).

Given data availability, the discussion in this paper mainly focuses on EU countries which are also OECD members. EU countries adopted different fiscal consolidation policies in response to the negative consequences of Great Recession and sovereign debt crisis, which can be categorised into four groups of nations according to OECD (2012). Therefore, in section 3.5.1., country-level treatment intensity is created based on this fact to account for different levels of exposure to austerity measures across EU nations. First, some EU countries, especially Greece, Ireland and Portugal, sought bailouts from international financial institutions including International Monetary Fund, European Central Bank and European Commission while participated in structural adjustment programs (Stuckler and Basu, 2009; Lane, 2012; OECD, 2012). However, the International Monetary Fund (IMF) applied the structural-adjustment lending, namely offering financial support connected with conditionality including economic policy reforms (Summers and Pritchett, 1993). The structural adjustment programs involve stabilization, liberalization, deregulation and privatization (Summers and Pritchett, 1993). Specifically, stabilization refers to fiscal and monetary policies such as fiscal consolidation to restore balance-of-payments and maintain currency stability (Kentikelenis, 2017). Liberalization involves removing trade barriers and promoting foreign direct investment (Kentikelenis, 2017). Deregulation encompasses reducing government interventions in economic activities and facilitating a free market while privatization of publicly-owned corporations is aimed at enhancing market power (Kentikelenis, 2017). Therefore, this group of countries which received financial assistance from "troika" need to comply with the conditionality of fiscal austerity and structural reforms. Second, several EU countries witnessed market pressure with a rise in long-term interest rates, but they could repay debts without the IMF program and had consolidation needs of more than 3 percent of GDP during 2012-30 (OECD, 2012). This second group of EU countries includes Belgium, Hungary, Italy, Poland, Slovenia, the Slovak Republic and Spain (OECD, 2012). The third category of EU nations consists of Finland, Austria, the Czech Republic, Denmark, France, Germany and the Netherlands (OECD, 2012). Finland did not experience so much market pressure as the second group of countries, but still implemented fiscal consolidation to reduce deficit or debt (OECD, 2012). Austria, the Czech Republic, Denmark, France, Germany and the Netherlands entered into excessive deficit procedure assessed by European Commission, which attempted to slash their general government deficit lower than 3 percent of GDP (OECD, 2012). The fourth group of EU nations involves Estonia, Luxembourg and Sweden, which had lowest or no consolidation needs due to lower deficits and smaller gross debt-to-GDP ratios, compared with the above-mentioned nations (OECD, 2012).

Most nations in the sample[34] of this research implemented fiscal consolidation policies in 2010 and mainly adopted expenditure reduction policies, although Greece, Portugal, Poland, Italy and Belgium enforced consolidation policies with a combination of tax revenue increase and government spending cuts (OECD, 2012). Specifically, most public spending reductions centred on social protection, health and education (OECD, 2012). In terms of consolidation measures based on public expenditure cuts, almost all the EU countries in the sample reduced operational expenditures in the public sector by cutting wages and staffing while they also cut down on welfare benefits, such as family allowance in Austria, unemployment benefits in Germany, child benefits in Denmark and sickness benefits in Czech Republic (OECD, 2012). Some nations including Austria, Greece and Poland shrank pension benefits while a number of countries, such as France, Italy, Germany, Greece and Spain, raised retirement age by two to five years (OECD, 2012). As for the revenue-based consolidation policies, the most frequently applied policy is to increase consumption tax including value-added tax and excise duties, while several nations introduced new taxes, such as special banking levy in Austria, nuclear fuel tax and airline travel tax in Germany, tax on energy sector in Denmark as well as capital gain tax in France (OECD, 2012). In addition, Italy introduced extra road tolls from highways whereas Poland decreased active labour market programs (OECD, 2012).

3.2.2 Health System Reform

Besides welfare expenditure cuts, the reduction of health spending was another important part of the fiscal austerity for several EU nations including Netherlands, Belgium, Greece, Italy and Spain (OECD, 2012). Different health system reforms were initiated by these countries in order to contain healthcare costs. For example, the financial crisis may promote the structural reform in healthcare system including merger and closure of healthcare providers as well as more emphasis on outpatient and primary care (Quaglio *et al.*, 2013). In addition, Ireland, Romania, Slovenia, Slovak and the United Kingdom cut down on or froze salaries and curtailed job positions in healthcare systems (Quaglio *et al.*, 2013). Some EU countries, such as Portugal, increased medical costs for patients (Quaglio *et al.*, 2013).

Specifically, an introduction of and an increase in user fees is a widely adopted health policy for different types of healthcare services, such as primary care in Netherlands and Portugal; hospital care in Denmark, France, Netherlands, Italy and Portugal; long-term care services in Netherlands; as well as dental care in Denmark (Wenzl, Naci and Mossialos, 2017). A decrease in population

[34]The sample of countries in empirical analysis is comprised of Austria, Germany, Netherlands, Spain, Italy, France, Denmark, Greece, Belgium, Czech Republic and Poland.

healthcare coverage is one consequence of some healthcare reforms, for example, the tightening of eligibility criteria for long-term care services in Netherlands (Wenzl, Naci and Mossialos, 2017). In addition, some health policy changes reduced healthcare service coverage (Wenzl, Naci and Mossialos, 2017). For instance, Denmark, Spain, Netherlands, Portugal and Italy shrank hospital care provision by hospital closures and mergers as well as curtailing hospital beds (Wenzl, Naci and Mossialos, 2017). Moreover, several nations aimed at lowering healthcare provider payments and prices which covers wages of health workforce, health technology prices and funding for healthcare (Wenzl, Naci and Mossialos, 2017). The structure of healthcare providers was reformed by slashing overheads, hiring freeze and curtailing capital investments in a number of nations (Wenzl, Naci and Mossialos, 2017). Furthermore, in order to enhance the quality of healthcare services, Denmark, Spain and Portugal promoted evidence-based prescriptions while Denmark, France and Portugal launched e-health systems enabling information exchange (Wenzl, Naci and Mossialos, 2017).

3.2.3 Population Ageing in Europe

Population ageing is a prominent demographic phenomenon in the 21st century around the globe, especially in Europe. A decline in fertility was considered the main reason for the initial population ageing in Europe (Grundy and Murphy, 2017). A number of European countries witnessed a gradual drop in fertility rates during the early decades of the twentieth century before a ‘baby boom’ during the aftermath of World War II (Grundy and Murphy, 2017). Since the 1970s following the baby boom, the fertility rates either fell across Southern and Eastern Europe or oscillated between 1.5 and 2 in Northern and Western Europe, which, when combined with the ageing of baby-boomers, caused an older age structure in EU populations (Grundy and Murphy, 2017).

The problems induced by population ageing would be aggravated during the period when some fiscal austerity policies aimed at cutting public health spending and welfare benefits across Europe. The population size, age structure and health status of the population determine the demand for healthcare services and public health spending (Grundy and Murphy, 2017). In particular, the population ageing is an important factor in increasing healthcare demand due to multi-morbidity conditions and the associated higher medical expenses, especially among men aged 55 and older as well as women aged 60 and above in Europe (Grundy and Murphy, 2017). Most lifetime healthcare expenses are spent in proximity to death (Grundy and Murphy, 2017). Population ageing can also influence public health financing because health technologies have extended older people’s lifespan without any improvement in their health conditions, which increased healthcare expenditures (Grundy and Murphy, 2017). Additionally, across most EU member states, public health is chiefly funded by social security contributions of working-age groups, whereas an ageing society led to a larger old age dependency ratio which is projected to increase from 26 percent in 2010 to 52 percent in 2060 resulting in a possible lack of public funding for health in the future (HU, NL and LU, 2012).

3.3 Literature Review

3.3.1 The Effect of Fiscal Austerity on the Elderly's Health Outcomes and Healthcare Use

To date, several studies have revealed a negative correlation between fiscal austerity and older people's health outcomes, although the evidence from this paper with respect to the relationship between fiscal austerity and physical as well as mental health conditions among the elderly is inconsistent with some of the existing research.

Specifically, previous research has already established that fiscal austerity led to higher rates of suicidality and other cause-specific mortality among the elderly in the European periphery countries and UK. Loopstra *et al.* (2016a) demonstrate that across different local authorities in England, a surge in mortality rates of older people aged 85 and above was significantly connected with a reduction in government spending on Pension Credits, which offers financial aid to impoverished pensioners, and a decline in the number of Pension Credit beneficiaries. Likewise, across Eurozone periphery countries including Greece, Italy, Ireland, Portugal and Spain, Antonakakis and Collins (2015) show that fiscal austerity during the period between 1968 and 2012 increased suicides of males aged between 65 and 89 in the short, medium-and long term, whereas females were not influenced by fiscal austerity (Antonakakis and Collins, 2015). Additionally, in Greece, fiscal austerity is found to result in a rise in suicide rates for people aged 65-89 since the pensions and salaries of the elderly were substantially slashed (Antonakakis and Collins, 2014). These papers imply that the welfare benefits older people received can measure individual risk exposure to austerity, which motivates the current study to create an individual-level treatment intensity based on the number of welfare benefits accepted by each individual in the empirical analysis.

There is a relatively small body of literature that is concerned with the impact of fiscal austerity on health outcomes besides mortality of older people, most of which is descriptive, whereas the empirical evidence about this research question receives scant attention. Much of the existing literature emphasises the negative effect of impoverishment caused by fiscal austerity on health conditions of the elderly on the basis of the premise that economic deprivation in older age induces worse health consequences (Montgomery *et al.*, 2007). Fiscal austerity in the UK reduced the supportive home care services, which influenced the disabled older people dependent on these services (Ginn, 2013). Moreover, a cut in annual Winter Fuel Payment (WFP) exposed senior citizens to low temperatures and malnourishment, while because of a hike in housing rents, the elderly in poverty migrated to new places without social circles, which resulted in loneliness (Ginn, 2013). In addition, the change in indexation of pensions from the higher Retail Price Index to lower Consumer Price Index reduced the real value of pensions and the pensioners' living standards would deteriorate over time (Ginn, 2013). Furthermore, the near-zero interest rates led to lower lifetime savings and annuities while an increase in the income tax payable reduced older people's disposable income (Ginn, 2013). This work can be complemented by McKee and Stuckler (2013), who note that in the UK, the poor performance of pension funds, freezing tax allowance for the elderly, a reduction in some universal benefits and reforms to the healthcare systems pose a threat to senior citizens' health. By contrast, Akhter *et al.* (2018) demonstrate that in the wake of fiscal austerity including government budget reductions and welfare cuts, a considerable mental health gap exists between the least and the most economically disadvantaged local authority districts in Stockton-on-Tees, but there is no variation in the mental health gap as well as the associated social and behavioural determinants of mental health from April 2014 to October 2015. These findings can be attributed to respondents in the sample who are mostly older than the general population in Stockton-on-Tees because the elderly were protected from the negative effect of fiscal austerity to a large extent by state pension 'triple lock' and other unchanged Universal Credit for senior citizens such as Winter Fuel Payment (Akhter *et al.*, 2018). This study highlights the essential role of social safety net in protecting people against negative economic shocks to health (Akhter *et al.*, 2018).

This chapter also corroborates and complements the strand of the preceding literature which has explored the effect of fiscal austerity on the elderly's healthcare utilisation. Several lines of evidence suggest that the elderly encountered barriers to healthcare access due to fiscal austerity policies across EU countries including Spain (Tavares and Zantomio, 2017), Portugal (Legido-Quigley *et al.*, 2016; da Costa *et al.*, 2017; Doetsch *et al.*, 2017; Tavares and Zantomio, 2017) and Italy (Tavares and Zantomio, 2017). The most common cause of a decline in healthcare use includes higher medical expenses and financial hardship (Legido-Quigley *et al.*, 2016; da Costa *et al.*, 2017; Doetsch *et al.*, 2017; Tavares and Zantomio, 2017). These studies also highlight the need for taking account of individual heterogeneity in socioeconomic conditions when evaluating the effect of austerity on healthcare utilisation and health outcomes among the elderly.

Specifically, Tavares and Zantomio (2017) discover that across Spain, Portugal and Italy which were severely hit by financial crisis and undertook stringent austerity policies during 2011, senior citizens aged 50 and over with lower socioeconomic status used less secondary healthcare services given their healthcare needs because of a shortage of socioeconomic resources. In Italy and Spain, individuals with lower socioeconomic status utilised more primary healthcare services possibly because these people substituted free primary healthcare for specialised healthcare (Tavares and Zantomio, 2017). In Portugal where government healthcare spending was reduced more than other nations, the pro-rich horizontal inequity in GP visits is significantly large owing to the existence of user fees in GP visits along with the larger proportion of private healthcare expenses and out-of-pocket payments in total healthcare expenditure (Tavares and Zantomio, 2017). da Costa *et al.* (2017) point out that in Portugal, 22.5% of the elderly patients aged 65 and over in the sample reported that they visited physicians less often during austerity because of obstacles to arranging appointments, less healthcare demand and financial hardship. More than 25% of the elderly patients mentioned that due to financial constraints, they had difficulty accessing healthcare services, such as private medical appointments, dental appointments, and purchase of hearing aids, while 30% of the older patients discontinued using prescribed drugs (da Costa *et al.*, 2017). Around 26% of the elderly patients reduced use of public healthcare services because of financial constraints possibly caused by higher medical costs and most of them chose lower-priced medical treatment (da Costa *et al.*, 2017). Moreover, older people's adherence to medication is affected by medication costs, multiple morbidities, self-assessed health status and the availability of medical care, which implies that an increase in co-payment could change the elderly's medicine taking behaviours and consequently lead to poorer health (da Costa *et al.*, 2017). Additionally, the unmet medical need for people aged between 16 and 80 more than doubled in Portugal from 2010 to 2012 while the increase in unmet medical need of individuals in employment was the largest, followed by the unemployed, the retirees and other economically inactive individuals (Legido-Quigley *et al.*, 2016). The most reported reason for limiting access to healthcare services is financial constraints, followed by long waiting time, lack of time for medical care due to work or family affairs, as well as the postponement of medical treatment to make the body self-healing (Legido-Quigley *et al.*, 2016). Costa-Font, Jimenez-Martin and Vilaplana (2018) suggest that in Spain, the reduction in long-term care subsidization caused by fiscal austerity during 2012 significantly increased hospital admissions and hospital length of stay for senior citizens. A qualitative study by Doetsch *et al.* (2017) reveals that in Portugal, current financial status and decreased pensions are the most important factors which restrict the elderly's access to medical care services. Milbourne (2015) points out that in UK, the closure of public services due to fiscal austerity had a geographical effect on the elderly living in rural places because of the barriers to travelling to alternative public service facilities.

3.3.2 The Effect of Fiscal Austerity on Health Outcomes and Healthcare Use for Other Population Groups

This chapter relates to the broader literature regarding the relationship between fiscal austerity and health outcomes as well as healthcare utilisation among different age groups or all age groups as a whole, but no research concentrates on the older age cohort. Toffolutti and Suhrcke (2019) demonstrate that across 28 EU countries, the mortality rates excluding suicides among people aged below 65 are pro-cyclical while fiscal austerity is linked to higher mortality of cirrhosis and chronic liver disease as well as greater all-cause mortality. Additionally, both fiscal austerity and recessions are related to a surge in suicide rates, whereas the influence of macroeconomic status on overall mortality is larger than that of fiscal austerity (Toffolutti and Suhrcke, 2019). In Greece, more strict austerity policies had a significant impact on suicide rates for males aged between 45 and 89 while the impact was insignificant for females aged from 10 to 89 (Antonakakis and Collins, 2014). Antonakakis and Collins (2014) attribute the increase in suicide rates of the group of individuals aged 45 and over to a large reduction in their wages and pensions. However, emigration could reduce the negative influence of fiscal austerity on suicide rates among females and younger people aged 10-24 possibly because males in families work in a foreign country and send money home to relieve financial burdens of the household (Antonakakis and Collins, 2014). Arca, Principe and Van Doorslaer (2020) argue that the austerity policy Piano di Rientro (PdR) in Italy, which was aimed at cost reduction in health system and was implemented since 2007 and 2010, induced a 3.8 percent decline in government health spending and a 4.5 percent increase in amenable mortality per 100 euro decline in per capita health expenses. In particular, the PdR scheme resulted in a surge in avoidable death rates caused by circulatory system diseases for males and a rise in amenable mortality from neoplasms among both males and females (Arca, Principe and Van Doorslaer, 2020).

Several studies have focused on other vulnerable populations, such as lone women pensioners, disabled older people, lone parents and the unemployed. However, such individual heterogeneity has been ignored in empirical analysis of the impact of austerity on health in existing literature and this paper aims to consider differences in individual exposure to austerity in empirical strategy. According to Ginn (2013), the reduction in spending on the UK public sector such as social care services since 2010 resulted in poorer living standards for lone women pensioners and disabled senior citizens while fiscal austerity had the most negative impact on income for lone parents especially females. Owing to cuts in government grants, many local authorities could only offer social care services to the most seriously disabled elderly (Ginn, 2013). Following government spending cuts on public services and benefits as part of austerity policies in the UK, many senior citizens failed to receive social care funded by local authorities because they did not meet eligibility criteria, while they had difficulty self-funding social care since the purchasing power of their pensions and public benefits reduced, which resulted in curtailing social activities, cancelling meals on wheels and increasing social isolation (Macdonald and Morgan, 2020). In addition, some older people were particularly worried about social stigma of claiming government funds which was propagated in media coverage of government policies (Macdonald and Morgan, 2020). Barr, Kinderman and Whitehead (2015) claim that since the end of 2008, fiscal austerity and welfare reforms may explain the increasing trend in the prevalence of self-reported mental health problems across individuals aged from 18 to 59 in England, especially among the unemployed with lower education levels. After the introduction of austerity policies in Greece which involved hospital mergers and reducing the size of healthcare workforce from 2012 to 2013, most chronic patients with Alzheimer, hypertension, diabetes and chronic obstructive pulmonary disease encountered obstacles to healthcare access because of financial barriers, followed by long waiting lists and geographical barriers (Kyriopoulos *et al.*, 2014).

3.3.3 The Effect of Business Cycles on Health Outcomes

Finally, this paper is connected with research into the impact of Great Recession on health outcomes and health behaviours. Overall, these studies provide important insights into the interrelationship between macroeconomic conditions and individual health status, many of which can be applied to the relationship between fiscal austerity and health conditions.

A seminal study in this area by Ruhm (2000) notes that in Unites States, a 1 percent increase in state unemployment rate from 1972 to 1991 is correlated with a 0.5 to 0.6 percent decline in total mortality mostly caused by motor vehicle accidents and preventable diseases including cardiovascular diseases, liver diseases and influenza, which can be explained by a reduced smoking behaviour, an increase in physical activities and a healthier diet. In contrast, suicide as an indicator of mental health increased during economic downturn (Ruhm, 2000). In the same vein, a decrease in the national unemployment rate among 23 Organization for Economic Cooperation and Development (OECD) nations during 1960-1997 is related to a rise in total mortality and death rates due to cardiovascular diseases, influenza, liver ailments and vehicle accidents, while the procyclicality of the mortality rates is stronger in countries where social insurance scheme is more generous (Gerdtham and Ruhm, 2006). Three mechanisms may explain the pro-cyclicality of mortality rates during an economic boom: less leisure time for health-enhancing behaviours due to higher opportunity cost of leisure; adverse working environment, work-related stress and use of health as an input into production; a temporary increase in income and the associated risky behaviour such as drunk driving (Gerdtham and Ruhm, 2006). Miller *et al.* (2009) complement the preceding literature by arguing that a higher mortality correlated with an economic upturn is caused by "externalities" of the macroeconomic conditions because children and the retirees, who are inactive in labour markets, also experienced the procyclicality of mortality, while a larger share of procyclical deaths is attributable to motor vehicle accidents due to an increase in the number of vehicles on the road during an expansion of economic activities. Thus, factors outside of labour market which can influence health over business cycles should be taken into account. As an explanation for the health impact of economic recession, Quaglio *et al.* (2013) claim that unemployment could induce stress and anxiety while economic recession could aggravate the spread of infectious disease. Furthermore, some health consequences of recession are associated with a decline in road traffic fatality, an increase in homicide and alcohol abuse, as well as more physical activities caused by higher transportation costs (Quaglio *et al.*, 2013).

Previous studies have also paid attention to health status of older people during economic downturn. Contrary to 'healthy recession' found in the preceding literature, the mortality rates of the elderly aged 65 and over are countercyclical in U.S from 1994 to 2008 while when the state unemployment rate increased, the elderly had poorer mental health (McInerney and Mellor, 2012). Besides, higher unemployment rate is associated with more inpatient healthcare utilization (McInerney and Mellor, 2012). As for health behaviours, the surge in unemployment rates is not related to smoking, but the body mass index is reduced in the lower part of BMI distribution (McInerney and Mellor, 2012). One possible explanation for these results is economic stress hypothesis which claims that the older people's retiree income and returns on investments were affected by economic slowdown leading to anxiety (McInerney and Mellor, 2012). Furthermore, McInerney and Mellor (2012) show that healthcare providers increased the acceptance of new Medicare patients during economic downturn, which explains the greater healthcare utilisation from the perspective of supply side. Coveney *et al.* (2020) find that the income related health inequalities (IRHI) were not widened among 7 European countries during 2008 financial crisis because the sticky social transfer such as pensions remained stable and consequently the senior citizens' relative income improved compared with market income. Nonetheless, in countries such as Greece where the government implemented a reduction in social safety net, IRHI expanded considerably and the moderating effect of the sticky social transfers on IRHI was counterbalanced by fiscal austerity (Coveney *et al.*, 2020).

Health behaviours might be potential mediators in the effect of recession on health status. Xu (2013) demonstrates that in US, economic expansions are correlated with a rise in smoking as well as a reduction in physical exercise and doctor's visits. In England, the 2008 Great Recession is associated with unhealthy diet, higher BMI and an increase in the likelihood of being obese possibly because of financial difficulties and the purchase of inexpensive but unhealthy foods, whereas drinking and heavy smoking decreased due to lower income (Jofre-Bonet, Serra-Sastre and Vandoros, 2018).

3.3.4 Mechanisms Underlying the Causal Effect of Fiscal Austerity on Health Outcomes

A growing body of literature has proposed possible mechanisms for the influence of fiscal austerity on health outcomes, many of which can apply to the aged. Following Stuckler *et al.* (2017), this section discusses mediating mechanisms related to social risk factors and health system reforms.

Specifically, the financial crisis and the subsequent fiscal austerity policies have raised a lot of public health concern over social risk factors across EU countries. First, the declining trend in the prevalence of food insecurity during 2005-2010 has been reversed since 2010 (Loopstra, Reeves and Stuckler, 2015). The prevalence of food insecurity has been increasing in some EU countries and UK following financial crisis and fiscal austerity. For instance, Greece, Spain and France witnessed a surge in the number of people requiring emergency food assistance from charities while the Trussell Trust in the UK supplied emergency foods to over 900,000 people from 2013 to 2014 (Loopstra, Reeves and Stuckler, 2015). The study by Loopstra *et al.* (2016c) suggests that an increase in unemployment rates and a cut in annual average wages are significantly correlated with rising food insecurity due to financial hardship across 21 EU nations. Food insecurity can result in nutritional deficiencies and chronic conditions such as metabolic syndrome (Parker *et al.*, 2010; Seligman, Laraia and Kushel, 2010). In the UK, the public spending cuts induced by fiscal austerity led to a dearth of social care support for older people, such as the help with purchasing and preparing food, and the elderly with lower income experienced food insecurity (Purdam, Esmail and Garratt, 2019). In addition, receiving emergency food assistance carries stigma among some senior citizens which prevents them seeking emergency support with food while malnutrition induced by food insecurity brings about cognitive impairment, slower rehabilitation of diseases and prolonged hospital stays among older adults (Purdam, Esmail and Garratt, 2019).

Second, the Great Recession and austerity across EU countries had a negative influence on housing related services, such as higher levels of evictions, homelessness, utility bill arrears and longer social housing waiting lists (FEANTSA, 2011). Among the limited research in the relevant area, Loopstra *et al.* (2016b) demonstrate that in England, a 10 percent decrease in Gross Value Added per capita is correlated with a 0.48 increase in homelessness claim rates while a 10 percent reduction in government welfare spending is related to a 0.83 rise in homelessness claim rates. Moreover, a 10 percent decline in government expenditures on Pension Credits is linked to a 1.16 per 1000 household surge in the number of homelessness claims while older people aged 65 and above underwent the largest rise in homelessness claims during 2010-2011 (Loopstra *et al.*, 2016b).

Third, some fiscal austerity policies can result in poverty among the elderly and had the largest impact on the poorest senior citizens, which in turn negatively affected their physical and mental health. The elderly people were heavily reliant on fixed incomes from pensions or other resources (Antonakakis and Collins, 2014;2015). The curtailment of public spending on pensions could induce stress to pensioners, which might cause heart attack or stroke, while the spending cuts also resulted in inadequate nutritious food, social isolation as well as health damaging living environment, such as insufficient heating and dampness (Loopstra *et al.*, 2016a). In UK, the elderly lost entitlement to other public benefits absent eligibility for Pension Credits (Loopstra *et al.*, 2016a).

As for mechanism in terms of health system reforms, a decrease in medical capacity including hospital beds and healthcare staff, a decline in hospitalization rates as well as migration to seek healthcare in regions unaffected by reforms could lead to poorer health outcomes (Arca, Principe and Van Doorslaer, 2020). In particular, based on extensive literature review, the study by Kentikelenis (2017) offers a more comprehensive and general conceptual framework that presents channels related to health system through which structural adjustment programs influenced population health. These economic reform programs proposed by the International Monetary Fund (IMF) and the World Bank were implemented as conditionality to acquire financial assistance from international financial institutions during a financial crisis. Firstly, the structural adjustment policies affect health through their direct impact on health system (Kentikelenis, 2017). The cuts in public health expenditure could influence the volume and quality of healthcare services (Kentikelenis, 2017), whereas wage reduction, redundancies and hiring freeze resulted in the loss of healthcare workforce (Kentikelenis, 2017). Moreover, the introduction of co-payments and user charges is associated with a reduction in healthcare access for low-income individuals, higher management fees and bureaucracy (Kentikelenis, 2017). Deregulation strengthened the role of private healthcare provision, but narrowed down public healthcare services, which adversely affected the poorer population who cannot afford private healthcare (Kentikelenis, 2017).

Structural adjustment can also affect health via its indirect influence on health system (Kentikelenis, 2017). Currency devaluation as one part of stabilization restrained the importation of medicines and medical equipment while liberalization and privatization reduced tariffs and public revenue which would have been invested in health system (Kentikelenis, 2017). Additionally, structural adjustment can change social determinants of health such as wealth, education, environment and social cohesion (Kentikelenis, 2017). For instance, the privatization of healthcare services impeded healthcare access and can lead to poorer health conditions in the long run, which may further cause catastrophic health expenditure and poverty (Kentikelenis, 2017).

3.4 Data

The data in this study come from the Survey of Health, Ageing and Retirement in Europe (SHARE). SHARE is a micro level longitudinal dataset collected biennially since 2004, which includes information on socioeconomic status, health-related outcomes (including physical health conditions, mental health status, healthcare use and health behaviours), social activities and social networks for older people aged 50 and above across 28 European countries and Israel (SHARE-ERIC, 2020). The immigrants were not followed through in the survey (Borsch-Supan *et al.*, 2013). The main advantage of using SHARE data is its complexity compared with traditional survey data because of its cross-national characteristics with a wide variety of data about individuals, households and social network (Borsch-Supan *et al.*, 2013), which is the major reason for using SHARE data in this study.

The sample used in empirical analysis includes senior citizens aged 50 and older from Austria, Germany, Netherlands, Spain, Italy, France, Denmark, Greece, Belgium, Czech Republic and Poland, which were affected by financial crisis to a certain extent and have adopted fiscal consolidation policies as a response to the crisis. In addition, the sample includes data from wave 1 to wave 7 except for SHARELIFE retrospective survey in wave 3 which concerns respondents' life histories. Therefore, the data cover a timespan between 2004 and 2017. Although the data were collected from wave 1 until wave 7 for most countries, Greece did not participate in the survey in waves 4 and 5 due to funding problems (Borsch-Supan *et al.*, 2013). Also, the data were not gathered for Poland in waves 1 and 5 as well as for the Czech Republic in wave 1 (Börsch-Supan, 2020a).

3.4.1 Dependent Variables

The following variables are used as health outcomes of interest. First, self-perceived health (SPH) is a measure of overall health status and well-being of individuals. This variable is categorised into 5 levels of health conditions: excellent, very good, good, fair and poor, among which higher values of SPH indicate worse health conditions. The SPH is chosen as a measure of health outcomes for the following reasons. The major advantage of using SPH is that it is consistently recorded across all waves in SHARE. What's more, compared with more specific health outcomes, SPH is a comprehensive and the most attainable measure of health conditions, which captures different dimensions of health (Jylha, 2009, as cited in Au and Johnston, 2014). Self-perceived health is also found to be able to predict mortality, age-related functional changes and healthcare utilisation (Frijters, Haisken-DeNew and Shields, 2005). However, SPH cannot reflect all dimensions of health conditions such as mental health, physical health and feelings of vigour while it depends on what aspects of health status individuals focus on when assessing their SPH (Au and Johnston, 2014). In particular, the predominant factor people think of when evaluating SPH is subjective vitality, followed by physical and mental health (Au and Johnston, 2014). Therefore, a null impact on SPH should not be interpreted as no effects on all dimensions of health outcomes (Au and Johnston, 2014).

Second, the analysis employs the EURO-D scale variable to measure mental health problems, which is a scale variable regarding depression symptoms and is created on the basis of 12 items in terms of late-life depression in EU countries (Mehrbrodt, Gruber and Wagner, 2019). These items include depression, pessimism, suicidality, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment and tearfulness (Mehrbrodt, Gruber and Wagner, 2019). The maximum score of the EURO-D scale variable is 12 indicating “very depressed” whilst the minimum score is 0 meaning “not depressed”. This study constructs a dummy variable for depression which is equal to one if the EURO-D variable is no less than 4 indicating showing depression symptoms and zero otherwise.

Third, several indictors of overall physical health conditions are used to capture different dimensions of physical health. The Instrumental Activities of Daily Living (IADL) index denotes the number of a person’s limitations to instrumental activities of daily life and measures whether someone has any difficulties doing activities, such as preparing a hot meal, shopping for groceries, making phone calls, taking medicines, money management, using a map, using transport as well as doing housework and laundry (Mehrbrodt, Gruber and Wagner, 2019). The IADL index ranges between 0 and 9 while higher values of the index represent lower mobility levels of an individual (Mehrbrodt, Gruber and Wagner, 2019). In addition, IADL index indicates the elderly’s daily functional capacity (Lawton and Brody, 1969) and can be used as a test for dementia as well as cognitive impairment (Barberger-Gateau *et al.*, 1992). The second measure of physical health considers the total number of self-reported chronic diseases given the fact that the chronic disease is prevalent among older people in Europe and the management of chronic conditions is a matter of important concern to policymakers (World Health Organization. Regional Office for *et al.*, 2010). Moreover, the chronic diseases are further disaggregated into categories below: heart attack, hypertension, high blood cholesterol, stroke, diabetes, chronic lung disease, cancer, stomach ulcer, Parkinson disease, femoral fracture and cataracts. The analysis creates dummy variables for each specific chronic disease.

In terms of mortality, the paper investigates how fiscal austerity influenced the cause-specific death in the following wave, which is an important indicator of public health. Specifically, the causes of mortality can be broken down into the following items: cancer, heart attack, a stroke, other cardiovascular-related illnesses (including heart failure and arrhythmia), respiratory disease, decrepitude, digestive system diseases (such as gastrointestinal ulcer and inflammatory bowel disease), accidents, mental and behavioural disorders as well as severe infectious disease (such as pneumonia, flu and septicemia). Indicators for each cause of death in the next wave are generated as dependent variables.

Furthermore, the study investigates possible mediating factors underlying the causal impact of fiscal austerity on health. The first mediator is considered to be healthcare utilisation including the use of outpatient and inpatient care. Specifically, the outcomes of interest include a dummy variable for whether a person used outpatient care (including emergency room or outpatient clinic visits, but excluding dentist visits), the total number of nights a person stayed in hospital and the number of times of hospital admissions as an inpatient. The second mediating factor involves behavioural risk, including heavy drinking, smoking, and physical activities. In particular, a dummy variable about heavy drinking is generated, which equals one if an individual drank more than 5 or 6 days a week. In order to measure smoking behaviour, the analysis uses the number of years smoked and a binary variable indicating whether a person smoked at the present time. Additionally, the frequency of doing vigorous sports or activities is a categorical variable and the categories of outcomes include (1) more than once a week, (2) once a week, (3) one to three times a month and (4) hardly ever, or never.

3.4.2 Independent Variables

In section 3.5, the DD and DDD model specifications control for confounding covariates described below. In the DDD method, the individual-level treatment intensity discussed in section 3.5.2, which indicates respondents' heterogeneous exposure to fiscal austerity, is created on the basis of income source prior to the starting year of fiscal austerity. The income source variable includes the social security benefits and social assistance each individual received in the year before the interview date. In particular, the social security benefits encompass public old-age pension, public old-age supplementary pension or public old-age second pension, public early retirement or pre-retirement pension, main public sickness benefits, secondary public sickness benefits, main public disability insurance pension, secondary public disability insurance pension, public unemployment benefit or insurance, main public survivor pension, secondary public survivor pension, public war pension as well as public long-term care insurance. This income source variable is utilised to estimate the total number of welfare benefits and social assistance each individual received each year in order to measure individual socioeconomic vulnerability to fiscal consolidation. The income source variable is selected because it is inclusive of different types of public benefits comparable across EU nations and data about income source are collected in all waves.

The confounding covariates are related to individual sociodemographic characteristics including age, gender, marital status, household size (Arezzo and Giudici, 2017) and education levels (Conti, Heckman and Urzua, 2010). In particular, the household size is a measure of social capital, which is an important determinant of self-perceived health, while higher social capital decreases the likelihood of having a poorer self-perceived health (Arezzo and Giudici, 2017). These sociodemographic features have been considered key factors in influencing self-perceived health in existing research, such as Lanari, Bussini and Minelli (2015); Arezzo and Giudici (2017); Genback *et al.* (2018). Other variables, such as household income, occupation and employment status, are also used as the determinants of health by those papers, but they are not employed in DD and DDD of this study in order to avoid bad control problems.

In addition, the country-level treatment intensity is constructed using the unemployment rates, government expenditure and revenue. More specifically, the analysis employs data from Eurostat database regarding annual total general government expenditure and revenue as a percentage of GDP as well as the annual unemployment rates for people aged 15-74 as a percentage of active population.

Table 3-1 presents the descriptive statistics for the socio-demographic characteristics in EU countries with a higher and lower degree of fiscal austerity in the sample. The degree of fiscal austerity in a country is assumed to be higher (lower) if the country-level treatment intensity defined in 3.5.1 is larger (smaller) than the 50th percentile in the sample. In general, the sex ratio, the average age, average household size, educational attainment and marital status are comparable among nations with higher and lower degree of fiscal austerity. The proportion of females is slightly larger than males in both subsamples. In addition, the percentage of the elderly with educational levels lower than upper secondary education is larger in nations with a lower degree of fiscal austerity relative to its counterpart.

Table 3-1. Descriptive Statistics for Covariates of Countries with Higher and Lower Degree of Fiscal Austerity

Variables	Countries with higher degree of austerity	Countries with lower degree of austerity
	value	value
Average age in years	65.78	65.96
Average household size	2	2
Gender (%):		
Female	55.75	55.91
Male	44.25	44.09
Education (ISCED-97 coding) (%):		
None	4.06	4.55
Primary education	18.85	21.42
Lower secondary education	16.64	17.56
Upper secondary education	36.95	32.99
Post-secondary non-tertiary education	1.81	1.76
First stage of tertiary education	20.19	20.42
Second stage of tertiary education	1.08	0.83
Marital status (%):		
Married and living together with spouse	69.52	69.17
Registered partnership	0.62	1.05
Married, living separated from spouse	1.13	1.26
Never married	5.45	5.49
Divorced	8.54	7.93
Widowed	14.75	15.09

Notes: Countries with higher degree of fiscal austerity is defined as those whose country-level treatment intensity is not less than the 50^{th} percentile while countries with lower degree of fiscal austerity is defined as those whose country-level treatment intensity is smaller than the 50^{th} percentile. The educational levels are coded based on the International Standard Classification of Education 1997 (ISCED-97) levels.

3.5 Empirical Strategy

To conduct causal inference analysis of the effect of fiscal austerity policies on the elderly's health outcomes, sections 3.5.1 to 3.5.4 deal with the empirical methodology including extensions of DD and DDD methods as well as the construction of the country-level and individual-level treatment intensity.

Overall, section 3.5.3 describes the baseline analysis of this study, which adopts an extension of the canonical difference-in-differences (DD) framework with continuous treatment intensity at the country level. Section 3.5.1 introduces in detail how to construct the country-level treatment intensity. The identification strategy of DD relies on such a continuous treatment intensity at country level as a treatment variable for the purpose of capturing tightness of fiscal policies across EU countries. Therefore, the method compares changes in outcomes across EU nations which implemented different fiscal austerity policies in the post-treatment period relative to the pre-treatment time. The principal assumption underlying this method is that individual exposure to fiscal austerity is exogenous to health outcomes and that the countries with a higher degree of fiscal austerity should follow the same time trend as other nations with a lower degree of fiscal austerity prior to the enforcement of fiscal consolidation, which is similar to the parallel trend assumption required in a standard DD method with treatment and control groups. By comparing various EU countries, this method differences out unmeasured confounding factors which influence health outcomes.

Following Callaway, Goodman-Bacon and Sant'Anna (2021), a continuous treatment intensity is exploited for the following reasons. Firstly, all EU nations adopted fiscal austerity policies to some extent, so no available control groups not influenced by fiscal austerity policies can be employed in a binary DD framework. Secondly, the utilisation of the treatment intensity is useful for identifying the impact of the tightness of fiscal policies in a dose-response function rather than the effect of the existence of fiscal austerity policies. The former is the objective of the current research. Moreover, the relationship between outcomes and a treatment intensity can support causal inference analysis to estimate the average treatment effect on the treated (ATT) for each unit increase in the treatment intensity (Callaway, Goodman-Bacon and Sant'Anna, 2021).

Nonetheless, as noted by Fetzer (2019), a major threat to identification strategy is that individuals may select in or out of welfare benefits induced by fiscal austerity policies. By contrast, the treated group of interest consists of those who consistently received social security benefits before austerity measures (Fetzer, 2019). Accordingly, to resolve the non-random sample selection problem, the empirical analysis seeks to separately identify whether interviewees who select in or out of social benefits due to fiscal austerity or because of other factors independent of austerity, the former of which could induce sample selection bias (Fetzer, 2019). Section 3.5.4 addresses such concern over selection bias by employing a difference-in-difference-in-differences (DDD) method with continuous treatment intensity at the individual level in addition to the country-level treatment intensity. Section 3.5.2 provides full details of the definition of the individual-level treatment intensity, which aims at identifying individual exposure to austerity more precisely.

As for the treatment timing in DD and DDD, the following EU countries in the sample implemented fiscal austerity in 2010: Belgium, Czech Republic, Greece, Poland and Spain, whereas the enforcement of fiscal austerity policies began in 2011 for other EU nations including Italy, Germany, Netherlands, France, Denmark and Austria (OECD, 2012).

3.5.1 Treatment Intensity at the Country Level

The DD framework employs as a treatment variable the continuous treatment intensity at country level, which represents the fiscal stance of each nation and captures the exposure of the population in a country to fiscal austerity. The country-level treatment intensity is defined based on the Blanchard Fiscal Impulse (or the AAFI index). The major advantage of the Blanchard Fiscal Impulse is its simplicity and that it can correct for the variation in fiscal policies induced by the business cycle which is related to unemployment rates (Alesina *et al.*, 1995). Moreover, the results regarding the changes in budgetary position using the Blanchard Fiscal Impulse are comparable to other measures of fiscal stance including those proposed by OECD and IMF (Alesina *et al.*, 1995). Specifically, the Blanchard Fiscal Impulse estimates the fiscal impulse to be the difference between the predicted primary deficit in year t and the actual primary budget deficit in year $t-1$ (Alesina *et al.*, 1995). The predicted primary deficit is calculated as the subtraction of the estimated total revenues as a proportion of GDP from the predicted government expenditures as a share of GDP, both of which would happen if the impact of business cycle is eliminated or if the unemployment rates stay the same as the preceding year (Alesina *et al.*, 1995). The construction of the Blanchard Fiscal Impulse follows the procedure below proposed by Toffolutti and Suhrcke (2019) and Alesina *et al.* (1995).

Firstly, in order to adjust for the confounding effect of business cycle on government expenditure and revenues, the following regression is estimated separately for each country in the sample.

$$G_t = \alpha_0 + \beta_1 t + \beta_2 U_t + \varepsilon_t \tag{3-1}$$

where G_t represents the government expenditure as a percentage of GDP in year t; U_t denotes the unemployment rate in year t; t indicates the linear time trend and ε_t is the error term. The analysis runs the same regression using the government revenue as a share of GDP (denoted by T_t) as the dependent variable.

Secondly, to partial out the cyclical components of fiscal policies, the analysis evaluates the unemployment-adjusted government spending (and revenue) using the unemployment rate in the preceding year as a predictor as specified below.

$$\widehat{G_t} = \hat{\alpha}_0 + \hat{\beta}_1 t + \hat{\beta}_2 U_{t-1} \tag{3-2}$$

where $\hat{\alpha}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ are coefficient estimates from equation (3-1). Likewise, the calculation of the unemployment-adjusted total government revenue $\widehat{T_t}$ employs the same model specification.

Finally, the Blanchard Fiscal Impulse is calculated to be the difference between the unemployment-adjusted primary deficit and the actual primary deficit in the previous year.

$$Blanchard\ Fiscal\ Impulse = \left(\widehat{G_t} - \widehat{T_t}\right) - (G_{t-1} - T_{t-1}) \tag{3-3}$$

On the basis of the Blanchard Fiscal Impulse, the country-level treatment intensity is calculated to be the cumulative sum of Blanchard Fiscal Impulse over the entire post-treatment period, which indicates the time span following the implementation of the fiscal austerity. Therefore, the country-level treatment intensity indicates the cumulative fiscal impulses in each nation. Furthermore, the analysis standardises the country-level treatment intensity, and the coefficient of interest on the DD variable represents the causal impact of fiscal austerity on health outcomes associated with a one standard deviation increase in the country-level treatment intensity.

3.5.2 Treatment Intensity at the Individual Level

Besides the country-level treatment intensity, the DDD method constructs an individual-level treatment intensity to capture the socioeconomic vulnerability of each individual to fiscal austerity. The treatment intensity at the level of individuals is created based on the number of public benefits each interviewee received before the fiscal austerity was implemented. The number of welfare benefits can signify the financial and social vulnerability of each individual to fiscal austerity for the following reasons. EU nations cut down on public spending on welfare benefits to varying degrees, whereas the demand for social protection soared since the onset of the recession (Leschke, Theodoropoulou and Watt, 2012). Therefore, fiscal austerity was a major shock to incomes of those who relied on social security benefits since they are generally more vulnerable to tight fiscal policies and worsened macroeconomic conditions. Similarly, receiving social assistance has been considered in the past literature to construct a socioeconomic vulnerability index by Esposito *et al.* (2017), which indicates the socioeconomic deprivation of families.

For the purpose of avoiding the selection problem suggested by Fetzer (2019), the individual-level treatment intensity takes into account the number of public benefits received prior to the initial year of fiscal austerity. Prior to constructing the individual-level treatment intensity, we create an individual austerity index with respect to the risk exposure of personal health to fiscal austerity. The index is estimated to be over the entire pre-treatment period the time average of the normalised total number of public benefits each individual received in each year before fiscal austerity (termed pre-austerity period), where for the purpose of making the treatment intensity comparable across EU nations with different degree of fiscal austerity, the normalisation is carried out by dividing the total number of public benefits for each person in the pre-period by the maximum number of welfare benefits available in each country. The formula for calculating the individual austerity index is specified as follows.

$$Ind\_Aus_{ij} = \frac{1}{T}\sum_{t=1}^{T}\frac{\sum_k \mathrm{I}(b_{ikjt} = k)}{\max\limits_i \sum_k \mathrm{I}(b_{ikjt} = k)} \tag{3-4}$$

where Ind_Aus_{ij} represents the individual austerity index for individual i in country j; b_{ikjt} indicates the welfare benefit k received by individual i in country j during year t; T denotes the total number of years before the first year of fiscal austerity. Finally, the individual-level treatment intensity II_{ij} is defined below as the standardised individual austerity index to facilitate the interpretation of the treatment effect, so that the treatment intensity is constant for each person which lies within the range from 0 to 1.

$$II_{ij} = \frac{Ind\_Aus_{ij} - \overline{Ind\_Aus}}{s}$$

where II_{ij} represents the individual-level treatment intensity for individual i in country j; $\overline{Ind\_Aus}$ denotes the mean value of individual austerity index; s is the sample standard deviation of individual austerity index.

3.5.3 Difference-in-Differences with Treatment Intensity

The first analysis used to identify the causal effect of fiscal austerity on health outcomes involves the main DD model specification as established below.

$$Y_{ijt} = \theta CI_{ij}Post_{jt} + \beta X_{ijt} + W_t + \alpha_i + \varepsilon_{ijt} \tag{3-5}$$

where i, j and t respectively represent individual i, country j and wave t. Y_{ijt} denotes the elderly's health-related outcomes of interest, such as self-perceived health, physical health conditions, mental health problems, healthcare utilisation and health behaviours. CI_{ij} represents the country-level treatment intensity while $Post_{jt}$ is a time dummy variable which takes the value of one for the post-treatment period and zero otherwise. α_i indicates the individual fixed effects and ε_{ijt} denotes the random error term. X_{ijt} captures individual sociodemographic characteristics including age, gender, marital status, household size and education level. W_t denotes the wave fixed effects which can capture the evolution of individual health outcomes over time due to unobservable factors, such as health promotion campaigns across EU countries or innovations in medical technology. In particular, θ represents the average treatment effect of interest, which measures the causal impact of fiscal austerity policies on health-relevant outcomes of the elderly in EU countries. The robust standard errors of coefficients are clustered at individual level to allow for correlations between health outcomes across different waves within each individual. The model is estimated by using the within-transformation to eliminate the unobserved individual-specific heterogeneity, which resolves the endogeneity bias as a consequence of the correlation between individual fixed effects and random error terms.

3.5.4 Difference-in-Difference-in-Differences with Treatment Intensity

The second causal inference method employs DDD with treatment intensity to identify the causal effect of fiscal austerity on the elderly's health outcomes. Given the different degree of socioeconomic vulnerability of older people to fiscal austerity, the identification strategy of DDD exploits the variation in individual-level exposure to austerity among the elderly besides the country-level exposure to fiscal austerity.

In particular, the DDD model specification is constructed as follows.

$$Y_{ijt} = \theta II_{ij} CI_j Post_{jt} + \beta X_{ijt} + W_t + \alpha_i + \varepsilon_{ijt} \qquad (3\text{-}6)$$

where i, j and t represent an individual unit, country and wave separately. CI_j is the country-level treatment intensity for country j and II_{ij} represents the individual-level treatment intensity for respondent i who lives in country j. The definitions of the dependent variable and other independent variables are identical to those described in model (3-5). ε_{ijt} is the stochastic disturbance term. θ is the ATT of interest, which measures the causal effect of fiscal austerity policies on health-related outcomes for older people with different levels of socioeconomic vulnerability to austerity across countries with different degree of exposure to fiscal austerity. The standard errors are clustered at the individual level. Similar to model (3-5), the model specification (3-6) is estimated using the within-transformation to eliminate individual fixed effects. The next section is concerned with placebo test and a number of robustness checks.

3.5.5 Placebo Regression and Robustness Check

The empirical methods depend on the parallel trend assumption that in the absence of fiscal austerity, no systematic differences in health-relevant outcomes of the aged exist among EU countries with varied treatment intensity when using DD, or in the case of DDD, the health outcomes of older people with different levels of vulnerability to fiscal austerity would have evolved at the same rate across EU nations more or less exposed to fiscal consolidation policies. The assumption differentiates itself from that in a standard DD framework which involves the comparison of outcomes between treatment and control groups. Therefore, to ensure the internal validity of the method, the study then conducts a placebo test to check whether common time trend assumption holds true for both DD and DDD, which expects that unobserved factors do not differentially influence the trends in outcomes of interest among countries with different treatment intensity so that the treatment effects are not driven by these unobservable factors. Specifically, the placebo test is carried out using the sample from the pre-policy period including waves 1 and 2, whereby waves 1 and 2 are counterfactually assumed to be the pre- and the post-austerity waves respectively. The common time trend assumption is warranted if the effect of the counterfactual fiscal austerity on older people's health is statistically insignificant using sample from the pre-austerity period. All the placebo effect results are shown beneath the treatment effect estimates in all tables between Table 3-2 and Table 3-8.

Furthermore, the analysis performs robustness checks by examining how the causal effect of interest behaves if two alternative model specifications are employed. Time-variant differences across nations are confounders which could cause biased estimates, but can be resolved by controlling for confounding covariates in DD and DDD (Zeldow and Hatfield, 2021). Therefore, the first robustness test removes covariates X_{ijt} regarding individual specific characteristics from the main model specification to check whether there are any confounders which could bias estimates if not accounted for.

The second robustness test controls for a time dummy variable for the entire post-treatment period rather than a set of wave dummies, the latter of which considers changes in time effects across waves. For all the reasons mentioned above, the preferred model specifications are equation (3-5) and (3-6), which allow for both wave dummies and individual specific characteristics. All the results of the robustness tests are presented in the first and second column for each health outcome in all tables between Table 3-2 and Table 3-8.

3.6 Results

This research is primarily concerned with the elderly's self-perceived health, death in the next wave, physical and mental health status. The section also aims to explore mediating factors including behavioural risk factors and healthcare utilisation, which explain why fiscal consolidation influenced health conditions of older people.

3.6.1 Difference-in-Differences with the Country-level Treatment Intensity

The validity of the DD strategy with a continuous treatment intensity relies on the common trend assumption, which requires that the corresponding DD estimates in the placebo test appear to be statistically insignificant over the pre-policy years. Therefore, this section only reports DD results which do not violate the parallel time trend assumption.

Table 3-2 provides the difference-in-differences estimates of the causal effect of fiscal austerity on mortality due to other cardiovascular related disease (including heart failure and arrhythmia), disease of the digestive system (such as gastrointestinal ulcer and inflammatory bowel disease) as well as accident. In columns 1, 4 and 7, the difference-in-differences regression does not include wave fixed effects and the set of covariates regarding individual sociodemographic characteristics. Columns 2, 5, 8 control for individual sociodemographic variables. Columns 3, 6 and 9 include both individual sociodemographic covariates and wave dummies, which is the preferred model specification while other model specifications examine the robustness of DD estimates. The placebo test results are displayed underneath each DD estimate, all of which are statistically insignificant. Columns 3 and 9 illustrate that fiscal austerity measures did not have a discernible impact on the likelihood of mortality caused by other cardiovascular-related illness and accidents among older people living in EU countries exposed to tighter fiscal austerity policies relative to the counterparts within EU nations with a less stringent austerity measures. By contrast, in column 6, fiscal austerity increased the probability of death due to disease of the digestive system for the elderly. In addition, excepting the first specification without controlling for wave fixed effects and sociodemographic covariates, the magnitude of estimated causal effects of interest is similar throughout the second model which includes covariates as well as the third specification which adds in covariates and wave fixed effects. Both the magnitude and significance of the results for death due to accidents are robust to all model specifications. Thus, it is desirable to control for individual sociodemographic characteristics in the difference-in-differences model specification, otherwise these covariates would confound the causal effect of interest. To sum up, fiscal austerity resulted in an increase in the likelihood of death caused by digestive disorders although the magnitude of the causal effect appears to be small, whereas austerity measures had a null effect on mortality due to other cardiovascular related diseases and accident among older people. The digestive diseases can be caused by multiple factors, such as smoking, heavy drinking, unhealthy dietary habits, severe gastro-oesophageal reflux disease as well as inequality in uptake of screening and medical care services (O'Morain and O'Morain, 2019).

The evidence regarding a slight increase in death caused by digestive disease can partially confirm the hypothesis that fiscal austerity induced worsened health outcomes. Now the analysis explores whether the health status of older people indeed worsened with austerity policies introduced across Europe. Table 3-3 illustrates how fiscal austerity causally influenced chronic health conditions for senior citizens in European countries. The most surprising aspect of the results from column 6 shows that one standard deviation increase in country-level treatment intensity led to a significant reduction of 0.07 in the cumulative number of chronic diseases among the aged. The robustness check shows that estimates of the effect are robust to different model specifications in column 4 which excludes wave dummies and covariates as well as column 5 that only adds the sociodemographic covariates. Furthermore, the analysis provides additional details in terms of which specific chronic condition drives the results and probes whether the causal impact of fiscal austerity on each particular chronic condition is consistent with the effect on the total number of chronic diseases. In line with a decline in the number of chronic diseases, results obtained from the preferred specification in columns 3, 6 and 9 demonstrate that senior citizens in nations with higher degree of fiscal austerity were significantly less likely to develop high blood pressure, high blood cholesterol, stomach ulcer and cataracts. These results appear to be robust and similar when using different model specifications. Moreover, according to estimates obtained from the preferred specification, fiscal austerity had little causal effect on the possibility of living with stroke, diabetes and chronic lung disease while the estimated effects are still statistically indistinguishable from zero if the model excludes wave fixed effects and adds in individual sociodemographic covariates (in columns 2, 5 and 8). Contrary to the expectation that fiscal austerity resulted in poorer health status, together the counterintuitive but strong evidence to emerge from the data suggests that the elderly were less likely to develop chronic diseases in EU nations more exposed to fiscal austerity.

The next step is to probe for the possible mediating factors which could explain the causal impact of fiscal austerity on health consequences. The clear evidence of an improvement in chronic health conditions of the elderly during austerity time contradicts relevant findings in the preceding literature and is inconsistent with results with respect to an increase in cause-specific mortality after the implementation of fiscal austerity. Therefore, the study is interested to investigate what happened to mediators in the wake of fiscal austerity policies and deduce how the effect on mediating factors translated into a drop in the likelihood of getting chronic diseases as well as a rise in death due to digestive disorders. Following the existing research, the analysis pays special attention to a sequence of possible mediating factors regarding behavioural risk factors (according to Ruhm (2000), Gerdtham and Ruhm (2006), Charles and Decicca (2008), McInerney and Mellor (2012), Xu (2013) and Jofre-Bonet, Serra-Sastre and Vandoros (2018)) as well as the uptake of healthcare services (as suggested by Arca, Principe and Van Doorslaer (2020), Tavares and Zantomio (2017), da Costa *et al.* (2017), Legido-Quigley *et al.* (2016) and Kyriopoulos *et al.* (2014),), which are likely to be affected by macroeconomic environment and could in turn influence health outcomes.

The difference-in-differences estimates of causal effect of fiscal austerity on healthcare use and behavioural risk factors are reported in Table 3-4 by employing the same model specifications described above. The columns 3 and 6 highlight that the elderly people in EU countries with higher exposure to fiscal austerity were significantly less likely to engage in vigorous physical activities such as sports, heavy housework or a manual labour job, whereas the number of years of smoking remarkably picked up in EU nations with more stringent austerity measures. The estimates of the causal impact remain stable when applying alternative difference-in-differences model specifications. Additionally, austerity measures had no discernible effect on the uptake of outpatient care for senior citizens and the results still hold true when the wave fixed effects are disregarded in the model specification. Thus, the evidence strongly suggests that fiscal austerity tended to induce unhealthy behaviours including physical inactivity and increased smoking among older people living in EU countries more affected by fiscal austerity, which can partly result in an increase in death occurrences caused by digestive diseases (Franceschi *et al.*, 1987; Guslandi, 2000). Nevertheless, the mechanism underlying a decrease in the likelihood of developing chronic diseases remains inconclusive.

Table 3-2. The Impact of Fiscal Austerity on Cause-specific Death of the Elderly in EU Countries

Causes of death	Other Cardiovascular Related Disease			Digestive Disease			Accident		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	-.00108* (.000500)	.000113 (.000514)	-.000136 (.000518)	.000190 (.000169)	.000476** (.000181)	.000416* (.000185)	-.000556 (.000304)	-.000288 (.000312)	-.000370 (.000314)
Placebo effect	-.000805 (.000650)	-.000844 (.000664)	-.000844 (.000664)	.0000346 (.000296)	.0000613 (.000295)	.0000613 (.000295)	-.000581 (.000390)	-.000636 (.000399)	-.000636 (.000399)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	132028	130234	130234	131344	129565	129565	131306	129526	129526

Notes: The table presents DD estimates of the causal effect of fiscal austerity on cause-specific deaths. The placebo test results are shown below each DD estimate. The outcomes include dummy variables for deaths due to other cardiovascular related disease, disease of digestive system and accident. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

Table 3-3. The Impact of Fiscal Austerity on Chronic Health Conditions of the Elderly in EU Countries

Chronic conditions	High Blood Pressure			High Blood Cholesterol			Stroke		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	-.0364*** (.00228)	-.0255*** (.00233)	-.0256*** (.00237)	-.0344*** (.00221)	-.0286*** (.00225)	-.0281*** (.00229)	-.00268** (.000933)	-.00133 (.000955)	-.00123 (.000972)
Placebo effect	.00237 (.00197)	.00282 (.00206)	.00282 (.00206)	-.00390 (.00205)	-.00379 (.00212)	-.00379 (.00212)	.00111 (.000814)	.000846 (.000849)	.000846 (.000849)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	211300	208943	208943	211300	208943	208943	211300	208943	208943
Chronic conditions	Diabetes			Chronic Lung Disease			Stomach Ulcer		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	-.00620*** (.00135)	-.0000976 (.00138)	.000463 (.00141)	-.00284** (.00104)	-.000569 (.00107)	.000735 (.00110)	-.00944*** (.00126)	-.0118*** (.00127)	-.0113*** (.00130)
Placebo effect	.000598 (.00104)	.000831 (.00109)	.000831 (.00109)	.000903 (.000883)	.00106 (.000921)	.00106 (.000921)	-.00126 (.00114)	-.00177 (.00120)	-.00177 (.00120)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	211300	208943	208943	211300	208943	208943	211300	208943	208943

Table 3-3. Continued

Chronic conditions	Cataracts			The Number of Chronic Diseases		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect	-.0142*** (.00151)	-.0112*** (.00154)	-.0102*** (.00157)	-.119*** (.00663)	-.0666*** (.00677)	-.0730*** (.00689)
Placebo effect	.00123 (.00121)	.00123 (.00126)	.00123 (.00126)	-.000536 (.00535)	.00242 (.00563)	.00242 (.00563)
Covariates	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes
Observations	211300	208943	208943	211296	208939	208939

Notes: The table presents DD estimates of the causal effect of fiscal austerity on each chronic disease and the total number of chronic conditions. The placebo test results are shown below each DD estimate. The outcomes include the total number of chronic diseases as well as dummy variables for high blood pressure, high blood cholesterol, stroke, diabetes, chronic lung disease, stomach ulcer and cataracts. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

Table 3-4. The Impact of Fiscal Austerity on Healthcare Utilisation and Behavioural Risk of the Elderly in EU Countries

Healthcare use	Visit a Medical Doctor					
	(1)	(2)	(3)			
Treatment effect	-.00660** (.00228)	-.00202 (.00231)	-.000941 (.00234)			
Placebo effect	.0000495 (.00215)	.000349 (.00226)	.000349 (.00226)			
Covariates	No	Yes	Yes			
Wave dummies	No	No	Yes			
Observations	209839	207501	207501			
Behavioural risk	The Number of Years the Individual Smoked			Frequency of Doing Vigorous Sports or Activities		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect	.810*** (.236)	1.054*** (.233)	1.371*** (.235)		.0239*** (.00267)	.0245*** (.00271)
Placebo effect	-.0325 (.605)	-.239 (.741)	-.239 (.741)		-.00382 (.00240)	-.00382 (.00240)
Covariates	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes
Observations	78004	77929	77929		183284	183284

Notes: The table presents DD estimates of the causal effect of fiscal austerity on healthcare use and behavioural risk. The placebo test results are shown below each DD estimate. The outcomes include a dummy for whether an individual visited a medical doctor, the number of years a respondent smoked and the frequency of doing vigorous sports or activities. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1 and 4 exclude covariates and wave dummies. Columns 2 and 5 include covariates, but exclude wave dummies. Columns 3 and 6 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

3.6.2 Difference-in-Difference-in-Differences with Continuous Treatment Intensity

This section turns to the triple difference estimates of the causal impact of fiscal austerity on health-related outcomes. There is no violation of the parallel trend assumption if the triple difference estimates of the health effects in the placebo test using sample from the pre-austerity period are statistically insignificant. Similar to difference-in-differences model specification, for each health outcome, the first model specification does not take into account the individual sociodemographic covariates and wave fixed effects. The second specification includes confounding covariates while the third one additionally adds in a sequence of wave dummies, which is the preferred specification. This section only looks into findings corroborated by placebo test results which satisfy the common trend assumption. Unless otherwise stated, all the reported estimates below are obtained from the preferred model.

As a first step, Table 3-5 presents the triple difference estimates of how fiscal austerity affected the self-perceived health as well as mental and physical health of older people. As set out in Table 3-5, what stands out in the table is that the elderly individuals more vulnerable to fiscal austerity were significantly more likely to report poorer self-perceived health in countries with more stringent austerity policies. This finding is in line with the expectation that fiscal austerity led to worse health conditions. The results remain unchanged when estimating alternative model specifications. In terms of psychological problems, the table reveals that the causal influence of fiscal austerity on the likelihood of suffering from depression is statistically insignificant, partially implying that the mental health status of the elderly individuals more exposed to fiscal austerity were not affected in countries with higher degree of exposure to fiscal austerity. Next, the research investigates whether daily functional capacity of older people, which is measured by instrumental activities of daily living index, was impaired due to fiscal austerity. According to the table, no significant increase in IADL index is detected, which suggests that fiscal austerity did not affect older people's functional mobility in everyday life activities. Also, all these triple difference estimates of the causal effect appear to be robust when applying alternative model specifications. Collectively, fiscal austerity causally led to poorer self-perceive health of the elderly, but it is not driven by mental health problems or a decline in functional capacity.

The next research question is concerned with whether the worsened self-assessed health can be corroborated by the aggravation of chronic health conditions induced by fiscal austerity. As displayed in Table 3-6, the null impact of fiscal austerity on the aggregate number of chronic diseases implies that overall, the elderly people's chronic conditions were not aggravated markedly by the implementation of austerity measures. Surprisingly, the probability of developing stroke, cancer and cataracts indeed fell significantly among more vulnerable older people living in EU countries more severely affected by fiscal austerity. What's more, fiscal austerity policies did not significantly influence the likelihood of suffering from heart attack, high blood pressure, high blood cholesterol, diabetes, chronic lung diseases and stomach ulcer among senior citizens. The robustness check shows that all triple difference estimates of the causal effect are similar when applying alternative model specifications, except for those regarding stroke, which are only robust to the second specification with the inclusion of confounding covariates. Taken together, these results imply that the chronic health conditions of older people improved rather than worsened with the introduction of austerity measures, which is a surprising piece of evidence, but is consistent with findings obtained from the difference-in-differences method with a country-level treatment intensity. Nevertheless, these findings appear to contradict the previous evidence of poorer self-perceived health in this paper.

Finally, the study probes whether fiscal austerity resulted in an increase in mortality after the enforcement of fiscal austerity. Table 3-7 illustrates that austerity measures led to a significant fall in mortality due to other cardiovascular related illnesses, the estimates of which appear to be consistent throughout all model specifications. There is no evidence that austerity measures had an impact on deaths caused by decrepitude, digestive diseases, accident as well as mental and behavioural disorders while the findings are robust to all model specifications. It is noteworthy that the enforcement of fiscal austerity policies had a null effect on mortality owing to digestive system disorders once the triple difference method accounts for the treatment intensity at the individual level.

In summary, since self-perceived health can be determined by various factors, such as physical health, mental health and social capital (Au and Johnston, 2014; Yang *et al.*, 2021), it remains unclear why self-perceived health appears to be poorer, although empirical evidence has discovered a null effect of austerity measures on mental health, functional ability and the number of chronic conditions together with an improvement in several particular chronic health conditions and a decline in cause-specific mortality following the introduction of fiscal austerity.

Having found out aggravation of self-perceived health and an improvement in several health outcomes, the next step is concerned with exploring mediating mechanisms underlying the estimated causal impact, including behavioural risk factors and the uptake of medical services. Table 3-8 presents the triple difference estimates of the causal effect of fiscal austerity on mediating factors which can explain how fiscal austerity influenced health outcomes. As the table shows, older people with higher levels of exposure to fiscal austerity were more likely to engage in heavy drinking in nations more influenced by austerity policies. The estimation results are similar across different model specifications. However, the probability of smoking, the total number of years of smoking as well as the frequency of participating in vigorous activities or sports among the elderly did not change significantly during years of austerity, which implies that fiscal austerity did not induce heavier smoking or physical inactivity among the more vulnerable senior citizens. Turning now to the empirical evidence regarding medical care utilisation, the most striking finding is that older people with larger degree of susceptibility to austerity had significantly less access to outpatient care services, which is robust to all model specifications, in line with the hypothesis that older people with higher vulnerability experienced obstacles to healthcare access in countries more affected by austerity. Meanwhile, the inpatient medical care utilisation measured by the total number of nights in hospital and the frequency of hospital admissions remain stable following fiscal consolidation among older people more exposed to austerity policies.

In conclusion, it is difficult to explain the counterintuitive evidence in this research, but heavier drinking and lack of access to outpatient healthcare services may partly explain the poorer self-perceived health induced by fiscal austerity policies. Furthermore, since the health outcomes of interest are self-reported by the respondents during the interview, it is plausible to infer that the observed improvement in some health conditions as well as the absence of the impact of austerity on other health status can be attributable to lack of healthcare access and diagnoses of diseases among older people with larger degree of socioeconomic vulnerability in EU countries more exposed to fiscal austerity measures. As a consequence, it seems possible that most older people did not know their health problems at the time of the interview and failed to report the presence of physical or mental diseases in the survey despite feeling unwell and making a lower subjective assessment of their own overall health status. However, this account must be approached with some caution because poor self-perceived health is not equivalent to worsened outcomes of all dimensions of health while self-perceived health is determined by what aspect of health outcomes a person is considering when rating their health (Au and Johnston, 2014).

Table 3-5. The Impact of Fiscal Austerity on Self-perceived Health, Mental Health and Physical Health of the Elderly in EU Countries

Health outcomes	Self-perceived Health			Euro-D Variable			Depression		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	.0212*** (.00466)	.0195*** (.00465)	.0182*** (.00466)	.00368 (.0138)	.00340 (.0139)	.00670 (.0139)	.00357 (.00271)	.00338 (.00271)	.00394 (.00273)
Placebo effect	.00480 (.00501)	.00505 (.00501)	.00505 (.00501)	-.00839 (.0116)	-.00910 (.0116)	-.00910 (.0116)	-.000736 (.00258)	-.000798 (.00258)	-.000798 (.00258)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	141521	140289	140289	131331	130190	130190	131331	130190	130190
Physical health	Instrumental Activities of Daily Living Index								
	(1)	(2)	(3)						
Treatment effect	-.00471 (.00780)	-.00685 (.00778)	-.0105 (.00783)						
Placebo effect	.00164 (.00485)	.00156 (.00487)	.00156 (.00487)						
Covariates	No	Yes	Yes						
Wave dummies	No	No	Yes						
Observations	141444	140211	140211						

Notes: The table presents DDD estimates of the causal effect of fiscal austerity on self-perceived health, physical health and mental health. The placebo test results are shown below each DDD estimate. The outcomes include self-perceived health, Euro-D variable, a dummy for suffering from depression and instrumental activities of daily living index. For each dependent variable, three model specifications are used. The covariates include age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DDD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

Table 3-6. The Impact of Fiscal Austerity on Chronic Health Conditions of the Elderly in EU Countries

Chronic conditions	High Blood Pressure			High Blood Cholesterol			Stroke		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	.00375 (.00238)	.00335 (.00239)	.00295 (.00239)	-.000238 (.00234)	-.000404 (.00234)	-.0000387 (.00235)	-.00217 (.00112)	-.00229* (.00112)	-.00232* (.00113)
Placebo effect	-.000632 (.00207)	-.000503 (.00207)	-.000503 (.00207)	-.00281 (.00210)	-.00279 (.00210)	-.00279 (.00210)	.00121 (.00102)	.00114 (.00102)	.00114 (.00102)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	141378	140151	140151	141378	140151	140151	141378	140151	140151
Chronic conditions	Diabetes			Chronic Lung Disease			Stomach Ulcer		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	-.00118 (.00149)	-.00149 (.00148)	-.00152 (.00149)	-.00183 (.00124)	-.00209 (.00124)	-.00190 (.00124)	.000999 (.00142)	.00105 (.00143)	.000990 (.00143)
Placebo effect	-.000534 (.00109)	-.000472 (.00109)	-.000472 (.00109)	.000885 (.000935)	.000993 (.000935)	.000993 (.000935)	.000638 (.00119)	.000538 (.00119)	.000538 (.00119)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	141378	140151	140151	141378	140151	140151	141378	140151	140151

Table 3-6. Continued

Chronic conditions	Heart Attack			Cancer			Cataracts		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	.00161 (.00171)	.00136 (.00171)	.00114 (.00171)	-.00253* (.00110)	-.00258* (.00110)	-.00230* (.00111)	-.00938*** (.00188)	-.00971*** (.00188)	-.00963*** (.00189)
Placebo effect	-.000130 (.00152)	-.000178 (.00152)	-.000178 (.00152)	.0000859 (.000917)	.0000980 (.000916)	.0000980 (.000916)	.00102 (.00148)	.000978 (.00148)	.000978 (.00148)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	141378	140151	140151	141378	140151	140151	141378	140151	140151
Chronic conditions	The Number of Chronic Diseases								
	(1)	(2)	(3)						
Treatment effect	.00268 (.00756)	-.000318 (.00752)	-.00571 (.00750)						
Placebo effect	-.00384 (.00586)	-.00340 (.00585)	-.00340 (.00585)						
Covariates	No	Yes	Yes						
Wave dummies	No	No	Yes						
Observations	141375	140148	140148						

Notes: The table presents DDD estimates of the causal effect of fiscal austerity on each chronic disease and the total number of chronic conditions. The placebo test results are shown below each DDD estimate. The outcomes include the total number of chronic diseases as well as dummy variables for heart attack, high blood pressure, high blood cholesterol, stroke, diabetes, chronic lung disease, stomach ulcer, cancer and cataracts. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DDD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

Table 3-7. The Impact of Fiscal Austerity on Cause-specific Death of the Elderly in EU Countries

Causes of death	Other Cardiovascular Related Illness			Decrepitude			Disease of the Digestive System		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	-.00198**	-.00213**	-.00215**	.000607	.000562	.000503	-.0000200	-.0000234	-.0000237
	(.000714)	(.000713)	(.000711)	(.000437)	(.000442)	(.000438)	(.000235)	(.000236)	(.000234)
Placebo effect	-.00137	-.00134	-.00134	-.00176	-.00179	-.00179	.000196	.000207	.000207
	(.000932)	(.000933)	(.000933)	(.000990)	(.001000)	(.001000)	(.000434)	(.000433)	(.000433)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	94864	93971	93971	94549	93660	93660	94356	93471	93471
Causes of death	Accident			Mental and Behavioural Disorders					
	(1)	(2)	(3)	(4)	(5)	(6)			
Treatment effect	-.000195	-.000192	-.000216	.000133	.000131	.0000977			
	(.000426)	(.000426)	(.000430)	(.000189)	(.000191)	(.000192)			
Placebo effect	.000259	.000246	.000246	.000340	.000355	.000355			
	(.000379)	(.000378)	(.000378)	(.000210)	(.000216)	(.000216)			
Covariates	No	Yes	Yes	No	Yes	Yes			
Wave dummies	No	No	Yes	No	No	Yes			
Observations	94317	93432	93432	94289	93404	93404			

Notes: The table presents DDD estimates of the causal effect of fiscal austerity on cause-specific deaths. The placebo test results are shown below each DDD estimate. The outcomes include dummy variables for deaths due to other cardiovascular related disease, decrepitude, disease of digestive system, accident as well as mental and behavioural disorders. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DDD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

Table 3-8. The Impact of Fiscal Austerity on Healthcare Utilisation and Behavioural Risk of the Elderly in EU Countries

Healthcare use	The Number of Times Being an Inpatient			Total Nights Stayed in Hospital			Whether Visited a Medical Doctor		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	.000369 (.00474)	-.000441 (.00475)	-.000693 (.00475)	.0746 (.0420)	.0694 (.0422)	.0734 (.0420)	-.00530* (.00220)	-.00545* (.00220)	-.00519* (.00221)
Placebo effect	.00647 (.00383)	.00682 (.00387)	.00682 (.00387)	.0528 (.0454)	.0552 (.0457)	.0552 (.0457)	-.00179 (.00222)	-.00165 (.00222)	-.00165 (.00222)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	141337	140107	140107	141224	139996	139996	140481	139263	139263
Behavioural risk	Drinking More Than 5 or 6 Days a Week			Whether a Person Smokes at the Present Time			The Number of Years a Person Smoked		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment effect	.00793* (.00358)	.00814* (.00359)	.00849* (.00365)	-.0119*** (.00331)	-.01000** (.00330)	-.000239 (.00336)	.306 (.319)	.348 (.306)	.466 (.303)
Placebo effect	.00226 (.00176)	.00187 (.00176)	.00187 (.00176)	.000668 (.00132)	.000449 (.00132)	.000449 (.00132)	.375 (.827)	.609 (.860)	.609 (.860)
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Wave dummies	No	No	Yes	No	No	Yes	No	No	Yes
Observations	102657	101672	101672	105058	104071	104071	48816	48778	48778

Table 3-8. Continued

Behavioural risk	Frequency of Doing Vigorous Sports or Activities		
	(1)	(2)	(3)
Treatment effect	-.00463 (.00275)	-.00424 (.00274)	-.00465 (.00276)
Placebo effect	-.000952 (.00243)	-.000742 (.00243)	-.000742 (.00243)
Covariates	No	Yes	Yes
Wave dummies	No	No	Yes
Observations	134800	133583	133583

Notes: The table presents DDD estimates of the causal effect of fiscal austerity on healthcare use and behavioural risk. The analysis explores whether healthcare use and behavioural risk can be mediating factors which explain the causal effect of fiscal austerity on health outcomes. The placebo test results are shown below each DDD estimate. The outcomes regarding healthcare utilisation include the number of times being an inpatient in hospital, the total number of nights an individual stayed in hospital and a dummy for whether the individual visit a medical doctor. The dependent variables of interest about behavioural risk include a dummy for drinking more than 5 or 6 days a week, a dummy for whether an individual smoked at the present time, the number of years a respondent smoked and the frequency of doing vigorous sports or activities. For each dependent variable, three model specifications are used. The covariates capture individual sociodemographic characteristics including age, gender, marital status, household size and education level. Columns 1, 4 and 7 exclude covariates and wave dummies. Columns 2, 5 and 8 include covariates, but exclude wave dummies. Columns 3, 6 and 9 control for both covariates and wave dummies, which is the preferred model specification. The last row displays the number of observations used in DDD regression. The robust standard errors clustered by individual ID are given in parentheses. The stars represent significance at the following p-values: * for p<.05, ** for p<.01, and *** for p<.001.

3.7 Discussion

Scant attention in the existing empirical literature has been paid to the question of how fiscal austerity policies causally influenced health outcomes of the elderly people. The main objective of this research is to identify the causal impact of fiscal austerity on health outcomes of older people. The paper hypothesises that fiscal austerity worsened health conditions of the elderly. Indeed, the current study find that older people experienced poorer self-perceived health while the probability of death due to digestive diseases was raised following the introduction of fiscal austerity policies across European nations. Contrary to the assumption, it is surprising to note that austerity measures adopted across EU nations led to a decline in the possibility of developing chronic health conditions (including cancer, cataracts, stroke, hypertension, high cholesterol and gastric ulcers) as well as a reduction in mortality caused by other cardiovascular related illness. Moreover, other health outcomes appear to be unaffected by austerity measures, which includes depression symptoms, functional capacity and the total number of chronic diseases. The improvement in health conditions of the elderly cannot support the findings in previous research which claims that fiscal austerity could damage health status of older people, such as Montgomery *et al.* (2007), Loopstra *et al.* (2016a), Ginn (2013) and McKee and Stuckler (2013).

All in all, during years of fiscal austerity, the elderly's self-perceived health was significantly worsened, but some physical and mental health outcomes seem to be improved while others were unaffected by austerity measures. These results appear to contradict each other. The reason for this is not clear, but this research further explored several possible mediating factors associated with behavioural risk factors and medical care utilisation, which could partially explain the causal effect of fiscal austerity policies on health outcomes. Prior studies have implied the importance of access to medical care services and behavioural risk factors as a mediating mechanism underlying the interrelationship between fiscal austerity and health conditions. In particular, the barriers in healthcare access can be attributed to poverty and higher healthcare costs (Legido-Quigley *et al.*, 2016; da Costa *et al.*, 2017; Doetsch *et al.*, 2017; Tavares and Zantomio, 2017), whereas the unhealthy behaviours include increased smoking, physical inactivity (Xu, 2013) and unhealthy diet (Jofre-Bonet, Serra-Sastre and Vandoros, 2018). By contrast, lower income may result in a reduction in alcohol and cigarette consumption (Jofre-Bonet, Serra-Sastre and Vandoros, 2018). An important finding of the current research is that fiscal austerity induced heavier drinking, an increased smoking, physical inactivity as well as a decline in use of outpatient care services. On the one hand, these results suggest that unhealthy behaviours among older people in EU nations may have worsened self-perceived health of the elderly. On the other hand, when considering healthcare effect to be a mediating mechanism, a possible explanation for the causal impact of fiscal austerity on health outcomes might be that the reduction in outpatient healthcare utilisation implies lack of access to healthcare services and the unmet medical needs for screening tests or diagnoses of diseases. Since health outcomes in the survey are self-reported by interviewees, it may be that most respondents in the sample were not aware that they suffered from a certain disease and did not report the presence of health problems at the time of the interview, which leads to the absence of negative impact of fiscal austerity on health status. However, their subjective assessment of overall health conditions is 'poor' due to feelings of illness or worse psychological well-being. A note of caution is due here since self-perceived health depends on what dimension of health respondents are thinking about when rating their health (Au and Johnston, 2014).

Furthermore, the lack of medical services is in line with the observed rise in mortality owing to disease of the digestive system. The increase in the deaths due to digestive disease is likely to be related to inequality in access to medical treatment for digestive disorders and the associated higher medical expenditure across Europe (O'Morain and O'Morain, 2019).

To better understand the mechanism in terms of healthcare utilisation, further research is required to study whether older people had unmet medical needs and the reasons thereof. However, the variable with respect to unmet healthcare needs are not available in wave four, whereas the relevant survey questions before wave 3 are inconsistent with those after wave 4. Due to these data problems, the study did not evaluate the causal effect of fiscal austerity on unmet medical needs. However, previous research has truly found that the percentage of older people who reported unmet medical need for medical examination increased during the period of fiscal austerity in European countries (Petmesidou, Pavolini and Guillén, 2014; Doetsch *et al.*, 2017) while the reasons for this include financial difficulties (Petmesidou, Pavolini and Guillén, 2014; Doetsch *et al.*, 2017), long waiting list (Petmesidou, Pavolini and Guillén, 2014) and long distance to hospitals (Petmesidou, Pavolini and Guillén, 2014). Therefore, whilst this paper did not empirically conform lack of screening tests or diagnoses of diseases as a mediating mechanism, preceding literature did substantiate the fact that there was an increased unmet healthcare need for medical examination among the elderly in EU countries induced by fiscal austerity.

Furthermore, the reasons for lack of healthcare access might be related to public healthcare spending cuts imposed by fiscal consolidation policies across EU countries and the subsequent health system reforms, which includes increased healthcare charges and a reduction in healthcare resources (Wenzl, Naci and Mossialos, 2017).

3.8 Conclusion

Fiscal consolidation was adopted by many EU countries in order to reduce government deficits and debts in the wake of financial crisis and Eurozone sovereign debt crisis. However, fiscal austerity has been recognised by some researchers as 'a failed experiment' on citizens within the affected countries because of the subsequent human costs, most notably the negative effect of austerity on health outcomes, which has been overlooked by policymakers (McKee *et al.*, 2012). Across Europe, a rise in ageing population will increase healthcare demand and medical expenses due to poorer health conditions such as multi-morbidity for the elderly. A key policy priority may therefore be to carefully plan for public health financing and healthcare system, which takes account of the health outcomes of senior citizens to guarantee healthy ageing. However, the effect of fiscal austerity on the elderly's health has received scant attention in research literature. The purpose of this paper is to investigate the causal effect of fiscal austerity on health outcomes of senior citizens across 11 European nations.

This study has shown that fiscal austerity resulted in poorer self-perceived health, but contrary to hypothesis, austerity did not have a significant impact on mental health, functional capacity and the number of chronic diseases for the elderly. As for a particular type of chronic conditions, evidence suggests a significant decline in the probability of developing cancer, cataracts, stroke, hypertension, high cholesterol and gastric ulcers. In addition, the analysis demonstrates a statistically significant reduction in death caused by other cardiovascular related illnesses during a time of austerity, but no significant changes in other cause-specific deaths. The amelioration of some health outcomes and the null impact on other health conditions are hard to reconcile with the worsened self-perceived health. A further examination of potential mediating mechanisms indicates that fiscal austerity led to unhealthy behaviours including heavier drinking, an increased smoking, physical inactivity as well as a reduction in outpatient healthcare utilisation. Thus, unhealthy behaviours can partially contribute to worse self-perceived health. Another possible explanation for poorer self-assessed health is that the elderly with higher exposure to austerity in countries with higher degrees of austerity encountered barriers to healthcare access, so they experienced unmet healthcare need for medical examination or diagnoses of diseases and were incognisant of their health problems. Since health outcomes are self-reported, the respondents in the sample failed to report the presence of health problems, which leads to either an improvement in some health outcomes or no effect on other health conditions despite feelings of illness or experiencing lower mental well-being. The restricted access to healthcare services may be caused by the structural adjustment reforms in health system, which reduced healthcare resources, decreased healthcare coverage and increased medical costs (Kentikelenis, 2017; Wenzl, Naci and Mossialos, 2017; Arca, Principe and Van Doorslaer, 2020). In particular, financial difficulties and higher medical expenses are major reasons for lack of healthcare access among the elderly (Legido-Quigley *et al.*, 2016; da Costa *et al.*, 2017; Doetsch *et al.*, 2017; Tavares and Zantomio, 2017). However, the results should be interpreted with caution because self-perceived health cannot reflect all aspects of health outcomes and it depends on a respondent's consideration when assessing health status (Au and Johnston, 2014).

The findings of this study have several practical policy implications. First, despite massive public spending cuts in the healthcare sector, policymakers and hospital managers are advised to take account of whether a specific health policy would incur difficulties in accessing healthcare services for the elderly. In order to make healthcare services more accessible to older people, one objective of public health system could be to efficiently allocate the limited healthcare resources and enhance productivity. Second, continued efforts might be needed to consider whether an alternative policy as a response to financial crisis can achieve fiscal goals without causing negative health consequences and the policy needs to focus on the origin of the financial crisis, which is financial deregulation.

Limitations remain in this paper. This study is limited by the lack of data on whether individuals had unmet medical need, unmet medical need due to costs and unmet medical need due to long waiting time in the pre-austerity period, which can provide evidence on the presence of unmet medical need and the reasons for it. Another limitation of the dataset is the absence of information on malnutrition and homelessness, which are also considered important factors leading to worse self-perceived health.

Finally, this paper proposes several directions for future research. Firstly, if data regarding healthcare supply are available, further research is needed to fully understand the impact of fiscal austerity on delivery of healthcare services and health system efficiency. Secondly, a question raised by this study is how public health system can efficiently allocate scarce healthcare resources to vulnerable groups of population in the structural adjustment program. More broadly, further work needs to be done to establish whether an alternative fiscal policy can be adopted to cope with the negative effect of financial crisis on economic performance, but avoid human costs such as the negative impact on health outcomes and healthcare access. In addition, it might be worthwhile to evaluate whether government expenditure cuts in public sectors other than health system will incur smaller loss compared with a reduction in public health spending.

Chapter 4 Exposure to Wildfires and Health Outcomes of Vulnerable People: Evidence from US Data

4.1 Introduction

Climate change has increased the risk and intensity of wildfires in US in recent years. Wildfires have quadrupled the number of acres burned in the United States during the last 40 years (Burke *et al.*, 2021). A surge in wildfire activity can be attributable to several reasons. Firstly, higher temperature and an increased vapor pressure deficit due to human activities led to greater fuel aridity (Westerling *et al.*, 2006; Abatzoglou and Williams, 2016). Secondly, the expansion of wildland-urban interface exacerbated the wildfire risk (Radeloff *et al.*, 2018). The past few decades witnessed a rise in wildfire management costs due to the enhanced prevalence and intensity of wildfires as well as extended wildfire season (United States Forest Service, 2015). The expenditure on wildfire suppression by US Federal Agencies amounted to $24 billion from 2000 to 2013 (Calkin, Thompson and Finney, 2015). The total annualized cost of wildfires is estimated to range between $71.1 billion and $347.8 billion (Thomas *et al.*, 2017). Among the total costs of wildland fires, the assessment of the adverse health costs incurred by wildfires have received considerable critical attention in public health and economics of wildfire.

Pregnant women and the elderly have been identified as two population groups who are relatively vulnerable to health threats of wildfires (Liu *et al.*, 2015; Amjad *et al.*, 2021). Previous research has suggested that wildfire exposure is associated with adverse birth outcomes and health problems among older adults aged 65 and above. In particular, wildfires have a detrimental impact on neonatal health through maternal exposure to air pollutants released from wildfires and psychological problems of mothers induced by traumatic experiences during wildfires (Amjad *et al.*, 2021). Overall, the research regarding neonatal health effect of wildfires provides mixed evidence. It has been previously observed that maternal exposure to wildfires is correlated with prematurity (Holstius *et al.*, 2012; Abdo *et al.*, 2019; Amjad *et al.*, 2021); a decline in birth weight (Holstius *et al.*, 2012; Abdo *et al.*, 2019; Amjad *et al.*, 2021) or low birth weight (Jones and McDermott, 2021); fetal, infant and child deaths (Jayachandran, 2009) as well as birth defects including cleft lip, congenital respiratory diseases and nervous system abnormalities (Requia *et al.*, 2021). By contrast, O'Donnell and Behie (2015) have offered contradictory findings that wildfires are linked to macrosomia or larger birth weight. In addition, results in terms of the windows of susceptibility for maternal exposure to wildfires remain inconclusive across different studies (Jayachandran, 2009; Holstius *et al.*, 2012; Abdo *et al.*, 2019; Jones and McDermott, 2021; Requia *et al.*, 2021).

Most studies investigating the health impact of wildfires on adults have focused on all age groups as a whole, whereas few studies have focused on the effect of wildfires on health conditions of the elderly, who are more susceptible to wildfire smoke than any other age groups (DeFlorio-Barker *et al.*, 2019; Masri *et al.*, 2021). The existing body of research on the influence of wildfires on adults' health suggests that wildfires are related to a higher risk of respiratory diseases (Frankenberg, McKee and Thomas, 2005; Chen, Verrall and Tong, 2006; Moore *et al.*, 2006; Liu *et al.*, 2015; Reid *et al.*, 2016; Sheldon and Sankaran, 2017; Walter *et al.*, 2020; Aguilera *et al.*, 2021), poorer general health status (Kim *et al.*, 2017), greater difficulties with activities of daily living (Frankenberg, McKee and Thomas, 2005; Kim *et al.*, 2017) as well as mental disorders including post-traumatic stress disorder, major depressive disorder and generalized anxiety disorder (To, Eboreime and Agyapong, 2021). However, there is no significant effect on cardiovascular diseases (Moore *et al.*, 2006; DeFlorio-Barker *et al.*, 2019).

Based on all the foregoing findings, the purpose of this paper is to investigate the causal impact of wildfire exposure on birth outcomes as well as health status of the elderly aged 65 and older across US counties. The wildfire data for this study were collected from Fire Statistics System (FIRESTAT) created by United States Department of Agriculture (USDA) Forest Service (2021), which provides detailed data about the geographic locations and the start date of wildfires. The dataset with respect to pregnancy outcomes during the period from 1998 to 2004 originates from the public use birth data files offered by National Vital Statistics System (NVSS), but this study only has access to data in terms of counties with a population size no fewer than 100,000. The current research also employs health-related data for the elderly from Behavioural Risk Factor Surveillance System (BRFSS) data between 2001 and 2010. All three datasets include information about county and monthly date, which is used as location and time index. Specifically, this paper firstly examines the causal effect of wildfire exposure on birth outcomes including birth weight, premature birth and congenital anomalies. Then, the analysis looks into the impact of wildfires on health conditions of older people concerning general physical and mental health, physical activities as well as asthma symptoms.

To investigate how wildfire exposure affected both birth outcomes and older adults' health outcomes, three sub-questions are examined for each outcome of interest. In the first one, we study the individual causal effect of each of the five most sizeable wildfires on neonatal health and older people's health status at individual level. A difference-in-differences (DD) model is applied to micro level data in this event-specific study and the distance from wildfires to each county is used as a continuous treatment intensity. For birth outcomes, the DD findings suggest that the largest wildfire leads to a slightly larger probability of giving birth to newborns with other circulatory or respiratory anomalies. Moreover, the second largest wildfire resulted in a marginal rise in the likelihood of low birth weight. However, both effects are close to null. As for the health impact of wildfires on older people, the older age group experienced asthma symptoms more often as a consequence of the second largest wildfire.

The second research question examines how multiple massive wildfires jointly affect health outcomes of the newborns and the elderly using the micro-level data. For birth outcomes, 5 large wildfires are employed, which burned more than 5000 acres and whose distance to each county is less than 20 km. For older people's health outcomes, the analysis exploits 63 wildfires, which induced more than 50 burned acres and whose distance to each county is smaller than 20 km[35]. The two-way fixed effects (TWFE) regression is adopted given that more than two time periods exist and counties receive treatment at different time. The canonical DD method can no longer be used because treatment timing varies across counties and the post-treatment period cannot be identified in control groups (Goodman-Bacon, 2021). The TWFE results show that the combined impact of multiple large wildfires which burned more than 5000 acres slightly increased the probability of prematurity. With respect to older people's health conditions, multiple wildfires led to a more frequent occurrence of asthma symptoms and an extended period of poorer mental health.

Finally, the third research question assesses the aggregate impact of multiple wildfires of different sizes on average health outcomes at the county level. When treatment effects are heterogeneous across counties or over time, TWFE estimate is a biased estimate of the average treatment effect on the treated (ATT) based on the common trend assumption (de Chaisemartin and D'Haultfœuille, 2020). In light of the disadvantages of TWFE and the heterogeneity of the treatment effects across counties throughout the time span, the methodological approach taken in the third research question is to calculate $DID_{+,t}$ estimates suggested by de Chaisemartin and D'Haultfœuille (2020). The $DID_{+,t}$ estimator adjusts for heterogeneity in treatment effects among groups or over time when calculating the average treatment effect on the treated (de Chaisemartin and D'Haultfœuille, 2020). The analysis demonstrates that maternal exposure to wildfires modestly reduced the risk of omphalocele and cleft lip. Additionally, there is a slight increase in the length of gestation due to being exposed to wildfires. The estimates of the dynamic treatment effects at the county level show that wildfires enhanced birth weight and the

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[35] See section 4.4.2 for more details.

likelihood of delivering macrosomic infants for exposure during any trimester of pregnancy. Furthermore, neonates are more likely to develop omphalocele for prenatal exposure to wildfires during the first trimester. In terms of the elderly population, wildfire exposure resulted in physical inactivity.

This paper aims to contribute to the existing empirical research on the health impact of wildfires in the following aspects. First, the study estimates health costs of wildfires associated with vulnerable groups, which provides input into cost-benefit analysis of wildfire exposure. According to empirical results, the presence of a null health effect of wildfires on several health indicators suggests that when using resources to deal with the damage induced by wildfires, mitigating health effect may not be a policy priority. Instead, governments and local communities may apply targeted intervention strategies to buffer economic and environmental impact of wildfires in the first instance. Second, the research to date has tended to focus on the impact of air pollutants emitted from wildfires on birth outcomes and health conditions of adults, but it has not considered the influence of wildfires on health through psychological problems induced by traumatic wildfire events. The research design of the current analysis provides fresh insights into assessing the health impact of wildfires through both exposure to air pollution and suffering from mental health problems, which advances the understanding of the health consequences of wildland fires in a holistic way. Third, most preceding literature with regard to the health effect of wildfires in US only pays attention to a single state or several areas in one state, such as Colorado (Abdo *et al.*, 2019), California (Heft-Neal *et al.*, 2022) and California's South Coast Air Basin (Holstius *et al.*, 2012). This analysis employs data from a broader set of US counties to set up the treated and control groups in causal inference. In addition, besides the health of neonatal, this paper focuses on the health impact of wildfires on the older age group, which is another group vulnerable to wildfires, but is seldomly studied in previous research. Finally, by employing the available health variables in the data, the current study examines the impact of wildfires on a broader category of health outcomes including birth weight and the length of gestation for birth outcomes as well as general physical and mental health, physical activities and asthma symptoms for the elderly. Moreover, the analysis turns to studying the effect of wildfires on congenital anomalies which receive scant attention in previous research.

In terms of methodology, the research methods adopted by most of the previous papers are correlational in nature, so evidence for causal relationship is lacking. The current research conducts causal inference analysis by using difference-in-differences method for event-specific analysis, two-way fixed effects regression to estimate the health effect of multiple large wildfires as well as $DID_{+,t}$ estimates recommended by de Chaisemartin and D'Haultfœuille (2020) for the county-level analysis. This paper offers explanations for advantages and disadvantages of each method as well as the suitability of each approach in view of the data structure, the number of post-treatment periods and the variation in treatment timing. A major advantage of $DID_{+,t}$ estimates advanced by de Chaisemartin and D'Haultfœuille (2020) is that it allows for the heterogeneity of the treatment effects of wildfires across counties or over time.

The remaining sections of this paper are organised as follows. The paper begins by providing a more detailed review of the literature described above. Then, it will go on to introduce the datasets used and explain the empirical strategy adopted in analysis. Section 4.5 presents the main empirical findings regarding the health impact of wildfire exposure on neonates and the elderly. Section 4.6 discusses several potential mechanisms underlying the health effects and the implications of the null effects. The paper concludes with section 4.7. Finally, most tables and figures of empirical findings can be found in Appendix C.

4.2 Literature Review

4.2.1 Wildfires and Birth Outcomes

The preceding research obtains inconsistent findings of the relationship between maternal wildfire exposure and birth outcomes depending on study population, exposure assessment, birth outcomes and methodologies (Amjad *et al.*, 2021).

In a systematic review of the scientific evidence regarding the correlation between exposure to wildfires and unfavourable outcomes of pregnancy, Amjad *et al.* (2021) conclude that wildfire exposure in the later stage of gestation is correlated with preterm birth and lower birth weight, whereas the relationship between wildfire exposure and infant death rates or small for gestational age is indecisive. The exposure to air pollutants released from wildfires and the stress reaction are plausible mediating mechanisms for the adverse birth outcomes (Amjad *et al.*, 2021).

Several authors have studied the impact of wildfires on birth outcomes in selected US states. Abdo *et al.* (2019) demonstrate that exposure to wildfire smoke $PM_{2.5}$ during the second trimester of gestation is linked to a higher likelihood of preterm birth in Colorado between 2007 and 2015 while wildfire smoke $PM_{2.5}$ exposure during the first trimester of pregnancy is correlated with a decline in birth weight (Abdo *et al.*, 2019). Instead of studying wildfire smoke in Colorado which was mostly transported from the US Pacific Northwest and Western Canada (Brey et al., 2018, cited in Abdo *et al.*, 2019), Heft-Neal *et al.* (2022) focus on wildfire smoke in California mostly released from neighbouring regions between 2006 and 2012, which draws upon a larger variation in air pollution. They find that an additional day of wildfire smoke exposure during pregnancy raises the possibility of premature birth by 0.49% in the late pregnancy period and such a relationship is possibly induced by exposure to medium or high intensity smoke-days (Heft-Neal *et al.*, 2022). Similarly, Holstius *et al.* (2012) suggest that maternal exposure to a string of 2003 Southern California wildfires, which destroyed more than 750,000 acres, results in a modest reduction in birth weight in South Coast Air Basin and the effect of the wildfires on birth weight is the largest for exposure in the second trimester. The two underlying mechanisms for the effect are psychological stress and biological mechanisms (Holstius *et al.*, 2012) such as oxidative stress, changes in maternal-placenta exchange as well as endocrine dysfunction (Slama et al., 2008, as cited in Holstius *et al.*, 2012). A recent study by Jones and McDermott (2021) is more concerned with mega-wildfires that burned larger than 100,000 acres across US counties from 2010 to 2017 and draw our attention to the affected population residing within the flame zone. Jones and McDermott (2021) conclude that exposure to mega-wildfires during gestation witnessed a higher risk of low birth weight and preterm birth.

In addition, previous studies discovered evidence of the relationship between wildfire exposure and poor birth outcomes in other countries. Jayachandran (2009) shows that maternal exposure to air pollution caused by 1997 Indonesian wildfires, which burned more than 12 million acres, results in 15600 fetal, infant and child deaths in Indonesia by using birth outcomes from 2000 Census of Population for Indonesia as well as aerosol index from Earth Probe Total Ozone Mapping Spectrometer (TOMS) to measure airborne smoke and dust. The main reason for infant mortality is acute respiratory infection induced by postnatal exposure to air pollutants while fetal growth is affected by in utero exposure to air pollution (Jayachandran, 2009). In addition, polycyclic aromatic hydrocarbons (PAHs) in particulate matter can pass through the placenta and damage central nervous system activity of a fetus, which retards fetal growth (Jayachandran, 2009). Requia *et al.* (2021) contribute to the existing literature by investigating the correlation between air pollution caused by wildfires and birth defects. By applying a logistic regression, Requia *et al.* (2021) find that maternal exposure to wildfire smoke across Brazil from 2001 to 2018 led to a higher possibility of congenital anomalies including cleft lip for exposure in the second trimester, congenital respiratory disorders during the second trimester of exposure as well as nervous system malformation for exposure during the first trimester. Requia *et al.* (2021) maintain that the impact of wildfires on congenital malformations can be attributable to toxicological effect of pollutants and psychological stress due to damage induced by wildfires.

In contrast to the preceding findings, O'Donnell and Behie (2015) report that maternal exposure to the 2003 Canberra wildfires led to larger birth weights of male foetuses, but insignificant changes in gestational age. O'Donnell and Behie (2015) maintain that the higher birth weights are caused by macrosomia and the possible causal pathway is that maternal psychological stress can raise cortisol levels as well as enhance blood glucose levels, which increases the risk of macrosomia.

4.2.2 Air Pollution and Maternal Mental Health as Mediating Mechanisms

Much of the previous literature emphasises the impact of air pollutants released from wildfires on fetal development as a biological mechanism for the relationship between wildfires and birth outcomes. However, there has been little discussion about psychological effects of wildfires as another causal pathways linking exposure to wildfires with birth outcomes.

4.2.2.1 Air Pollution and Birth Outcomes

This section reviews the literature which finds supporting evidence for air pollution as a mediating mechanism. Empirical findings from several studies suggest that air pollution caused by other types of fires or ambient air pollutants can have a negative influence on pregnancy outcomes. Additionally, a number of studies have examined which exposure window during pregnancy leads to adverse birth outcomes, but there has been little consensus on which trimester of exposure to air pollution is associated with a higher possibility of disadvantageous birth outcomes (Salam *et al.*, 2005).

Rangel and Vogl (2019) find that air pollutants including particulate matter 10 (PM_{10}) and ozone (O_3) emitted from sugarcane harvest burning in Brazil resulted in lower birth weight, a reduction in gestational length and higher fetal death rates. Ye *et al.* (2018) show that exposure to ambient air pollutants including nitrogen dioxide, particulate matter 2.5 ($PM_{2.5}$) and PM_{10} during the second and third trimester of pregnancy is related to low birth weight and a greater possibility of preterm birth in Taizhou from 2013 to 2016, because air pollutants can retard placental growth and affect maternal-fetal exchange of oxygen and nutrients (Kannan et al., 2006, cited in Ye *et al.*, 2018). Salam *et al.* (2005) find that prenatal exposure to ambient carbon monoxide over the first trimester as well as ozone during the second and third trimester are correlated with smaller birth weight and intrauterine growth retardation (IUGR) in California between 1975 and 1987, which can be explained by maternal inflammation due to ozone and fetal tissue hypoxia caused by carbon monoxide. In contrast to the findings of Ye *et al.* (2018), nitrogen dioxide has no relationship with birth weight (Salam *et al.*, 2005).

To summarize, a higher likelihood of prematurity is associated with air pollutants including $PM_{2.5}$ (Wilhelm and Ritz, 2005; Lee *et al.*, 2013; Ha *et al.*, 2014; Arroyo *et al.*, 2016), PM_{10} (Wilhelm and Ritz, 2005), carbon monoxide (CO) (Wilhelm and Ritz, 2005), O_3 (Lee *et al.*, 2013; Arroyo *et al.*, 2016), sulphur dioxide (SO_2) and total suspended particles (TSP) (Bobak, 2000). In addition, low birth weight is correlated with $PM_{2.5}$ (Wilhelm and Ritz, 2005; Ha *et al.*, 2014), PM_{10} (Wilhelm and Ritz, 2005), CO (Wilhelm and Ritz, 2005), nitrogen dioxide (NO_2) (Arroyo *et al.*, 2016), O_3 (Arroyo *et al.*, 2016), SO_2 and TSP (Bobak, 2000).

The exposure windows during which the effects of each air pollutant on birth outcomes are observed remain inconsistent across existing research. Low birth weight has been found to be associated with maternal exposure to the following air pollutants in different trimesters: NO_2 in the second trimester (Arroyo *et al.*, 2016; Ye *et al.*, 2018), O_3 in the first (Arroyo *et al.*, 2016), second and third trimesters (Salam *et al.*, 2005), CO in the first (Salam *et al.*, 2005) and third trimester (Wilhelm and Ritz, 2005), SO_2 and TSP in the first trimester (Bobak, 2000), as well as $PM_{2.5}$ in all trimesters (Ha *et al.*, 2014). Prematurity appears to be closely linked to maternal exposure to $PM_{2.5}$ in the first (Lee *et al.*, 2013), second (Arroyo *et al.*, 2016) and all trimesters (Ha *et al.*, 2014), ozone in the first trimester (Lee *et al.*, 2013; Arroyo *et al.*, 2016), CO in the first trimester (Wilhelm and Ritz, 2005), SO_2 and TSP in the first trimester (Bobak, 2000), as well as NO_2 in the second trimester (Ye *et al.*, 2018). Moreover, the risk of small for gestational age is discovered to be correlated with maternal exposure to $PM_{2.5}$ and PM_{10} during the first trimester (Lee *et al.*, 2013) while intrauterine growth restriction is associated with prenatal exposure to O_3 in the third trimester and CO in the first trimester (Salam *et al.*, 2005).

Another relatively small strand of literature has considered the impact of air pollution on congenital anomalies. In a systematic review and meta-analysis, Vrijheid *et al.* (2011) propose that maternal exposure to NO_2 and SO_2 is more likely to incur congenital cardiac anomalies, such as coarctation of the aorta and tetralogy of Fallot, while exposure to PM_{10} could enhance the possibility of atrial septal defect. Farhi *et al.* (2014) demonstrate that exposure to higher levels of PM_{10} and nitrogen oxides concentrations during the entire pregnancy are linked to congenital malformations of the circulatory system. Liu *et al.* (2017) point out that higher PM_{10} concentrations can increase the risk of fetal cardiovascular malformations including atrial septal defect, fetal patent ductus arteriosus and overall congenital heart malformations in the first two months of pregnancy.

At odds with earlier findings, however, Melody *et al.* (2019) show that maternal exposure to larger release of $PM_{2.5}$ from the 2014 Hazelwood coal mine fire in Victoria is not significantly correlated with low birth weight, small or large for gestational age and prematurity for births in Latrobe Valley, whereas higher fine particulate matter concentrations is related to larger birth weight among women with gestational diabetes mellitus. Moreover, no significant association between the trimester of exposure and outcomes of pregnancy is detected (Melody *et al.*, 2019).

Melody *et al.* (2019) ascribe the null effects and lack of statistical power to the small sample size and low particulate matter exposure.

4.2.2.2 Mental Health and Birth Outcomes

Few studies have investigated whether maternal psychological health acts as a potential mechanism for the effect of wildfires on neonatal outcomes. However, previous studies have explored the relationship between maternal mental health and birth outcomes. In a systematic review, Staneva *et al.* (2015) conclude that prenatal depression, anxiety and stress increase the possibility of spontaneous preterm birth. Liou, Wang and Cheng (2016) propose that maternal stress during pregnancy has no effect on low birth weight or preterm birth, whereas depressive symptoms and anxiety over 25 to 29 weeks of gestation increases the risk of preterm birth. Dole *et al.* (2003) suggest that pregnancy-related anxiety increases the risk of spontaneous prematurity while negative life events can induce medically indicated preterm births.

As for the underlying mechanism, Dunkel Schetter (2011) suggests that the causal pathways linking maternal stress to birth outcomes include neuroendocrine-mediating process, inflammatory and immune mediating process as well as behavioural-mediating process. Specifically, the neuroendocrine-mediating process involves activation of the hypothalamic-pituitary-adrenal axis of the pregnant women and elevated production of corticotropin-releasing hormone from the placenta (Dunkel Schetter, 2011). The inflammatory and immune-mediating processes concern enhanced proinflammatory cytokines and C-reactive protein (Coussons-Read et al. 2003, 2005, 2007, cited in Dunkel Schetter, 2011) as well as vaginal bacterial infections due to maternal stress (Dunkel Schetter & Glynn, 2010, cited in Dunkel Schetter, 2011). The behavioural-mediating processes include unhealthy behaviours induced by stress, such as substance use, tobacco use, unhealthy diet and physically demanding activities (Dunkel Schetter, 2011). In a review paper, Murphy *et al.* (2021) point out that epigenetic change is the mechanism connecting air pollutants and maternal stress induced by bushfires with unfavourable neonatal health outcomes.

It has previously been observed that wildfires have a negative impact on mental health of the pregnant women. A qualitative study by Brémault-Phillips *et al.* (2020) discovers that following the 2016 wildfire in Fort McMurray Wood Buffalo (FMWB) which burned 579,767 hectares, most pregnant women exposed to the wildfire experienced fears while thirty-four percent of the pregnant women considered wildfires to be the most traumatic events in their life. Verstraeten *et al.* (2021) suggest that the severity of the post-traumatic stress disorder-like symptoms experienced by pregnant women following the 2016 Fort McMurray Wood Buffalo (FMWB) wildfire is determined by peritraumatic distress and social support.

4.2.3 The Effect of Wildfires on Physical and Mental Health of Adults

Evidence from preceding research suggests that wildfires have an impact on physical health of adults, especially the respiratory systems. Some systematic reviews conclude that exposure to wildfire smoke is related to higher risk of respiratory diseases including asthma and chronic obstructive pulmonary disease (Liu *et al.*, 2015; Reid *et al.*, 2016; Walter *et al.*, 2020) whereas the relationship between wildfire smoke exposure and cardiovascular diseases is inconclusive (Liu *et al.*, 2015; Reid *et al.*, 2016; Walter *et al.*, 2020). In particular, young children, the elderly, people with lower socioeconomic status as well as individuals with antecedent respiratory diseases are more vulnerable to the negative health impact of wildfire smoke (Liu *et al.*, 2015). The air pollution due to 1997 Indonesian forest fires resulted in more difficulties with activities of daily living and an increased incidence of coughing among Indonesian adults (Frankenberg, McKee and Thomas, 2005) while the fire also induced upper respiratory tract infections and acute conjunctivitis among Singaporeans (Sheldon and Sankaran, 2017). Furthermore, in the long run, air pollution caused by the 1997 Indonesian wildfire has a negative effect on lung capacity and general health status as well as more difficulty with activities of daily living among older cohorts in Indonesia, whereas younger people have recuperated from the adverse health consequences 10 years after the wildfire (Kim *et al.*, 2017). In Southern California, higher levels of $PM_{2.5}$ emitted from wildfires are found to enhance daily hospital admissions for respiratory diseases (Aguilera *et al.*, 2021). Following the 2003 forest fires in British Columbia, larger levels of particulate matter is correlated with a sharp rise in physician visits for respiratory diseases, whereas there are no significant changes in visits for cardiovascular diseases (Moore *et al.*, 2006). Greater concentrations of PM_{10} released from bushfires in Brisbane from 1997 to 2000 are associated with more respiratory hospital admissions (Chen, Verrall and Tong, 2006).

Another strand of literature recognises the negative effect of wildfires on psychological health of adults. Mental disorders following the wildfires can be attributable to a number of factors, such as damage to personal property, concern for safety of loved ones and fear of unemployment (To, Eboreime and Agyapong, 2021). In a scoping review, To, Eboreime and Agyapong (2021) conclude that wildfires bring about post-traumatic stress disorder, major depressive disorder and generalized anxiety disorder, which can persist for several years after the wildfires. Caamano-Isorna *et al.* (2011) show that 2006 wildfires in Galicia significantly increased consumption of anxiolytics-hypnotics among the exposed population implying mental health problems. A broader literature suggests that various natural disasters can induce anxiety, depression, post-traumatic stress disorder (Makwana, 2019; Hrabok, Delorme and Agyapong, 2020) as well as a decline in subjective well-being (Rehdanz *et al.*, 2015).

4.3 Data

This section describes relevant datasets collected from different sources. Throughout this paper, the empirical analysis requires that health variables should be measured at the county level on a monthly basis.

4.3.1 Wildfires and Air Pollution

The data on historical wildfire events are obtained from Fire Statistics System (FIRESTAT) provided by United States Department of Agriculture (USDA) Forest Service (2021), which collects timely statistical data regarding wildfire incidents, fire behaviours and wildfire control measures (Fire and Aviation Management, 2016). This research uses data in terms of all wildfires which occurred from 1998 to 2010 across all US counties. The dataset includes detailed and key information with respect to ignition date, the date a fire was declared out, total acres burned, as well as the precise location at the point of origin of each wildfire including county name, state name, latitude and longitude using Global Coordinate System North American Datum of 1983 (NAD 83 datum) (Fire and Aviation Management, 2016; USDA Forest Service, 2021). This paper focuses on the period after 1998 because the geographic information about the wildfire locations is missing for more than fifty percent of wildfires before 1998.

In order to assign treatment status to each US county, all US counties are linked to each wildfire occurrence by longitude and latitude of the centroid of each county as well as the geographic coordinates of the point of origin of each wildfire. The geographic coordinates of each US county in 2010 mapping shapefiles are obtained from United States Census Bureau (2012), which contains latitude and longitude of each US county using North American Datum of 1983 (NAD 83)[36]. The analysis calculates the geodetic distance between the centroid of each county and the point of origin of wildfires[37]. The pairwise combinations of all counties with wildfires forms a panel dataset where the cross-sectional unit is each US county and the time index is the ignition date of wildfires.

Air pollution is measured by the daily air quality index (AQI) from the U.S. Environmental Protection Agency (2021b). The AQI ranges between 0 and 500 (U.S. Environmental Protection Agency, 2021a). Higher levels of AQI indicate larger levels of air pollution and AQI no greater than

[36] A datum is a collection of specifications of a coordinate system denoting positions on Earth (Schwarz, 1989). NAD 83 is the third horizontal datum in North America, which is similar to other global reference systems including World Geodetic System 1984 (Schwarz, 1989).
[37] The estimation of geodetic distance uses geonear module in Stata 17 (Picard, 2010) based on formulae specified in B.1.

50 denotes good air quality conditions (U.S. Environmental Protection Agency, 2021a). The AQI is summarised on a daily basis at the county level, which is an aggregate of all sub-daily AQIs collected at each monitor (U.S. Environmental Protection Agency, 2015). The defining parameters of AQIs include ozone, fine inhalable particles ($PM_{2.5}$), inhalable particles (PM_{10}), sulphur dioxide, nitrogen dioxide and carbon monoxide. Since the longitude and latitude information is unavailable in the dataset, the AQI dataset is matched to FIRESTAT dataset by using county name and date of measurement of AQI. The study uses AQIs from 1998 to 2004 in each county, which are collapsed to weekly average values because of the very large sample size which cannot be handled by limited computational resources.

4.3.2 Birth Outcomes

Birth outcomes across US counties originate from the public use birth data files provided by National Vital Statistics System (NVSS), which contains all births to US residents and non-residents registered in 50 US states, the District of Columbia, New York City as well as US territories (Steimel *et al.*, 2003), so that the dataset is representative of the national population and sample selection bias is minimized (Schoendorf and Branum, 2006). Natality data are mainly intended to monitor maternal and infant health in US (Schoendorf and Branum, 2006). One major limitation of using natality data is that due to confidentiality, birth data files have suppressed the day of birth as well as geographic information for counties and cities with a population size smaller than 100,000 (Steimel *et al.*, 2003) from 1989 to 2004 (National Center for Health Statistics, 2019). No geographic information is available in the public use natality data since 2005 (National Center for Health Statistics, 2019). Due to unavailability of restricted-use vital statistics data files as well as considering the time window of the sample of wildfire events, this study uses the public use micro-data files between 1998 and 2004.

The natality dataset should be used with caution because several states adopted the 2003 revision of the U.S. Standard Certificate of Live Birth since 2003 while all states employed the 1989 Revision of the U.S. Standard Certificate of Live Birth before 2003 (Steimel *et al.*, 2003). As a consequence, some variables, such as the number of prenatal visits, maternal education and tobacco use during pregnancy, are not comparable between revised and unrevised birth data (Steimel *et al.*, 2003). These variables are recoded in order to make data comparable between revised and unrevised birth certificates. For example, the education level is recoded into a dichotomous variable indicating whether the mother received more than 12 years of education considering that the 1989 version of birth certificate concerns the highest grade completed while the 2003 version records the highest degree or level of school finished according to Martin *et al.* (2005). The information on prenatal care is collected from different sources in different revisions of birth certificates (Martin *et al.*, 2005), so the number of prenatal visits is represented by a binary indicator denoting whether the pregnant woman has access to prenatal care or not in order to minimize the inconsistency across revisions.

The birth outcomes of interest available in birth data are birth weight, gestational age as well as a set of dummy variables for congenital anomalies including heart malformations, omphalocele, cleft lip and other circulatory or respiratory anomalies. In addition, two dichotomous derived variables of interest are created including low birth weight, which is defined as birth weight smaller than 2500 grams (Hughes, Black and Katz, 2017), as well as preterm birth defined as gestational age less than 37 weeks (Goldenberg *et al.*, 2008). Heart malformations and other circulatory anomalies are only recorded in the unrevised revision of the birth certificate, so the analyses in terms of these two health outcomes and other birth defects are carried out separately. Moreover, regression analysis controls for the following covariates available on birth certificates: fetal sex, the total number of prenatal care visits which is recoded into a dummy variable for whether the individual has access to prenatal care, plurality, pregnancy histories (total birth order defined as the total number of live births and other terminations), medical risk factors (dummy variables for diabetes, chronic hypertension and pregnancy-associated hypertension during the period of gestation), other risk factors for pregnancy (a dummy variable for tobacco use during pregnancy), as well as maternal demographic characteristics comprised of maternal age (a dummy for women aged 20-29 years old), race (a dummy for white or not), education levels (a dummy for receiving years of education larger than 12 years) and resident status (a dummy variable indicating whether a person is a resident or non-resident).

Although the beginning date of last normal menstrual period (LMP) is used as the initial date of gestation, LMP-based measurements are inaccurate because of recall bias and mistaken identification of LMP (Steimel *et al.*, 2003). Additionally, there are 1,242,256 missing values in LMP monthly date in the sample, so using LMP to calculate the start date of pregnancy is subject to selection bias. Furthermore, the clinical estimate of gestational age is applied in the data when LMP date is missing or inconsistent with birth weight (Martin *et al.*, 2005). Thus, using gestational age to estimate the start date of pregnancy is more reliable than LMP-based measurement. This paper calculates the beginning date of the period of gestation by subtracting gestational age from date of birth as well as using the date nine months prior to date of birth. In the sample, there are 281,163 missing observations in gestational age and no missing values in date of birth, which reduces the risk of sample selection bias due to missingness. Additionally, the county of occurrence is considered as the place where mothers reside in and used as county identifier.

4.3.3 Behavioural Risk Factor Surveillance System (BRFSS) Data

Health outcomes of the elderly are captured through BRFSS, which is a cross-sectional telephone survey carried out by state health departments on a monthly basis for the purpose of gathering surveillance data regarding behavioural risk factors and preventive health behaviours (Centers for Disease Control and Prevention, 2013). A probability sample of US residents aged 18 years and older were included in the survey and the number of states covered by the survey has been increasing over time (Centers for Disease Control and Prevention, 2000). The BRFSS questionnaire encompasses standard core questions (asked in each year by all states), rotating core questions (included by all states biennially), optional modules and state-added questions (Centers for Disease Control and Prevention, 2013).

This paper focuses on the elderly aged 65 and above to examine how wildfires affect health conditions of the vulnerable population group. In addition, the empirical analysis uses sample from 2001 to 2010 for the following two reasons. Firstly, the BRFSS data after 2011 are not comparable to data in preceding years due to changes in weighting methodology and the inclusion of cell phone data (Centers for Disease Control and Prevention, 2011). Secondly, although variables in terms of general physical and mental health as well as physical activities belong to the core component of questionnaire, the key variable of interest regarding asthma is part of optional modules and is only available after 2001. To make BRFSS representative of the US population, the final weight variable is applied in empirical analysis to adjust for different sampling probabilities, nonresponse and noncoverage bias (Centers for Disease Control and Prevention, 2000).

The county information is available across all years, whereas monthly date is recorded for a small number of health outcomes. The time index is computed by subtracting 30 days from the interview date. Specifically, the empirical strategy uses the following health outcomes of interest for which monthly date is accessible: the number of days physical health (including physical illness and injury) was not good during the last 30 days, the number of days mental health (including stress, depression and emotional problems) was not good during the last 30 days, a dummy for whether a person took part in any physical activities over the past month as well as a binary indicator for whether an individual had any symptoms of asthma (including cough, wheezing, shortness of breath, chest tightness and phlegm production when the person does not suffer from a cold or respiratory infection) more than twice a week in the last 30 days. Besides, the covariates which determine health outcomes incorporate age, gender, race (white non-Hispanic or not), marital status (married or not), a dummy for whether a person has children in the household or not, education levels (a dummy variable for receiving several years of education in college) as well as employment status (a dummy indicating whether a respondent is employed for wages or self-employed).

4.3.4 Data Linkage

The FIRESTAT, natality data and BRFSS data are linked in two different ways. To begin this process, FIRESTAT is collapsed into a dataset of the maximum total acres burned grouped by county and the start date of wildfire ignitions. When estimating the impact of wildfires at the individual level in sections 4.4.1 and 4.4.2, the collapsed wildfire dataset is directly combined with natality or BRFSS data on county (which is the county exposed to wildfires for FIRESTAT, the county of occurrence for natality data, and the county where each survey participant resides for BRFSS data) and monthly date (which is the beginning date of wildfires for FIRESTAT, the start date of gestational age for natality data and 30 days before the interview date for BRFSS). In addition, in order to estimate the effect of wildfires at county level in section 4.4.3, health variables and covariates of interest in both natality and BRFSS data are collapsed into monthly averages by county and monthly date. The converted wildfire dataset and natality or BRFSS data are then merged on county Federal Information Processing System (FIPS) code and monthly date. After merging, a panel dataset is formed where each county is the cross-sectional unit and monthly date is the time dimension.

Not all the counties exposed to wildfires in wildfire data are matched to those in natality and BRFSS data. Choropleth maps are produced to check whether the empirical analysis can make use of sufficient sample distributed across various US counties. The choropleth maps in Appendix C.1.1 compare the distribution of the sample sizes across US counties in wildfire data and natality data before merging with those in the combined datasets. Likewise, the choropleth maps in Appendix C.1.2 presents the sample sizes in each county in wildfire data and BRFSS data before and after merging. From the maps, we can see that non-missing observations in BRFSS are more widely spread out across US counties compared with natality data. In addition, the sample size of birth data and BRFSS is reduced after merging with wildfire data while the majority of non-missing observations in the merged datasets are focused on the Western US. Taken all together, there are adequate spatial overlaps of non-missing observations between wildfire data and natality or BRFSS data files over the time period of interest, which suggests that there is enough sample size in each county to conduct empirical estimation.

4.4 Empirical Strategy

This paper aims to investigate how wildfire exposure influences birth outcomes as well as health outcomes of older people. For each of the birth outcomes and health outcomes of the elderly, this paper studies three sub-questions by using three different empirical methods. To avoid attenuating the treatment effect of wildfires on health due to wildfires of small size, the objective of the first sub-question is to investigate the health impact of each of the five largest wildfires by employing the canonical difference-in-differences (DD) method with distance from counties to wildfires as continuous treatment intensity. The second sub-question studies the causal effect of multiple wildfires of large size on health outcomes by using two-way fixed effects (TWFE) regression, which relaxes the assumption that only the largest wildfire influenced health. The purpose of sub-question three is to examine the causal impact of multiple wildfires larger than a specific size on health outcomes at the county level via the method suggested by de Chaisemartin and D’Haultfœuille (2020).

To guide readers through this section, the research questions can be structured as follows.

1. The causal effect of maternal exposure to wildfires on birth outcomes
    1.1. The causal impact of each of the five largest wildfires on pregnancy outcomes
    1.2. The causal effect of multiple wildfires of large size on birth outcomes
    1.3. The causal impact of multiple wildfires larger than a certain size on birth outcomes at the county level
2. The causal impact of wildfire exposure on health outcomes of older people
    2.1. The health impact of each of the five largest wildfires
    2.2. The causal effect of multiple wildfires of large size on health outcomes
    2.3. The causal impact of multiple wildfires larger than a certain size on health outcomes at the county level

Next, we discuss the empirical methods adopted to resolve each sub-question, in which the dependent variables are birth outcomes and older people’s health outcomes.

4.4.1 Difference-in-differences (DD) with Continuous Treatment Intensity

Exposure to wildfires of different sizes has heterogeneous effects on birth outcomes and health status of the elderly. The first research question focuses on the health impact of each of the five largest wildfires in FIRESTAT, which is similar to event-specific estimates proposed by Cengiz *et al.* (2019) in the context of labour markets. This analysis employs the canonical difference-in-differences (DD) method with continuous treatment intensity using the individual-level repeated cross-sectional data. In particular, the distance from each county to the point of origin of wildfires is used as a continuous treatment intensity because when a wildfire occurred, all counties were exposed to some degree and a binary treatment status cannot be applied.

The first step in this estimation framework is to construct five wildfire-specific datasets, each of which corresponds to one of the five large-scale wildfires. For each dataset, we need to define treatment and control groups, as well as pre- and post-treatment periods. For both BRFSS and natality datasets, treated counties are defined as those within a 20-kilometre radius of a massive wildfire[38], while control counties are comprised of those which lie more than 100 kilometres away from the wildfire and where over the entire time span, no wildfires of any size has occurred within its 20-kilometre radius.

For birth outcomes, the pre- and post-treatment periods are specified below. The pre-treatment time window for each treated county is characterised as any month prior to pregnancy when pregnant women living in a county are not exposed to wildfires with total acres burned no less than 50, whose distance to the county is no larger than 20 km. Specifically, the 9-month time window before the start date of wildfires is considered as the post-treatment period while the 9-month time period prior to the post-treatment time window is defined as the pre-period. Therefore, each observation of birth outcomes in t months before the date of ignition during the post-treatment period indicates the corresponding pregnancy outcomes when the pregnant women are exposed to wildfires during the $(t+1)th$ month of gestation. The month 0 when a wildfire occurred corresponds to the maternal exposure to a wildfire during the first month of gestation. In particular, the start date of pregnancy is calculated by subtracting gestational age in months from the monthly date of birth. For BRFSS data, the pre-treatment period is a time window before the date of ignition when no wildfires which burned larger than or equal to 50 acres happened inside the 20-kilometre radius of the county. The analysis uses a 3-month time period before and after the start date of each wildfire as the pre- and post-treatment time window.

For each wildfire event, the estimation method uses the following canonical DD specification with distance as continuous treatment intensity.

$$H_{itf} = \alpha_0 + \beta_1 d_{if} + \beta_2 post_{tf} + \beta_3 d_{if} post_{tf} + \gamma X_{itf} + \varepsilon_{itf} \qquad (4\text{-}1)$$

[38] Appendix C.3 provides more detailed discussion on the relationship between AQI and distance from each county to wildfires, which gives supporting evidence on how the threshold of distance is chosen.

where i indicates individual and t is the monthly date of health outcomes in BRFSS or the start date of gestation in birth data. The subscript f denotes a specific large-scale wildfire and H_{itf} is the health outcomes of the elderly or birth outcomes. The continuous treatment intensity, d_{if}, is the distance between each county and wildfire location while $post_{tf}$ is a dummy variable equal to 1 for the post-treatment time window. Covariates X_{itf} represent individual characteristics which influence health outcomes of interest. In BRFSS data, X_{itf} includes age, gender, race, marital status, education level, employment status and whether having children in the household. In natality data, X_{itf} incorporates access to prenatal care; mother's education; tobacco use during pregnancy; medical risk factors for each pregnancy including diabetes, chronic hypertension and pregnancy-associated hypertension; plurality; maternal age; mother's race; fetal sex; total birth order and resident status. ε_{itf} is the error term. Robust standard errors are clustered at the county level to account for dependence between health outcomes within each county across time periods. The estimator β_3 represents the effect of each large wildfire on health outcomes of interest. The treatment effects are estimated for each of the five largest wildfires separately.

The causal identification requires a parallel trend assumption, where in the absence of wildfires, health outcomes for the treated and control groups would follow the same time trend. Therefore, a placebo test is performed where the corresponding time window one year before a wildfire is used on condition that over the whole placebo time period, the counties were not exposed to any wildfires which burned more than or equal to 50 acres and whose distance to the county is not greater than 20 km. The definition of the control group in the placebo test is the same as before.

4.4.2 Two-way Fixed Effects (TWFE) Regression Model

Analysis for the second research question identifies the causal effects of multiple large-scale wildfires on birth outcomes and health conditions of the elderly in a staggered adoption design. In order to estimate the treatment effect, the empirical question in this context diverges from the standard DD setup with two periods (pre- and post-treatment periods) and two groups (the treated and control groups) in section 4.4.1 on the grounds that there are more than two time periods and the treatments begin at different time points in the current setting. The empirical challenge is that the standard DD method cannot be applied to the context of variation in treatment timing for the reason that the post-treatment period cannot be identified in a control group (Goodman-Bacon, 2021).

For each dataset, the treatment group, control group, pre-treatment and post-treatment periods are defined below. For natality data, the treated group is made up of all counties located inside the 20-kilometre radius of wildfires. The identification requires that over the pre-treatment period, the treated counties should not be exposed to any wildfires that burned larger than or equal to 50 acres and whose distance to the treated counties is no more than 20 kilometres. The control group is defined as counties which were not exposed to wildfires of any size within its 20-kilometre radius during the entire time span from 1998 to 2004. The pre- and post-treatment periods are the same as those proposed in section 4.4.1. To avoid diluting the ATT through small-scale wildfires, analysis focuses on wildfires which burned more than 5000 acres[39].

For BRFSS data, we consider wildland fires which burned more than 50 acres rather than 5000, the latter of which induces insufficient sample size. The definitions of the treated and control groups are identical to those described in natality dataset. The time span of the pre-treatment and post-treatment periods are the same as those in 4.4.1.

The following TWFE regression specification is applied to the repeated cross-sectional natality data and BRFSS data:

$$H_{itc} = \alpha_t + \alpha_c + \beta D_{itc} + \gamma X_{itc} + \varepsilon_{itc} \quad (4\text{-}2)$$

where i and t have been defined previously in model (4-1) while c indicates the county individual i lives in. The α_t indicates the month fixed effect and α_c denotes the county fixed effect. The variable D_{itc} is a treatment dummy, which equals one if individual i living in county c receives treatment in month t. The setup is a staggered adoption design and once individuals are treated, the treatment status remains unchanged in the post-treatment period. The terms H_{itc}, X_{itc} and ε_{itc} have been defined in (4-1). Standard errors are clustered at the county level. The estimator of interest β denotes the overall causal effect of exposure to wildland fires on birth outcomes or health conditions of the elderly across counties over time. Finally, similar to the standard difference-in-differences method, the same placebo test for parallel trend assumption as specified in 4.4.1 is conducted for TWFE regression.

4.4.3 Difference-in-Differences with Heterogeneous Treatment Effects

In this section, we address the third sub-question on the causal effects of exposure to multiple wildfires on average health outcomes at the county level by applying the approach created by de Chaisemartin and D'Haultfœuille (2020). We employ a panel dataset with respect to average health outcomes in each county over time.

[39] A robustness test reduces the threshold of a large wildfire. See section 4.4.4 for more details.

As discussed in 4.4.2, the canonical DD method cannot be used when considering the causal effect of multiple wildfires and TWFE is an alternative approach. However, according to the DD decomposition theorem proposed by Goodman-Bacon (2021), the TWFE estimator is a weighted average of all possible DD estimators and the causal interpretation of TWFE estimates relies on two assumptions. Firstly, the average treatment effects should remain constant throughout the time period (Goodman-Bacon, 2021). Otherwise, the weights associated with TWFE estimator are negative, which induces problems when average treatment effects (ATE) are heterogeneous across groups or over time (de Chaisemartin and D'Haultfœuille, 2020). For example, the TWFE estimate can be negative when all ATEs are positive because of negative weights (de Chaisemartin and D'Haultfœuille, 2020). Secondly, variance-weighted average of the difference in counterfactual trends (VWCT) between timing groups and different time periods should equal zero, which is the parallel trend assumption when variation in treatment timing appears (Goodman-Bacon, 2021). Therefore, when treatment effects vary by group or over time, the TWFE estimate of the average treatment effect on the treated (ATT) is a biased estimate of ATT under the parallel trend assumption (de Chaisemartin and D'Haultfœuille, 2020). Given that the average treatment effects of wildfires on health outcomes are expected to change across counties and over time due to factors such as variation in prevention and mitigation strategies (Shonkoff *et al.*, 2011; Fisk, 2015; Parthum, Pindilli and Hogan, 2017; Koopmans *et al.*, 2020) as well as different distances between the point of origin of wildfires and counties, the use of TWFE would result in biased ATTs (de Chaisemartin and D'Haultfœuille, 2020) without a meaningful causal interpretation (Goodman-Bacon, 2021). To resolve the issue, we adopt an alternative empirical strategy proposed by de Chaisemartin and D'Haultfœuille (2020).

Following notation in de Chaisemartin and D'Haultfœuille (2020), suppose there are G counties and T time periods in the sample. For $t \in \{2, \dots, T\}$ and binary treatment status $(d, d') \in \{0,1\}$, the total number of observations with treatment status d' at month $t-1$ and d at month t is indicated by

$$N_{d,d',t} = \sum_{g:D_{g,t}=d,:D_{g,t-1}=d'} N_{g,t} \tag{4-3}$$

where $N_{g,t}$ is the number of observations in county g during month t and $D_{g,t}$ represents the treatment status in county g during month t.

de Chaisemartin and D'Haultfœuille (2020) suggest that under certain assumptions, an unbiased, consistent and asymptotically normal estimator of average treatment effect (ATE) of all switching units is

$$DID_M = \sum_{t=2}^{T} \left(\frac{N_{1,0,t}}{N_S} DID_{+,t} + \frac{N_{0,1,t}}{N_S} DID_{-,t} \right) \tag{4-4}$$

where

$$DID_{+,t} = \sum_{g:D_{g,t}=1,D_{g,t-1}=0} \frac{N_{g,t}}{N_{1,0,t}} \left(H_{g,t} - H_{g,t-1}\right) - \sum_{g:D_{g,t}=D_{g,t-1}=0} \frac{N_{g,t}}{N_{0,0,t}} \left(H_{g,t} - H_{g,t-1}\right), \tag{4-5}$$

$$DID_{-,t} = \sum_{g:D_{g,t}=D_{g,t-1}=1} \frac{N_{g,t}}{N_{1,1,t}} \left(H_{g,t} - H_{g,t-1}\right) - \sum_{g:D_{g,t}=0,D_{g,t-1}=1} \frac{N_{g,t}}{N_{0,1,t}} \left(H_{g,t} - H_{g,t-1}\right). \tag{4-6}$$

$$N_S = \sum\nolimits_{(g,t):t\geq 2,D_{g,t}\neq D_{g,t-1}} N_{g,t}$$

The variable $H_{g,t}$ denotes health outcomes of interest in county g during month t. The estimator $DID_{+,t}$ represents the joiners' (that switches from being untreated to treated) treatment effect while $DID_{-,t}$ indicates the leavers' (that changes from being treated to untreated) treatment effect. The variable N_S denotes the number of observations for all switching cells.

This paper focuses on $DID_{+,t}$, which is ATT in our context, since the study evaluates the causal impact of being exposed to wildfires on health outcomes compared with health conditions in the pre-treatment period when no wildfires happened. According to de Chaisemartin and D'Haultfœuille (2020), $DID_{+,t}$ is an unbiased estimator of ATT under the following assumptions. Firstly, the treatment status remains constant in county g during month t. Secondly, the potential outcomes and treatment status of different counties are mutually independent. Thirdly, the treatment sequence of a certain county is mean independent of the potential health outcomes without treatment. Fourthly, the method depends on the parallel trend assumption that the potential outcomes absent treatment follow the parallel trends over time across different counties. The analysis controls for covariates in model specifications, which include individual-specific characteristics X_{itf} as described in section 4.4.1. The estimator is asymptotically normal (de Chaisemartin and D'Haultfœuille, 2020). Standard errors are clustered by county.

Treatment dummies are created in the same way as those in the context of multiple wildfires in 4.4.2. The method uses two different definitions of pre-treatment period for both birth data and BRFSS. The first definition is that throughout the pre-treatment period of the treated counties, no wildfires of any sizes happened. The second one requires that over the entire pre-treatment time window, the counties were not exposed to any wildfires which burned the same number of acres as the wildfire in the post-treatment period. The second definition allows for smaller wildfires which are not expected to influence health outcomes in the pre-treatment period.

To test the assumptions of strong exogeneity and common trend, the placebo test examines whether treated counties diverge from counterfactual trends before switching treatment. Specifically, the placebo test compares variation in health outcomes from $t-2$ to $t-1$ between counties which are treated and untreated at time t (de Chaisemartin and D'Haultfœuille, 2020). The assumptions are satisfied if the placebo estimate is zero.

The ATT of wildfires on health outcomes vary with the size of wildfires and the distance between each county and wildfire location. In order to explore the heterogeneity of ATT by distance and fire size, the analysis uses 20 and 50 kilometres as thresholds for distance as well as 5 and 50 acres burned as cutoffs for wildfire sizes. Therefore, the study considers four different combinations of distance and wildfire sizes to estimate ATT of wildfires with total acres burned larger than the threshold of fire sizes on counties within a certain cutoff for distance of the point of origin of wildfires. Investigating smaller distances and larger wildfire sizes is impossible because after matching wildfire events to birth data or BRFSS, the number of treated counties appears to be small.

Finally, we estimate the dynamic treatment effects of wildfires on birth outcomes during trimesters of pregnancy using a follow-up estimation method put forward by de Chaisemartin and d'Haultfoeuille (2020) [40]. Specifically, this approach calculates the average treatment effect of having received treatment for the first time ℓ trimesters before by comparing changes in health outcomes between trimester $t-\ell-1$ and t for counties which were treated for the first time at $t-\ell$ relative to counties which were untreated from trimester 1 to t (de Chaisemartin and d'Haultfoeuille, 2020). The identifying assumptions require no anticipation, independent groups, strong exogeneity and common trends (de Chaisemartin and d'Haultfoeuille, 2020). In order to test for common trend assumption, the long-difference placebo estimator compares changes in health outcomes from trimester $t-2\ell-2$ to $t-\ell-1$ for counties treated for the first time at $t-\ell$ compared with counties untreated from trimester 1 to t (de Chaisemartin and d'Haultfoeuille, 2020). This placebo test checks whether treated and untreated counties experience parallel trends for $\ell+1$ trimesters (de Chaisemartin and d'Haultfoeuille, 2020). The dynamic analysis also controls for covariates X_{itf}.in model specifications. The state-specific linear time trend is included in the model to allow for various trends across states. The estimator is asymptotically normal (de Chaisemartin and d'Haultfoeuille, 2020). Standard errors are clustered by county. Likewise, the dynamic analysis employs 20 and 50 km as thresholds for distance as well as 5 and 50 acres burned as cutoffs for wildfire size.

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[40] The empirical estimation for both static and dynamic estimates are conducted by using "did_multiplegt" Stata module (Chaisemartin, D'Haultfoeuille and Guyonvarch, 2019) in Stata 17.

4.4.4 Robustness Check

We conduct several robustness checks for each approach, the results of which are shown in Appendix C.2 and C.3. For each method, the start date of pregnancy is calculated by subtracting gestational age in months from the monthly date of birth. Given the missing data of gestational age in birth certificates, a robustness check is performed whereby gestation starts 9 months prior to the date of birth while we assume no premature deaths occurred in this case.

As for TWFE in section 4.4.2, due to a small sample size of the treated groups in natality data, the robustness test in terms of birth outcomes reduces the threshold of a large wildfire and focuses on wildfires that destroyed more than 50 acres.

In terms of static $DID_{+,t}$ estimator in section 4.4.3, when studying the effect of wildfires on elderly's health outcomes, a robustness check employs different lengths of pre- and post-treatment time windows, i.e., 2 and 3 months before and after the wildfires. Additionally, when investigating dynamic treatment effects, the study examines whether ATT is robust to the inclusion of state-specific linear trend in the model specification.

4.5 Empirical Results

This section presents the causal effect of wildfires on birth outcomes and then shows the results for older people's health outcomes. For each outcome of interest, we analyse findings for three sub-questions: the causal effect of each of the five largest wildfires on health, the causal impact of multiple large wildfires on health and the causal influence of multiple wildfires on health at the county level. In addition, we present the dynamic effect of wildfires on birth outcomes during trimesters of gestation. Throughout the whole section, we only analyse ATT estimates which do not violate the parallel trend assumption.

4.5.1 Birth Outcomes

4.5.1.1 The Causal Effect of the Five Largest Wildfires on Birth Outcomes

The first research sub-question on the causal impact of the five largest wildfires, which are recorded in FIRESTAT, on birth outcomes estimates ATT by applying the difference-in-differences method with distance used as a treatment intensity. The time period in this estimation method runs from 1998 to 2004. The beginning date of pregnancy is computed by subtracting gestational age from date of birth. Results for the parallel trend test are displayed in Table C-3 and Table C-4. Table 4-1 demonstrate the ATT of each of the five largest wildfires on birth outcomes related to birth weight and gestational age. We initially expect that maternal exposure to wildfires results in lower birth weight and shorter gestational age. As seen from the table, the majority of the ATT estimates appear to be statistically insignificant with small magnitude. In general, being exposed to wildfires is not found to negatively affect most pregnancy outcomes. In particular, column 2 in Table 4-1 demonstrates that prenatal exposure to the second largest wildfire significantly increased the likelihood of having low birth weight infants slightly, which meets our expectations, but the magnitude of the effect is close to zero. Table 4-2 present the ATT of each of the five largest wildfires on birth defects and the presumption is that newborns tend to develop congenital disorders following maternal exposure to wildfires. Column 2 in Table 4-2 shows that the impact of the largest wildfire on other circulatory or respiratory anomalies is statistically significant and positive, but the effect is also close to zero. This suggests that maternal exposure to the wildfire of the largest size led to a minor increase in the likelihood of other circulatory or respiratory diseases among babies. Additionally, the probability of developing other congenital anomalies for neonates were not significantly affected when mothers were exposed to any of the five largest wildfires during pregnancy.

A robustness check calculates the start date of gestation as 9 months prior to date of birth. Table C-5 and Table C-6 present the placebo test results for common trend assumption associated with the robustness test. Table C-1 shows the ATT of each large wildfire on pregnancy outcomes in terms of birth weight and the length of gestation, while the ATT of each large wildfire on congenital malformations are shown in Table C-2. The findings demonstrate that the largest wildfire led to a significant but minor decrease in macrosomia, which is consistent with the previous result of an increase in low birth weight. No significant estimates of ATT are found for all other birth outcomes.

Overall, all these findings indicate that as expected, mother's exposure to the five largest wildfires resulted in a slight increase in low birth weight and the possibility of getting other circulatory or respiratory malformations among infants, but the magnitude of the effects appears to be negligible.

Table 4-1. The effect of the five largest wildfires on birth weight and gestational age

Birth outcomes	(1) Birth weight	(2) Low birth weight	(3) Macrosomia	(4) Gestational age	(5) Preterm birth
The largest wildfire					
ATT	-.00556 (.00819)	-.000000319 (.00000381)	-.00000604 (.00000319)	.0000260 (.0000393)	-.00000614 (.00000570)
Number of observations	418218	418218	418218	418479	418479
The second largest wildfire					
ATT	-.00902 (.00715)	.00000608* (.00000297)	-.00000345 (.00000337)	.0000161 (.0000446)	-.00000131 (.00000476)
Number of observations	827946	827946	827946	828210	828210
The third largest wildfire					
ATT	.0197 (.0183)	-.00000733 (.00000780)	-.00000193 (.00000674)	.000195 (.000105)	-.0000163 (.0000138)
Number of observations	232709	232709	232709	232827	232827
The fourth largest wildfire					
ATT	.0116 (.00616)	-.00000313 (.00000206)	.00000227 (.00000358)	.0000212 (.0000275)	-.000000439 (.00000325)
Number of observations	1177894	1177894	1177894	1178678	1178678
The fifth largest wildfire					
ATT	-.0108 (.0211)	.00000414 (.00000753)	-.00000139 (.0000130)	.00000479 (.0000523)	-.0000119 (.00000733)
Number of observations	206148	206148	206148	206243	206243

Note. The dependent variables include birth weight, a dummy for low birth weight, a dummy for macrosomia, gestational age and an indicator for preterm birth. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. The stars represent significance levels at the following p-values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is calculated as gestational age subtracted from date of birth. All estimates satisfy the parallel trend assumption.

Table 4-2. The effect of the five largest wildfires on congenital anomalies

	(1)	(2)	(3)	(4)
Birth outcomes	Heart malformations	Other circulatory/respiratory anomalies	Omphalocele	Cleft lip
The largest wildfire				
ATT	-.00000153	.000000970*	.000000535	-.000000470
	(.000000907)	(.000000428)	(.000000341)	(.000000383)
Number of observations	351739	351739	396873	396873
The second largest wildfire				
ATT	3.89e-09	-.000000102	.000000510	-.000000226
	(.000000380)	(.000000147)	(.000000267)	(.000000315)
Number of observations	822683	822683	822683	822683
The third largest wildfire				
ATT	4.33e-08	-.000000421	.000000947	.000000516
	(.00000106)	(.00000153)	(.000000671)	(.000000981)
Number of observations	215306	215306	231439	231439
The fourth largest wildfire				
ATT	.000000196	.000000994	1.72e-08	1.07e-08
	(.000000390)	(.000000971)	(.000000168)	(.000000361)
Number of observations	1175474	1175474	1175474	1175474
The fifth largest wildfire				
ATT	.000000194	.00000251	-.00000163*	.000000465
	(.00000202)	(.00000213)	(.000000675)	(.00000128)
Number of observations	203442	203442	203442	203442

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth. All estimates satisfy the parallel trend assumption.

4.5.1.2 The Causal Effect of Multiple Large Wildfires on Birth Outcomes

This section looks at the combined causal impact of multiple large wildfires which burned no smaller than 5000 acres on pregnancy outcomes by using the TWFE estimator. Table 4-3 summarises the findings by applying TWFE regression. As shown in the table, the probability that an individual was born preterm significantly increased by 0.00413 after maternal exposure to large wildfires, whereas the likelihood of developing omphalocele among infants is not significantly affected by wildfire exposure. Overall, unlike our conjecture, these results suggest that maternal exposure to multiple large wildfires had no significant effect on congenital malformations, but reduced the length of gestation.

The robustness test uses the monthly date 9 months ahead of date of birth as the beginning month of gestation. Findings are given in Table C-7. Due to the limitation of the sample size, the robustness test focuses on wildfires which ignited at least 50 acres. We find that there is a significant decline of 0.00722 in the likelihood of low birth weight, which appears to contrast with the findings that wildfires lead to low birth weight in the preceding literature. All other birth outcomes are not significantly influenced by multiple large wildfires.

As discussed in section 4.4.3, the treatment effect of wildfires can be heterogeneous across counties or over time and TWFE estimate of ATT is biased if the assumption of constant treatment effect is violated. Thus, the study relaxes the constant treatment effect assumption underlying TWFE and assesses the robustness of ATT estimates by using the $DID_{+,t}$ estimator suggested by de Chaisemartin and D'Haultfœuille (2020). Likewise, the estimation employs the two definitions of the start date of pregnancy specified above. Nevertheless, no significant effects of wildfires on any birth outcomes are identified.

Table 4-3. The effect of multiple large wildfires (burned at least 5000 acres) on birth outcomes.

Birth outcomes	Preterm birth	Omphalocele
ATT	.00413***	-.00000194
	(.000705)	(.0000252)
Number of observations	15965642	15801246
Parallel trend	Yes	Yes

Note. The dependent variables include an indicator for preterm birth and a dummy variable for omphalocele. Standard errors are clustered by county. The covariates in TWFE regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is estimated to be gestational age subtracted from date of birth. All estimates satisfy the parallel trend assumption.

4.5.1.3 Empirical Analysis at the County Level

The third sub-question investigates the aggregate causal impact of wildfires of various sizes on neonatal health at the county level using the $DID_{+,t}$ estimator developed by de Chaisemartin and D'Haultfœuille (2020) to calculate ATT. Table 4-4 and Appendix C.2.3 show the estimation results of $DID_{+,t}$ estimates. As mentioned in 4.4.3, findings are presented under two different definitions of pre-treatment period. To explore the heterogeneity of the ATT estimates along different dimensions of wildfire sizes and distances from each county to wildfires, this research calculates the $DID_{+,t}$ estimator by using the thresholds of wildfire sizes at 5 or 50 acres burned as well as employing the distance cutoffs at 20 or 50 kilometres. Therefore, the $DID_{+,t}$ estimators are estimated under four different scenarios, each of which corresponds to one combination of wildfire size and distance cutoff.

Specifically, under the first definition of pre-treatment period, no wildfires of any sizes happened throughout the pre-treatment period of the treated counties. When the start date of the gestation is defined as gestational age subtracted from date of birth, Table C-8 reveals that maternal exposure to the wildfires which burned at least 5 acres result in a significant increase in gestational age of 0.112 for counties within the 20-kilometre radius of wildfires. As shown in Table 4-4, Table C-8 and Table C-9, the study cannot identify any significant impact of wildfires on other neonatal health outcomes for any other cutoffs of distances and wildfire size. The robustness of ATT to the missingness of gestational age is examined by using 9 months before date of birth as the time index, the findings of which are summarised as follows. Table C-11 demonstrates that there is a slight decrease in the possibility of omphalocele and cleft lip for counties within the 50-kilometre distance to wildfires which destroyed at least 5 acres. Nevertheless, no significant effects of wildfires on any other birth outcomes are detected.

The second definition of the pre-treatment period relaxes the above-mentioned restriction by requiring that over the entire pre-treatment time window, counties were not exposed to wildland fires with the same number of total acres burned as those in the post-treatment period. Under this context, the analysis fails to discover any significant ATT estimates when using gestational age subtracted from date of birth as the beginning date of pregnancy. In the robustness check, the start date of gestation is calculated as 9 months before date of birth. Similar to previous findings using the first assumption of the pre-treatment period, Table C-13 shows that wildfires that burned at least 50 total acres result in a significant but slight reduction in the probability of developing cleft lip in counties within the 50-kilometre radius of wildfires. For all other ATT estimates, wildfires of other sizes have a null effect on birth outcomes in counties within either 20- or 50- kilometre distance from wildfires.

Table 4-4. The effect of wildfires on birth outcomes at the county level with wildfire size >=5 acres and distance<=50 km (under pre-period definition 1).

	Birth Weight and Length of Gestation				
Birth outcomes	Birth weight	Low birth weight	Macrosomia	Gestational age	Preterm birth
ATT	8.774 (9.710)	.00141 (.00476)	.00452 (.00512)	.0215 (.0482)	.00171 (.00615)
Number of observations	5606	5606	5606	5606	5606
Parallel trend	Yes	Yes	Yes	Yes	Yes
	Congenital Anomalies				
Birth outcomes	Heart malformations	Other circulatory or respiratory anomalies	Omphalocele	Cleft lip	
ATT	.0000396 (.000770)	.0000835 (.000754)	-.000118 (.000283)	-.000353 (.000528)	
Number of observations	5379	5379	5606	5606	
Parallel trend	Yes	Yes	Yes	Yes	

Note. The dependent variables include birth weight, a dummy for low birth weight, a dummy for macrosomia, gestational age, an indicator for preterm birth as well as dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. The covariates in TWFE regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. Throughout the pre-treatment period of the treated counties, no wildfires of any sizes happened. The start date of the gestation is defined as gestational age subtracted from date of birth. The starts represent significance levels at the following p-values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The last row shows whether the parallel trend assumption is satisfied. Standard errors are clustered by county.

4.5.1.4 Dynamic Effects of Wildfires on Birth Outcomes

Finally, the fourth research question investigates the dynamic causal effect of wildfires on birth outcomes for pregnant women exposed to wildfires during any trimester of pregnancy. First, we employ gestational age subtracted from date of birth as the month index. The main model specification accounts for the state-specific linear time trend, while as a robustness test, the model excludes different trends across states. The empirical results are set out in Appendix C.2.4.

In contrast to most existing literature, the following evidence suggests that there is a clear trend of increase in birth weight following wildfires of different sizes. According to Figure C-9, Figure C-13, and Figure C-19, closer inspection of results shows that for counties located within the 20-kilometre radius of wildfires which burned at least 5 and 50 acres as well as those inside the 50-kilometre distance to wildfires with no smaller than 5 acres destroyed, there is a significant decline in the probability of low birth weight of 0.01 following prenatal exposure to wildfires. However, the trimesters during which pregnant women were susceptible to wildfires appear to be inconsistent for different wildfire sizes and distance cutoffs. Moreover, as can be seen from Figure C-15, the results demonstrate a significant rise of 0.01 in the probability of fetal macrosomia if mothers were exposed to wildfires with no less than 50 total acres destroyed during the last trimester in counties within the 20-km distance to wildfires. All these results are robust to the exclusion of state-specific linear trend. To sum up, we find evidence that maternal exposure to wildfires during the last trimester increased the probability of delivering a macrosomic infant.

Figure C-21 suggest a slight but significant rise of 0.02% in the possibility of giving birth to infants with omphalocele for maternal exposure to wildfires over the first trimester for counties within 50 km of wildfires which burned no less than 50 acres, which is similar to the finding derived from robustness test in Figure C-20 for counties within the same radius of wildfires with at least 5 burned acres. The result of the robustness check in Figure D-2 indicates that wildfires led to a significant but minor increase in developing cleft lip among babies if pregnant women were exposed to wildfires over the third trimester in counties within 50 kilometres of wildfires which ignited no smaller than 5 acres. All in all, pregnant women exposed to wildfires during the first trimester tended to give birth to infants with congenital malformation.

In another robustness check, we adopt 9 months ahead of date of birth as the time index. In general, the ATT estimates using such an alternative definition of the start month of pregnancy are similar to those reported above. More specifically, as presented in Figure C-23, there is a significant but slight increase of 0.03% in the likelihood of developing omphalocele for maternal exposure during the first trimester for counties within 50-km of wildfires which burned at least 5 acres. In addition, from Figure C-25 we can see that the counties that lie within 50-km of wildfires with no fewer than 50 burned acres witnessed a small increase of 0.05% in the possibility of delivering a baby with heart malformations when maternal exposure to wildfires occurred within the second trimester. In Figure C-22, we observe a slight rise of 0.06% in the probability of developing cleft lip among neonates for prenatal exposure over the second trimester when we do not include the state-specific trend. After thinking about these robustness test results, we remain with the conclusion that prenatal exposure to wildfires slightly increased the risk of birth defects for neonates.

4.5.2 Health Outcomes of the Elderly

Turning to the elderly aged 65 and above who are also vulnerable to the negative impact of wildfires, we first investigate the causal impact of each of the five largest wildfires from FIRESTAT data on health outcomes from 2000 to 2010 by using the canonical DD method. The ATT estimates are reported in Table 4-5. In line with the expectation that wildfire exposure induces asthma symptoms, the findings demonstrate that senior citizens are 0.06% more likely to suffer from asthma symptoms more than twice a week following exposure to the second largest wildfire. Nonetheless, none of the other health outcomes appears to be significantly affected by exposure to massive wildfires.

The analysis continues with studying the causal impact of multiple large wildfires, which destroyed no fewer than 50 acres, on health status of older people by using TWFE regression. In Table 4-6, the probability of suffering from asthma symptoms more than twice a week is significantly raised by 0.467 after older people were exposed to wildfires. By contrast, wildfire exposure had a null impact on other health outcomes among senior citizens. These results are consistent with the causal effect of the five largest wildfires on health conditions of older people.

In order to correct for the treatment effect heterogeneity across counties and time periods, the estimation results using the method suggested by de Chaisemartin and D’Haultfœuille (2020) are summarised in Table 4-7. The multiple wildfires significantly increased the number of days mental health is not good by 2 days per month, indicating a negative influence on psychological health including stress, depression and emotional problems among older people.

Finally, turning to the overall causal impact of multiple wildfires on the elderly’s health at the county level, the method by de Chaisemartin and D’Haultfœuille (2020) is adopted to take into account the heterogeneity of the treatment effects among various counties or across time periods. The study considers time windows of both 2 and 3 months before and after the wildfires under two different definitions of the pre-treatment period.

Results based on the first definition of the pre-treatment period, which states that no wildfires of any sizes happened in the pre-period, are discussed below. When the time period covers 3 months before and after wildfire events, there is no sufficient sample in BRFSS for counties whose distance to wildfires of different sizes is no more than 20 kilometres. Surprisingly, the wildfires have a null impact on all health outcomes for counties located within the 50-kilometre radius of wildfires of different sizes. As for the pre- and post-treatment time window of 2 months, the sample size is inadequate to carry out estimation for counties within the 20-kilometre distance to wildfires of all sizes. As expected, Table 4-8 demonstrates that individuals residing in counties within the 50-kilometre radius of wildfires which burned at least 50 total acres were significantly less likely to participate in physical activities.

Under the second definition of the pre-treatment period, during the pre-period, counties were not exposed to any wildfires with the same threshold of size as those in the post-period. When considering the pre- and post-period of 2 and 3 months, results suggest that older people’s health outcomes were not significantly influenced by wildfire exposure.

Table 4-5. The effect of the five largest wildfires on health outcomes of the elderly

Health outcomes	(1) Number of days physical health not good	(2) Number of days mental health not good	(3) Participate in exercises	(4) Often have asthma symptoms
The largest wildfire				
ATT	.00202 (.00141)	-.00173 (.00123)	-.0000748 (.0000671)	-.000175 (.000452)
Number of observations	2150	2182	2221	77
The second largest wildfire				
ATT	-.000858 (.00119)	-.00134 (.000806)	.0000501 (.0000559)	.000641* (.000294)
Number of observations	4060	4131	4204	58
The third largest wildfire				
ATT	.000947 (.00114)	.000389 (.000624)	.0000424 (.0000402)	-.000187 (.000652)
Number of observations	5069	5159	5286	57
The fourth largest wildfire				
ATT	.00226 (.00139)	.000787 (.00114)	-.000103 (.0000562)	.000258 (.000268)
Number of observations	5506	5589	5692	101
The fifth largest wildfire				
ATT	-.000906 (.000967)	-.000874 (.000564)	-.0000300 (.0000506)	-
Number of observations	5733	5814	5922	-

Note. The dependent variables include in the last 30 days, the number of days physical health not good, the number of days mental health not good, a dummy for whether a person took part in any physical activities and a dummy for whether an individual had any symptoms of asthma more than twice a week. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The empty cells indicate insufficient sample size for estimation. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All estimates satisfy the parallel trend assumption.

Table 4-6. The effect of multiple large wildfires (which burned at least 50 acres) on health outcomes of the elderly.

Health outcomes	(1) Number of days physical health not good	(2) Participate in exercises	(3) Often have asthma symptoms
ATT	-.190 (.622)	.0114 (.0230)	.467* (.184)
Number of observations	732019	783165	10359
Parallel trend	Yes	Yes	Yes

Note. The dependent variables include in the last 30 days, the number of days physical health not good, a dummy for whether a person took part in any physical activities and a dummy for whether an individual had any symptoms of asthma more than twice a week. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The starts represent significance levels at the following p-values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4-7. The effect of multiple large wildfires (which burned at least 50 acres) on health outcomes of the elderly using an alternative estimator proposed by de Chaisemartin and D'Haultfœuille (2020).

Health outcomes	(1) Number of days physical health not good	(2) Number of days mental health not good	(3) Participate in exercises
ATT	-1.868 (2.049)	2.073** (.645)	.0738 (.0831)
Number of observations	103613	105263	107812
Parallel trend	Yes	Yes	Yes

Note. The dependent variables include in the last 30 days, the number of days physical health not good, the number of days mental health not good and a dummy for whether a person took part in any physical activities. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The estimation is carried out using "did_multiplegt" command in Stata. The starts represent significance levels at the following p-values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4-8. The effect of wildfires on health outcomes at the county level with wildfire size >=50 acres and distance<=50 km (using pre-period definition 1 and a 2-month time window before and after treatment).

Health outcomes	(1) Number of days physical health not good	(2) Participate in exercises	(3) Often have asthma symptoms
ATT	-2.203 (6.340)	-.516* (.256)	-.0695 (.350)
Number of observations	80	80	80
Parallel trend	Yes	Yes	Yes

Note. The dependent variables include in the last 30 days, the number of days physical health not good, a dummy for whether a person took part in any physical activities and a dummy for whether an individual had any symptoms of asthma more than twice a week. Standard errors are clustered by county. The covariates include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The estimation is carried out using "did_multiplegt" command in Stata. The starts represent significance levels at the following p-values: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The last row shows whether the parallel trend assumption is satisfied.

4.6 Discussion

The link between wildfire exposure and adverse health outcomes of neonates as well as adults has been examined in past literature. The first objective of this paper is to evaluate the causal impact of maternal exposure to wildfires on birth outcomes. On the question of the causal influence of maternal exposure to each of the five largest wildfires on health of the newborns, this study finds that the largest wildfire resulted in a slightly higher likelihood of other circulatory or respiratory anomalies while the second most sizeable wildfire minimally increased the probability of low birth weight, but the magnitude of both effects is close to zero. The adverse impact of wildfires on congenital respiratory malformations is consistent with Requia *et al.* (2021) while the results regarding the effect of wildfires on low birth weight support evidence from previous research by Jones and McDermott (2021), Amjad *et al.* (2021), Abdo *et al.* (2019) and Holstius *et al.* (2012). As for estimating the causal impact of multiple immense wildfires which burned more than 5000 acres on neonatal health, the most remarkable finding is that the probability of preterm birth was modestly increased following massive wildfires, which corroborates similar results discussed in Jones and McDermott (2021), Amjad *et al.* (2021), Abdo *et al.* (2019) and Heft-Neal *et al.* (2022). It is surprising to notice that at the county level, our results indicate that maternal exposure to wildfires led to a minor decrease in the likelihood of developing omphalocele and cleft lip as well as a slight rise in gestational age. The first known research in terms of how wildfires affect birth defects by Requia *et al.* (2021) demonstrates that air pollution emitted from wildfires results in higher incidence of cleft lip, but the pollutants have no effect on birth defects of the digestive system. The current study finds evidence that wildfires increased the risk of cleft lip slightly if mothers were exposed to wildfires during the third trimester in section 4.5.1.4. Another finding of our study obtained by estimating dynamic treatment effects shows that at the county level, wildfires had a positive effect on birth weight and incurred a higher possibility of macrosomia when pregnant women were exposed to wildfires during any trimester of pregnancy for different wildfire sizes and distances from wildfires. Although such findings are inconsistent with those in individual-level analysis, they are in agreement with evidence obtained by O'Donnell and Behie (2015), who suggest that maternal stress caused by wildfires induces macrosomia. Remarkably, our study finds evidence that maternal exposure to wildfires during the first trimester can induce a higher likelihood of omphalocele at the county level. Unfortunately, the current analysis does not detect any effects on other birth outcomes, so the evidence is not as strong as is commonly believed. Compared with our research, Requia *et al.* (2021) and O'Donnell and Behie (2015) employ a more complete birth dataset which includes almost all births in local areas and covers a longer time span, although the logistic regression and analysis of variance they adopt respectively suffer from confounding bias and do not have a causal interpretation.

It is not the task of this paper to examine the underlying causal pathways for the effect of wildfire exposure on adverse birth outcomes. Thus, we discuss possible underlying mechanism for our results based on earlier findings. In general, the potential mechanism underlying the detrimental impact of wildfires on neonatal health can be attributed to toxic air pollutants released from wildfires (Jayachandran, 2009; Holstius *et al.*, 2012; Amjad *et al.*, 2021; Requia *et al.*, 2021) and maternal mental health problems induced by wildfire exposure (Holstius *et al.*, 2012; Amjad *et al.*, 2021). Specifically, the first possibility suggests the following biological mechanisms through which particulate matter has a detrimental effect on fetal growth. Firstly, the particulate matter emitted from wildfires leads to oxidative stress, which further causes DNA damage (Kannan *et al.*, 2006) while the polycyclic aromatic hydrocarbons (PAHs) taken in by particulate matter result in a surge in DNA adducts, both of which cause low birth weight and intrauterine growth restriction (Kannan *et al.*, 2006). Secondly, particulate matter exposure is correlated with pulmonary and placental inflammation (Kannan *et al.*, 2006). Thirdly, particulate matter can elevate blood pressure of pregnant women (Kannan *et al.*, 2006). Other mediating factors include coagulation and impairment of endothelial function, which is related to preterm birth and intrauterine growth restriction (Kannan *et al.*, 2006). In addition, particulate matter can induce birth defects (including cardiac defects, orofacial defects, omphalocele, nervous system anomalies as well as musculoskeletal and chromosomal anomalies) through: oxidative stress and DNA damage, placental inflammation which leads to inadequate transport of oxygen and nutrition to foetus as well as epigenetic alterations (Teng, Wang and Yan, 2016).

The second understudied explanation believes that maternal stress during wildfires leads to adverse birth outcomes (Holstius *et al.*, 2012). The stress can be triggered by stressors such as property damage, fears of the safety of the foetus and concern over negative health impact of wildfires (Brémault-Phillips *et al.*, 2020). The first possibility underlying this interpretation is that epigenetic changes associated with maternal stress can damage neonatal health (Murphy *et al.*, 2021). The second possibility is that maternal stress can incur unhealthy behaviours such as sleep problems and loss of appetite (Dancause *et al.*, 2011). Thirdly, maternal stress raises glucocorticoids which can detrimentally influence birth weight and the length of pregnancy (Dancause *et al.*, 2011). Another explanation indicates that maternal stress gives rise to higher levels of corticotrophin-releasing hormones (CRH), adrenocorticotrophic hormone (ACTH) and cortisol, which can induce prematurity (Torche, 2011). In particular, the evidence that wildfires resulted in a rise in birth weight and a larger likelihood of macrosomia at the county level is in accord with O'Donnell and Behie (2015). O'Donnell and Behie (2015) infer that maternal stress elevates blood glucose levels through stimulating the secretion of cortisol levels, increased food intake and fewer physical activities, which makes intrauterine environment more glycaemic and increases the incidence of macrosomia. The increased macrosomia and birth weight is also consistent with similar findings by Oyarzo *et al.* (2012), which discovers that earthquake-related maternal stress is correlated with a higher possibility of macrosomia.

The second research question in this paper sought to determine the causal effect of wildfire exposure on health status among older people aged 65 and above. In this analysis, the elderly exposed to the second largest wildfire or multiple sizeable wildfires are found to suffer from asthma symptoms more frequently, which is in line with findings in previous studies (Liu *et al.*, 2015; Reid *et al.*, 2016; Walter *et al.*, 2020). Another notable finding at individual level reveals that the elderly experienced mental health problems for a longer time period after exposure to multiple massive wildfires, which confirms the negative relationship between wildfires and psychological well-being put forward by To, Eboreime and Agyapong (2021) and Caamano-Isorna *et al.* (2011). In addition, at the county level, older people participated in fewer physical activities within two months following wildfire exposure, which is consistent with Wasiak *et al.* (2013), Doubleday *et al.* (2021), Laumbach (2019) and Dix-Cooper *et al.* (2014).

We can only speculate on why wildfire exposure induced poorer health conditions of older people, which is beyond the scope of our research. Therefore, we base our explanation for underlying mechanism on other relevant studies. According to toxicological research, a plausible explanation for experiencing asthma symptoms more regularly after wildfires is that particulate matter released from wildfires causes oxidative stress and pro-inflammatory responses (Nakayama Wong *et al.*, 2011). Additionally, extreme heat and humidity caused by wildfires can stimulate airway C-fibre nerves, which induces asthma symptoms (Bernstein and Rice, 2013; Walter *et al.*, 2020). In terms of mental health issues triggered by wildfires, depression and post-traumatic stress disorder are triggered by the following risk factors: concern over one's own life and lives of the loved ones, loss of property as well as inadequate help from families, friends and the government (To, Eboreime and Agyapong, 2021). Moreover, anxiety is associated with emotional disturbance due to uncertainty about losses of and damage to possessions, loved ones and employment (To, Eboreime and Agyapong, 2021). Ecological grief can also lead to emotional distress (To, Eboreime and Agyapong, 2021). Finally, a decline in physical activities can be caused by burn injuries because of limitations in activities (Wasiak *et al.*, 2013), suggestions from the US Environmental Protection Agency and others during wildfires (Dix-Cooper *et al.*, 2014; Laumbach, 2019) and an enhanced public awareness of the risks of wildfire smoke exposure due to more effective public health messaging over time (Doubleday *et al.*, 2021).

Contrary to expectations, we obtain a number of null effects of wildfires on birth outcomes. Such null effects are in agreement with Melody *et al.* (2019), who find that there is no significant relationship between maternal exposure to coal mine fires and birth outcomes including birth weight, preterm birth and small for gestational age. Melody *et al.* (2019) also do not detect any significant correlation between exposure windows and neonatal health. Likewise, O'Donnell and Behie (2015) argue that wildfires have no impact on birth weight of females and gestational age for either gender. Another paper which also reports null results by Xiong *et al.* (2008) claims that post-traumatic stress disorder and depression induced by Hurricane Katrina are not significantly correlated with low birth weight and preterm birth. These three papers give possible explanations for their null effects, which also apply to our research.

Firstly, the null effects are likely caused by inadequate statistical power, but the available sample in the data is representative of the population in the relevant counties with a large population density. Such a limitation is also emphasised by Melody *et al.* (2019) and Xiong *et al.* (2008) in their research. Specifically, this study is unable to obtain restricted-use birth data files, so the sample is restricted to counties with a population size no smaller than 100,000. As a result, the number of US counties exposed to wildfires is relatively small, which limits the power of the tests, because some wildfires are more likely to occur in counties with lower population density. For example, in northern California where the population size is small, the dense forests are underexplored by humans and wildfires are often unnoticed with abundant vegetation which keeps wildfires blazing (Li and Banerjee, 2021). The densely populated regions are more likely to witness fewer wildland fires owing to increased fire suppression (Huang, Wu and Kaplan, 2015). The small sample of the treated units in the data implies that all the findings with respect to birth outcomes in this study should be interpreted with caution. Secondly, it seems plausible to assume that the null effects result from high parental investment to improve fetal health which acts as a buffer against the adverse impact of wildfires (O'Donnell and Behie, 2015). In addition, this paper speculates that pregnant women may receive enough support and care from families, the government and assistance programs which mitigates the detrimental impact of wildland fires on health of the newborns (Xiong *et al.*, 2008). Thirdly, pregnant women may take the necessary precautions to lessen the negative effect of wildfires on neonatal health after receiving advice and education from the government, public health service, healthcare providers or news agencies. For example, Centres for Disease Control and Prevention suggests that pregnant women pay attention to the guidance about exercise and stay outdoors as well as protect themselves from ash (National Center for Environmental Health, 2021).

However, without available data, this research is unable to test the hypothesis in terms of higher maternal glucose levels, maternal investment in fetal health, assistance received by mothers as well as precautionary measures taken by pregnant women. This discussion sketches out an agenda for future research which discovers similar findings and has access to the above-mentioned variables of interest: investigating factors which mitigate the adverse birth outcomes of wildfires.

4.7 Conclusion

The present study was designed to determine the causal effect of wildfires on birth outcomes and health outcomes of the elderly across US counties. The results in terms of pregnancy outcomes show that the largest wildfire slightly increased the risk of other circulatory or respiratory anomalies while the second largest wildfire led to a marginal rise in the probability of low birth weight, although the effects are minimal. In addition, the multiple large wildfires which burned more than 5000 acres moderately raised the risk of prematurity. Moreover, at the county level, maternal exposure to wildfires resulted in a small decline in the possibility of getting omphalocele and cleft lip among infants as well as a minimal increase in the length of pregnancy. Furthermore, both birth weight and risk of giving birth to macrosomic infants increased if mothers were exposed to wildfires in any trimester of pregnancy while the probability of developing omphalocele among neonates is raised due to prenatal exposure to wildfires during the first trimester of gestation. The major findings regarding older populations indicate that older people's exposure to the second largest wildfire or multiple massive wildfires led to frequent occurrence of asthma symptoms while the number of days the elderly experienced psychological problems is increased following exposure to multiple large wildfires. Furthermore, the county-level analysis reveals a reduction in physical activities for senior citizens induced by wildfires.

A major limitation of the present study is that it uses public use natality data, which exclude counties with a population size smaller than 100,000, due to unavailability of the complete restricted-use birth data files. Future research could use a more complete birth dataset with individuals across all US counties to increase the statistical power of the empirical methods. The second issue that was not addressed in this paper is that measures of maternal psychological health are unavailable in birth data. Further work is needed to fully understand how wildfire exposure could influence birth outcomes via maternal mental health problems.

An implication of these findings is that vulnerable populations including the older population group and pregnant women are at risk for the negative health consequences of wildfires. In order to minimise the health hazards caused by wildfires to susceptible populations, a key policy priority should therefore be to make preparations to provide enough health or social care services and other support for pregnant women and older people in case of wildfires. In addition, although global warming is expected to increase the frequency and intensity of wildfires in the future, effective wildfire management strategies can prevent the spread of wildfires, minimise losses of lives and property (Calkin *et al.*, 2014) as well as abate the adverse health impact of wildfires.

Chapter 5 Conclusion

5.1 Introduction

Crisis events can revolutionarily transform socioeconomic conditions in the world and presents a public health challenge. For example, the COVID-19 pandemic as a health and economic crisis has had a devastating effect on the global economy after the 2008 Great Recession (Bagchi *et al.*, 2020), while it could seriously damage physical and mental health in both the short and long term (Hossain *et al.*, 2020; Raveendran, Jayadevan and Sashidharan, 2021). Natural disasters could induce psychological distress, psychiatric illness and risk-taking behaviour (Esterwood and Saeed, 2020). Given the increased severity and frequency of natural disasters, there has been a rise in economic loss caused by natural disasters from 1960 to 2014 (Coronese *et al.*, 2019) and natural disasters led to financial hardships (Johar *et al.*, 2022). Furthermore, besides increasing income poverty (Sumner and Wolcott, 2009), financial crisis negatively influenced psychological well-being of the population (Volkos and Symvoulakis, 2021), although some research suggests that economic recession could improve health (Ruhm, 2000).

Evidence also suggests that the effects of disasters on economic indicators are heterogeneous for different types of disasters. For example, natural disasters had the largest negative effect on welfare, followed by wars and economic disasters, whereas in the long term, natural disasters and wars had a positive impact on GDP growth and welfare (Nishiyama *et al.*, 1991). By contrast, terrorist attacks and technological disasters promotes international trade among developed nations (Oh, 2015).

The purpose of this thesis is to quantify the causal effect of three different types of crisis events on health and economic outcomes. More specifically, the thesis is designed to respectively investigate the causal effect of SARS, fiscal austerity and wildfire exposure on Chinese stock market performance, older people’s health conditions, as well as health outcomes of newborns and the elderly. By studying the causal influence of the three crisis events, there are several important areas where the thesis as a whole makes an original contribution to. First, the thesis has been one of the first attempts to examine the effect of crisis events on a broader range of health and economic outcomes. Second, relative to the previous research, this thesis exploits data with more detailed information on measures of exposure to crisis events to enhance precision of estimates of the causal effect. Third, the analyses are carried out at the micro level rather than at the industry or country level in the preceding literature, so that this thesis can capture heterogeneity in disaster preparedness among firms or respondents as well as can control for other individual and firm specific characteristics. Forth, to avoid recall bias because of retrospectively collected data used in existing research, this thesis uses data from health surveys or birth certificates which are gathered at a certain collection interval. Fifth, the thesis pays attention to the effect of fiscal austerity and wildfires on vulnerable populations, who have received scant attention in the preceding literature. From a methodological perspective, this thesis establishes causal inference frameworks for estimation of the effect of crisis events, compared with the prevailing correlational analysis in most existing research which lacks causal interpretability. The causal inference approaches make improvement to correlational methods in expanding the understanding of the cause-and-effect relationship between crisis events and public health as well as economic conditions. The causal inference analysis estimates the costs or benefits of each crisis event after ruling out any other possible causes of a certain effect and adds to the evidence base to advise on future policies and practice.

Specifically, Chapter 2 studies the causal effect of 2003 SARS epidemic on stock returns and systematic risk of every sector in Chinese A-share stock market. The empirical analysis exploits data from Bloomberg in terms of closing prices of A-shares at the daily level for each sector in Shanghai Stock Exchange and Shenzhen Stock Exchange between 18 November 2002 and 10 November 2003. The empirical method includes event study of prices to estimate the dynamic effect of the key SARS related event (on 17 March 2003) on stock prices in one year. The analysis also employs event study based on market model to calculate the cumulative average abnormal returns (CAAR). Finally, the DDD and DD methods are employed to estimate the causal effect of SARS on stock returns. In risk analysis, motivated by Ramiah, Martin and Moosa (2013), Chapter 2 adjusts the CAPM (termed modified CAPM) based on DD and DDD to evaluate changes in systematic risk of different Chinese sectors induced by SARS.

Chapter 3 assesses the causal impact of fiscal austerity on health outcomes of the elderly aged 50 and above across 11 EU nations. The empirical analysis collects data from Survey of Health, Ageing and Retirement in Europe (SHARE). The empirical method adopts an extension of the standard difference-in-difference (DD) with country-level treatment intensity, as well as difference-in-difference-in-differences (DDD) with both individual and country level treatment intensity.

Chapter 4 examines health costs of exposure to wildfires related to pregnancy outcomes and health outcomes of senior citizens. The wildfire data were obtained from Fire Statistics System (FIRESTAT) while the data regarding birth outcomes from 1998 to 2004 were extracted from the public use birth data files provided by National Vital Statistics System (NVSS) in counties with a population size no fewer than 100,000. The data for the elderly’s health conditions were gathered from Behavioural Risk Factor Surveillance System (BRFSS) data from 2001 to 2010. The first question considers the causal effect of each of the five largest wildfires on infant health and older people's health outcomes using data at the individual level. The study uses a difference-in-differences (DD) model with the distance from wildfires to each county used as continuous treatment intensity. The second question estimates the causal effect of multiple large wildfires on health outcomes of the newborns and the elderly. The analysis employs the two-way fixed effects (TWFE) model given that there are more than two time periods and treatment started at different time in different counties. The third question investigates the impact of multiple wildfires of various sizes on average health outcomes at the county level. Since treatment effects are heterogeneous across counties or over time, TWFE estimator of the average treatment effect on the treated (ATT) is biased based on the parallel trend assumption (de Chaisemartin and D'Haultfœuille, 2020). Given the disadvantages of TWFE and the heterogeneity of the treatment effects across counties throughout the time period, Chapter 4 uses $DID_{+,t}$ estimator proposed by de Chaisemartin and D'Haultfœuille (2020), which accounts for heterogeneity in treatment effects among groups or over time. The first sub-question studies the causal effect of each of the five most sizeable wildfires on neonatal health and older people's health status at individual level. A difference-in-differences (DD) model is adopted in which the distance from wildfires to each county is used as a continuous treatment intensity. The second sub-question examines how multiple large wildfires affect health outcomes of the newborns and the elderly. The two-way fixed effects (TWFE) regression is used because there are more than two time periods and treatment began at different time in different counties. The canonical DD method can no longer be applied because treatment timing changes across counties and the post-treatment period cannot be defined in control groups (Goodman-Bacon, 2021). The third sub-question evaluates the aggregate impact of multiple wildfires of different sizes on average health outcomes at the county level. Since treatment effects are heterogeneous across counties or over time, TWFE estimator of the average treatment effect on the treated (ATT) is biased based on the parallel trend assumption (de Chaisemartin and D'Haultfœuille, 2020). Given the drawbacks of TWFE and the heterogeneity of the treatment effects across counties throughout the time window, Chapter 4 uses $DID_{+,t}$ estimator by de Chaisemartin and D'Haultfœuille (2020), which adjusts for heterogeneity in treatment effects among groups or over time.

The remaining part of this chapter proceeds as follows. In section 5.2, this chapter begins by presenting and discussing the main empirical findings. Section 5.3 identifies limitations of this thesis. Section 5.4 make recommendations for future research and practitioners.

5.2 A Summary of Empirical Results

Overall, the thesis assumes that the three different types of crisis events have a negative effect on health and economic outcomes, although positive effect of crisis events is possible, such as Ruhm (2000) and Gerdtham and Ruhm (2006). To begin with, the thesis has identified that epidemics had a damaging impact on stock market performance of most Chinese sectors. The second major finding is that natural disasters have a small negative effect on several pregnancy outcomes and older people's health status. The thesis has also implied that fiscal austerity limited outpatient healthcare access among the elderly and worsened their self-perceived health. A brief overview of empirical findings associated with each research question is demonstrated as follows.

Chapter 2 investigates the causal effect of SARS epidemic on returns and systematic risk of Chinese A-shares across different sectors. The cumulative average abnormal returns show a decreasing trend and remain negative over the entire SARS epidemic, which indicates that the Chinese A-share stock market as a whole witnessed a gradual decline in stock returns caused by SARS. A sector by sector analysis demonstrates that the SARS epidemic had a negative effect on A-share returns in the entire stock market and the following sectors: consumer discretionary, healthcare, industrials, and utilities. Unexpectedly, no sectors gained from the SARS epidemic. Moreover, there is a significant increase in the systematic risk of the financial sector, whereas the systematic risk of the communication services and utilities is not influenced by SARS. A possible explanation for these results may be public panic over the SARS epidemic and self-protection behaviours such as social distancing. Due to data unavailability, Chapter 2 is unable to engage with estimating the effect of public fear on stock market response. Furthermore, the magnitude of the decrease in A-share returns of stock market losers appears to be higher following the reopening of the stock market compared with the first sub-period of the SARS epidemic. One possible reason is that before the stock market closure, people did not know the risk of SARS in the earlier phase of the epidemic because of lack of information transparency, inaccurate information and slow government response (Lee and McKibbin, 2012). In late April and May, the cumulative number of SARS cases increased substantially and the public realised the severity of SARS as more public health measures were implemented, which induced public fear and had a large impact on business performance of different sectors.

Chapter 3 evaluates how fiscal austerity influenced health outcomes of the elderly. In line with the expectation that fiscal austerity had a negative influence on older people's health outcomes, the findings indicate that older people's self-perceived health (SPH), a measure of general health status with high reliability and validity for the elderly (Maddox and Douglass, 1973; Lundberg and Manderbacka, 1996; Miilunpalo *et al.*, 1997), worsened due to fiscal austerity. Next, the analysis seeks to examine whether fiscal austerity led to physical and mental health problems corresponding to the poorer self-assessed health. No evidence of showing depression symptoms or worsened functional capacity is found. Moreover, the total number of chronic conditions was not affected by fiscal austerity. Older people exposed to fiscal austerity were less likely to develop chronic diseases including cancer, cataracts, stroke, hypertension, high cholesterol and gastric ulcers, while there is no effect of austerity measures on the probability of having other chronic conditions including chronic lung diseases and diabetes. As for cause-specific mortality, difference-in-differences estimates reveal that death caused by digestive disorders increased as a result of fiscal austerity, which is consistent with the assumption that fiscal austerity damaged physical health. The results obtained from both DD and DDD demonstrate that austerity measures had a null impact on mortality caused by accident, but the triple difference estimates show that fiscal austerity decreased mortality due to other cardiovascular related illnesses. Overall, fiscal austerity worsened self-perceived health but appears to improve or have no effect on other health outcomes.

Chapter 3 also studies possible mediating mechanisms including behavioural risk factors and healthcare use underlying the causal effect of fiscal austerity on health outcomes. The empirical evidence demonstrates that fiscal austerity caused unhealthy behaviours including heavier drinking, an increased smoking and physical inactivity, which may explain the worsened self-assessed health and a rise in mortality due to digestive diseases after fiscal austerity began. Furthermore, the elderly used less outpatient care during fiscal austerity, which may indicate lack of access to healthcare services in line with the health system reforms associated with fiscal austerity policies in Europe. Taken together, results imply that older people may experience unmet medical need for medical examination and diagnoses due to barriers to access to medical services as a consequence of fiscal austerity, so that they did not know their physical and mental health problems. The existing research has suggested that older people in Europe encountered unmet medical need for medical examination after the introduction of fiscal austerity policies owing to financial difficulty, long waiting time or long distance to hospital (Petmesidou, Pavolini and Guillén, 2014; Doetsch *et al.*, 2017). However, the findings need to be interpreted with caution because self-perceived health cannot represent all aspects of health and can be determined by the aspect of health people are thinking about when assessing their overall health status (Au and Johnston, 2014).

Chapter 4 aims to study the causal effect of wildfire exposure on birth outcomes and health outcomes of older people. The empirical results are summarised as follows. First, for birth outcomes, the largest wildfire results in a slightly higher probability of developing other circulatory or respiratory anomalies among newborns. Moreover, the second largest wildfire marginally increased the likelihood of low birth weight. However, both effects are close to zero. As for the health impact of wildfires on older people, the elderly experienced asthma symptoms more often following the second largest wildfire.

Second, The TWFE results show that the combined impact of multiple large wildfires which burned more than 5000 acres slightly increased the probability of prematurity. Multiple wildfires enhanced the frequency of showing asthma symptoms and extended the period of poorer mental health for older people.

Finally, the analysis at the county level shows that maternal exposure to wildfires modestly reduced the risk of developing omphalocele and cleft lip whilst there is a slight increase in the length of gestation due to being exposed to wildfires. The estimates of the dynamic treatment effects at the county level show that wildfires increased birth weight and the likelihood of delivering macrosomic infants if mothers were exposed to wildfires during any trimester of pregnancy. One possible explanation is that maternal stress elevates blood glucose levels through stimulating the secretion of cortisol levels, increased food intake and fewer physical activities, which makes intrauterine environment more glycaemic and increases the incidence of macrosomia (O'Donnell and Behie, 2015). Furthermore, infants are more likely to develop omphalocele when prenatal exposure to wildfires happened during the first trimester. As for the elderly, wildfire exposure resulted in physical inactivity.

5.3 Further Discussion on Parallel Trend Assumption

Many papers have pointed out problems of existing pre-trend tests used in difference-in-differences (DD) and different variations of DD methods. First, testing a parallel trend assumption by examining differences in trends between the treatment and control groups during the pre-treatment period may have low power (Rambachan and Roth, 2019; Roth, 2019) so that pre-existing trends cannot be detected (Roth, 2019). Second, estimates of average treatment effect on the treated based on pre-trends tests may be biased by violation of parallel trend assumption because data that pass the pre- test for pre-trends are a selected sample from the data-generating process (Roth, 2019). Third, the aim of the pre-trends test is to ensure that the parallel trend assumption is satisfied in the post-treatment period in the absence of the treatment (Kahn-Lang and Lang, 2020). However, a parallel trend in the pre-treatment period does not imply that the parallel trend would persist throughout the post-treatment period (Kahn-Lang and Lang, 2020).

The causal inference methods adopted in this thesis rely on different parallel trend assumptions, which are violated for some research questions after conducting a pre-trends test.

Researchers have put forward suggestions when the parallel trend assumption is violated. For example, Rambachan and Roth (2019) believe that the pre-trends are suggestive of the differences in trends during the post-treatment period in the absence of the treatment. Rambachan and Roth (2019) propose that empiricists can perform a sensitivity analysis to calculate confidence sets under various hypotheses for differences in the post-treatment trends considering specified pre-trends. For instance, one can assume that violation of a parallel trend assumption during the post-treatment period is no greater than a multiple of the maximum value of the violation of the assumption in the pre-treatment period (Rambachan and Roth, 2019).

In terms of the issue of pre-testing, Roth (2019) finds that the bias conditional on passing the pre- testing is different from or worse than the unconditional bias in some settings. Roth (2019) thinks that researchers should examine whether the pre-trends tests are well-powered against violation of parallel trends assumptions. Furthermore, research needs to apply economic knowledge to judge whether parallel trend assumption is satisfied (Roth, 2019).

Kahn-Lang and Lang (2020) make further recommendations when using DD and relevant approaches. Research applying DD should consider why the levels of outcomes of interest are different between treatment and control groups by studying factors associated with such differences in the pre-treatment period, which informs whether the parallel trend exists (Kahn-Lang and Lang, 2020). In addition, establishing a correct DD functional form plays an important role in justifying the parallel trends in outcomes between the treatment and control groups (Kahn-Lang and Lang, 2020). Moreover, failing a parallel trend assumption may be caused by various sources and empiricists needs to understand different shocks which lead to the divergence from the parallel trend assumption in order to evaluate the validity of such an assumption (Kahn-Lang and Lang, 2020).

5.4 Limitations

The thesis is subject to several limitations. First, in the long term, the causal impact of crisis events on health and economic outcomes is time-varying, and the effect changes during different stages of the post-crisis period including the immediate post-crisis period and the long-term recovery period (Shiba *et al.*, 2021b). This thesis does not differentiate the immediate post-crisis period from the recovery phase, but the analysis takes account of variation in causal effect at key time points, such as the closure of Chinese stock market during the SARS epidemic and each trimester of gestation. Second, in empirical analysis, the health survey data only include individuals whose health outcomes are recorded ignoring those who were alive but were not willing to take part in the survey, as well as those who pass away before the interview of the survey (Shiba *et al.*, 2021b). In this case, the outcomes are conditioned upon censoring because of death or nonparticipation, which results in selection bias and underestimation of the true causal effect of a crisis event on health outcomes (Shiba *et al.*, 2021b). Third, different definitions of measure of exposure influence estimation results (Leyva, Beaman and Davidson, 2017). It is not the task of this thesis to examine the robustness of the empirical results to various measures of exposure to crisis events.

Moreover, there are two disadvantages of using standard difference-in-differences method (Yabe, Zhang and Ukkusuri, 2020). The first drawback is that the parallel trend assumption requires that the difference between the treatment and control groups is time constant when no treatment is imposed, whereas the difference in outcomes of interest may change over time, which invalidates causal inference analysis with DD (Hansen, 2007, as cited in Yabe, Zhang and Ukkusuri, 2020). Another downside is that classical DD is only suitable for estimating time-invariant causal effect while the effect of disasters varies with time due to post-disaster recovery and radioactive decay (Brodersen et al., 2015, as cited in Yabe, Zhang and Ukkusuri, 2020).

Notably, this thesis studies the heterogeneity of the effect of disasters by age based on the deductive approach, which chooses individual characteristics as sources of heterogeneity using preceding theory or empirical findings, but this overlooks more complicated heterogeneity patterns, such as interactions of multiple personal characteristics (Shiba *et al.*, 2021a).

In addition, similarly to Shiba *et al.* (2021a), the exposure assessment in this thesis may ignore extra changes at the individual level. In this thesis, the effect of SARS on stock returns may be heterogeneous across firms depending on pre-SARS financial conditions, corporate social responsibility activities before SARS, ownership and corporate governance (Ding *et al.*, 2021). However, data on these firm characteristics are unavailable.

An issue which cannot be addressed in this thesis is the limited access to data. First, due to unavailability of data, the thesis fails to probe the mechanism underlying some of the empirical results. Chapter 2 does not explore the potential mechanism underlying the response of stock market performance to the epidemic, such as whether the panic determined changes in stock returns and systematic risk. In Chapter 3, data on unmet medical need, unmet medical need due to costs and unmet medical need due to long waiting time in the pre-austerity period are unavailable, which can provide supporting evidence on whether there was a rise in unmet medical need. Chapter 3 also fails to obtain information related to malnutrition and homelessness, which are potential drivers of worsened self-perceived health during fiscal austerity. Chapter 4 is unable to verify whether the null effect of wildfire exposure on health outcomes of neonates and older people is driven by higher maternal glucose levels, maternal investment in fetal health, support received by mothers as well as precautions taken by pregnant women.

Second, in Chapter 4, due to unavailability of restricted-use birth data files, the presence of null impact may be a result of the small sample size of the treated counties in the data leading to inadequate statistical power.

5.5 Recommendations

5.5.1 Recommendations for Practitioners

The empirical results in this thesis have a number of practical implications. In general, the thesis evaluates the economic or health costs of three crisis events including epidemics, fiscal austerity and wildfires. The cost-benefit analysis may be of assistance to inform evidence-based policy making and promote effective resource allocations aimed at mitigating the adverse effect of crisis events on health or economic conditions. Compared with correlational research, the causal inference methods employed in this thesis produce more reliable estimates of the costs or benefits induced by a certain crisis event.

In particular, greater efforts are needed in China to provide financial support for sectors including consumer discretionary, healthcare, industrials and utilities in the face of epidemics, while formulating business strategies to reduce systematic risk during an epidemic could be a priority for companies in the financials sector. Given a decline in stock returns in most sectors and the amplified volatility, prevention of future epidemics or efficient mitigation strategies for managing any epidemics can avoid substantial economic losses and stabilise financial markets. Besides, more resources need to be allocated to enhance the ability of the above-mentioned sectors to build resilience to crisis events and provide financial assistance to the affected sectors which suffer a considerable loss.

As for fiscal austerity, when enforcing fiscal consolidation in the healthcare sector, a key policy priority could be to assess factors which can induce barriers to healthcare use and ensure older people’s access to healthcare services. Also, policy designers could explore an alternative policy instrument for tackling economic crisis to minimize the costs of adjustments associated with difficulties in healthcare access among vulnerable populations.

With respect to wildland fires, vulnerable population groups who are sensitive to wildfires, including pregnant women and the elderly with respiratory conditions, are advised to be evacuated promptly once a wildfire is detected to mitigate the negative consequences of wildfire exposure. The suggestion is consistent with McGee, McFarlane and Tymstra (2015). Local communities may consider providing more social support for these vulnerable groups. Besides, prenatal care practitioners could pay more attention to pregnant women who are exposed to wildfires in early pregnancy and provide adequate prenatal care to reduce the risk of adverse birth outcomes. Nevertheless, the empirical findings indicate a lot of null effects of wildfires on health outcomes among older people and infants. This implies that buffering adverse health outcomes caused by wildfires may not be a policy priority, whereas governments and local communities may direct limited resources to dealing with environmental or economic consequences of wildfires.

5.5.2 Recommendations for Future Research

The thesis has raised many research questions in need of further investigation. Several questions remain unanswered at the moment. The causal impact of crisis events on health outcomes in high-income countries such as US and EU may not be generalised to less well-off nations. For instance, natural disasters had a disproportionately large effect on low income countries because of lack of budget constraints to build the resilience of primary healthcare (Ray, Ghimire and Bc, 2019) and inadequate public sector healthcare infrastructure (Kaur, 2020). Nevertheless, little attention has been paid to the impact of climate change on health in middle- and low-income countries (Leyva, Beaman and Davidson, 2017). Therefore, a further study could assess how health outcomes are affected by natural disasters in low- and middle-income nations.

A natural progression of this work is to study resilience and resilience capacity[41] of the elderly or pregnant women in face of crisis events, which moderates the adverse impact of crisis events on health outcomes (Leyva, Beaman and Davidson, 2017). As discussed in Chapter 4, the presence of null effects of wildfire exposure on birth outcomes might be explained by the self-protection behaviour of pregnant women to mitigate the negative effect of wildfires on neonatal health after receiving suggestions and education from the government, public health service, healthcare providers or news agencies. This thesis does not engage with assessing resilience because the study is limited by lack of data associated with measures of resilience, which could be usefully explored in future research. More importantly, given the health and economic costs of crisis events, disaster preparedness is an essential measure to reduce the negative impact of disaster. For instance, inadequate primary healthcare services is threat to public health after a disaster and reinforcing the capacity of primary healthcare needs to be a priority in disaster management

[41] The resilience capacity includes hardiness, coping and self-concept (Hicks and Conner, 2014, as cited in Leyva, Beaman and Davidson, 2017).

(Mawardi *et al.*, 2021). Further research should be undertaken to explore more effective strategies for coping with crisis events as well as precautionary measures to minimise health and economic costs owing to crisis.

Surprisingly, individuals with complicated interactions between multiple characteristics appear to be more susceptible to disasters (Shiba *et al.*, 2021a). For instance, people with status inconsistency, such as higher earnings and lower education levels, suffer from increased vulnerability (Shiba *et al.*, 2021a). A further study could investigate why individuals with complex heterogeneity are more susceptible to disasters (Shiba *et al.*, 2021a) and explore whether people with interactions between other individual characteristics are vulnerable to crisis events.

More broadly, more unified research is needed to evaluate and compare the effect of different types of natural and man-made disasters on health outcomes. A small amount of literature, such as Sawada, Bhattcharyay and Kotera (2011), Wang (2009), Oh (2015) and Wang (2013), focuses on the economic costs and benefits induced by natural and man-made disasters. Such an investigation can inform policymakers about which types of disasters are expected to have the most devastating effect on economy and public health, so that sufficient resources can be rationed to those disasters in order to mitigate economic and human costs of the disasters.

Findings from each chapter suggest several courses of action for future research specific to each crisis event. In terms of epidemics, a question raised by chapter 2 is how public health measures can balance between disease control and economic slowdown. As for fiscal austerity, more work will need to be done to assess whether spending reductions in sectors other than healthcare will induce smaller costs in order to meet fiscal policy goals. With respect to wildfires, further work is needed to understand whether maternal stress caused by wildfires is one potential mechanism underlying the adverse pregnancy outcomes. This requires collecting detailed data regarding maternal mental health and well-being as well as the degree of maternal distress attributable to wildfires.

Methodologically, the thesis adopts causal inference methods when investigating the causal impact of each crisis event compared with correlational methods prevalent in previous research. The causal inference analysis using observational data can rule out other causes of the observed effect (Miller, Henry and Votruba-Drzal, 2016) and discover the causal relationship between crisis and health or economic outcomes, so that the method accurately evaluates the health and economic costs attributable to any crisis events. When randomised controlled trials cannot be conducted in reality, the causal inference approaches exploiting observational data prove useful in expanding our understanding of how interventions on the cause (or crisis events) will give rise to a specific health or economic effect. As a result, more research using causal inference methods is needed to quantify how exposure to a crisis event will causally lead to a certain effect. Moreover, further research should be undertaken to explore how the effect of crisis changes dynamically over time, which identifies the specific time points when the costs of crisis events are greatly increased and interventions are necessary to lessen the negative consequences of crisis events.

Appendix A Chapter 2

A.1 A Timeline of SARS-related Events

The following timeline of SARS-related events primarily quotes from World Health Organization (2003) unless otherwise cited and is complemented by events mentioned in the referenced papers.

- Year 2002

16 November 2002
The first known case of atypical pneumonia happens in Foshan, China.

- Year 2003

14 February
The Chinese Ministry of Health notifies WHO that the outbreak in Guangdong Province is congruous with atypical pneumonia clinically and the outbreak has been brought under control.

17 February
A Hong Kong man, who had travelled with his family to Fujian in January, dies of unknown causes in Hong Kong while his daughter formerly died of unknown causes in mainland China and his son is hospitalized.

19 February
An outbreak of “bird flu” in Hong Kong is reported to WHO. WHO starts its global influenza laboratory network and calls for augmented global surveillance.

21 February
A medical doctor from Guangdong, who developed respiratory symptoms five days ago, arrives in Hong Kong to attend a wedding and stays on the ninth floor in the Metropole Hotel. He shops with his brother-in-law from Hong Kong.

22 February
The Guangdong doctor is admitted to the intensive care unit with respiratory failure at the Kwong Wah Hospital in Hong Kong and he had treated patients infected with atypical pneumonia in Guangdong. He informs medical staff that he may have contracted a “very virulent disease”. Health authorities in Hong Kong are told that his symptoms developed on 15 February in mainland China.

Appendix A

23 February

A team of WHO experts arrives in Beijing, but is only permitted to work at the central level.

26 February

A Chinese-American businessman is admitted to the French Hospital in Hanoi with a 3-day fever and respiratory symptoms. He had lived on the same floor in the Metropole Hotel in a room across the hall from the Guangdong doctor before.

The businessman is treated by a WHO official, Dr Carlo Urbani, in Viet Nam.

28 February (Day -11)

Dr Urbani is apprehensive that there might be a case of avian influenza and reports to the WHO office in Manila. WHO headquarters increase the level of alert.

1 March

Brother-in-law of the Guangdong doctor is re-admitted to Kwong Wah Hospital.

A resident of Singapore, who lived on the ninth floor of the Hotel Metropole in Hong Kong from 21 to 25 February, is admitted to a hospital in Singapore with respiratory symptoms.

4 March

The Guangdong doctor dies of atypical pneumonia at Kwong Wah Hospital.

5 March

The Chinese-American businessman in Hanoi is medivaced to the Princess Margaret Hospital in Hong Kong while seven health care workers who had cared for him in Hanoi become sick.

A Toronto woman dies at Toronto's Scarborough Grace Hospital and five members of her family are infected and admitted to the hospital.

7 March

Health care staff at Hong Kong's Prince of Wales Hospital suffer from respiratory tract infection, which turn into pneumonia. All of them are linked to Ward 8A.

8 March

In Taiwan, a businessman who travelled to Guangdong is hospitalized with respiratory symptoms.

10 March

At least 22 staff at the Hanoi hospital are infected with influenza-like symptoms, twenty of whom show symptoms of pneumonia, one of whom needs breathing support, and another of whom is in critical condition.

The Ministry of Health in China asks WHO to clarify the cause of atypical pneumonia.

11 March

Dr Urbani travelled to Bangkok, where he is sick upon arrival and is instantly hospitalized.

12 March

WHO sends out a global alert about severe atypical pneumonia after an increase in reports of transmission among medical staff at hospitals in Hong Kong and Hanoi.

At the French Hospital in Hanoi, 26 staff show symptoms, 25 of whom have either pneumonia or acute respiratory syndrome, and 5 of whom are in critical condition. The hospital prevents new admissions.

Hong Kong health authorities officially announce an outbreak of unknown flu-like disease among hospital staff.

13 March

WHO releases an emergency alert to its partners in the Global Outbreak Alert and Response Network (GOARN).

The Chinese-American businessman dies at the Princess Margaret Hospital in Hong Kong. No cases among medical staff are reported.

The Ministry of Health in Singapore reports three cases of atypical pneumonia in young women who had lived on the ninth floor of the Metropole Hotel in late February.

The son of Toronto's first case dies in Scarborough Grace Hospital.

14 March

In Hong Kong, 39 staff at three hospitals receive treatments for flu-like diseases, 24 of whom manifest symptoms of pneumonia and are in "serious condition".

Health authorities in Ontario alert doctors, hospitals, ambulance services, and public health units across the province that four cases of atypical pneumonia exist in Toronto, which have led to 2 deaths within a single family.

The first members of a WHO GOARN multidisciplinary outbreak control team arrive in Hanoi.

15 March

Singapore health authorities inform WHO staff that a physician, who had treated the country's first two SARS patients, had boarded a flight from New York City to Singapore via Frankfurt. The physician, his wife and mother-in-law become Germany's first SARS cases.

WHO raises a rare travel advisory that SARS is transmitted through international air travel. WHO names the atypical pneumonia severe acute respiratory syndrome (SARS) based on its symptoms and declares it "a worldwide health threat".

WHO issues the first case definitions of suspect and probable cases of SARS. WHO also requests all travellers to care about the signs and symptoms of SARS, and provides suggestions for airlines.

Eight cases of atypical pneumonia including 2 deaths are reported in Canada.
Four intensive care specialists arrive in Hanoi to support the GOARN team there.
Sixteen cases of atypical pneumonia are discovered in Singapore.

17 March (event day)
China sends the first brief report to WHO about the Guangdong outbreak and claims that the outbreak has abated.
WHO builds a network of 11 chief laboratories in 9 countries to facilitate the identification of the pathogens and develop a robust and reliable diagnostic test. A similar network is established to pool clinical knowledge on symptoms, diagnosis, and management. A third network is created to investigate SARS epidemiology.

WHO began to publish the daily cumulative number of reported suspect and probable SARS cases online (World Health Organization, 2022, cited in Cherry, 2004).

18 March
SARS cases are discovered in Canada, Germany, Taiwan (China), Thailand, and the United Kingdom as well as in Hong Kong, Viet Nam, and Singapore. The cumulative total cases reported to WHO include 219 cases and 4 deaths.
In particular, Hong Kong reports 123 cases, Hanoi 57, and Singapore 23.
Evidence suggests that most SARS cases are health care workers, their family members, and others who have close face-to-face contact with SARS patients, so SARS is likely to spread through droplets of patients.

19 March
Brother-in-law of Guangdong doctor dies in a Hong Kong hospital.

20 March
The US reports its first cases.
The cumulative total number of cases reaches 306 with 10 deaths.

21 March
A WHO coordinating officer arrives in Singapore to evaluate the demand for international assistance.
WHO supplies policy instructions on hospital discharge and the follow-ups.

22 March
Hong Kong scientists designs the first “hand-made” diagnostic test and isolates a candidate causative agent. The exact identity of the virus remains unknown.

Thirteen countries covering three continents report a cumulative total number of 386 cases and 11 deaths.

24 March

The Singapore Ministry of Health announces home quarantine measures whereby contacts of SARS patients should stay at home for 10 days and more than 300 people are influenced.

25 March

Twenty-two passengers and 2 flight attendants connected with a 15 March flight from Hong Kong to Beijing are infected with SARS.

Scarborough Grace Hospital in Toronto does not admit new patients and visitors.

26 March

The first “grand rounds” consultation on SARS symptoms, diagnosis, and management is held online, bringing together 80 clinicians from 13 countries.

The WHO team in China inspects the case definition used during the outbreak of atypical pneumonia and believes that the cases are most possibly infected with the same disease as SARS.

World cumulative total of cases reaches 1323 with 49 deaths.

Ontario health officials alert to a likely public health emergency.

27 March

Scientists in the WHO lab network identify the causative agent of SARS as a new member of the coronavirus family.

Hong Kong introduces the school closures until 6 April and puts 1080 people in quarantine.

Chinese authorities disclose SARS cases in other areas of China.

WHO announces stricter advice to international travellers and airlines including screening at some airports.

28 March

China participates in WHO collaborative networks.

Some airlines start screening departing international passengers.

Financial analysts evaluate impact of SARS on stock markets and economic outcomes if outbreak is not contained before June.

29 March

Dr Carlo Urbani, the first WHO officer to identify the outbreak of SARS, dies of SARS in Thailand.

30 March

York Central Hospital does not admit new patients and hundreds of its employees are asked to

self-isolate. Thousands of Toronto residents stay in quarantine at home.
Hong Kong health authorities report that 213 residents in the Amoy Gardens housing estate have been hospitalized with SARS.

31 March
Health authorities in Hong Kong issue an isolation order to contain the further transmission of SARS.

2 April
WHO suggests that travellers who will visit Hong Kong and Guangdong delay all but essential travel until further notice, which is the toughest travel advisory announced by WHO in its 55-year history.
Chinese authorities reveal updates on statistics: 361 new SARS cases and 9 deaths in Guangdong from 1 to 31 March.
Chinese government permits WHO team to enter Guangdong.
The cumulative number of SARS cases reaches 2000 around the world.

3 April
The WHO team is allowed to access sites and interview medical staff at all levels in Guangdong.
Chinese Minister of Health tackles SARS-relevant problems on national television.

4 April
China starts reporting daily SARS cases and deaths electronically by province.
Contact tracing by Singapore health authorities locates 94 SARS cases linked to the country's index case.

6 April
A Finnish staff member of the International Labour Organisation dies of SARS in Beijing.

7 April
WHO points out the disadvantages of the three diagnostic tests to control the spread of SARS.
Morgan Stanley chief economist Stephan Roach shows that SARS incurred $30 billion losses in the global economy.

8 April
In Singapore, a vegetable hawker is hospitalized for SARS, who is not quarantined until 12 hours later when showing symptoms of SARS.
A total of 2671 SARS cases and 103 deaths are reported in 17 countries.

11 April

South Africa reports its first probable SARS case and 19 countries across four continents have discovered SARS cases.

14 April

The cumulative number of global SARS cases exceeds 3000.

15 April (day 21)

The Beijing team is granted an entry into military hospitals.
Hong Kong reports 9 SARS deaths, which is the largest number of deaths in a single day.

16 April (day 22)

The WHO laboratory network declares the definitive discovery of the SARS pathogen: a new coronavirus.
Health staff in Hong Kong report that SARS patients from the Amoy Gardens does not respond to treatment as well as patients from other groups.
In contrast to the official record of 37 SARS cases, the WHO team in Beijing proposes that the total number of SARS cases in Beijing ranges between 100 and 200.

17 April

Economic analysts in the Far East point out that a regional GDP loss of $ 10.6–$15 billion is induced by SARS while China experiences the largest losses of $2.2 billion. In Hong Kong, retail sales have decreased by half since mid-March. Tourists from mainland China have dropped by 75% to 80% while the entertainment and restaurant industries have witnessed an 80% decline in business.

18 April

The WHO team in Beijing expresses concern over the underreporting of SARS cases in military hospitals amidst increasing rumours about unreported SARS cases.
Hong Kong officers disclose the discovery of the probable environmental cause of the SARS outbreak in Amoy Gardens and the transmission likely happened via the sewage system.

19 April

Top government leaders in China require officials to report SARS cases truthfully.
Toronto authorities reveal 31 suspect and probable SARS cases associated with a charismatic religious group, the medical staff who treated them, and their close contacts.
The Vietnamese government plans to close its 1,130 km border with China.

Appendix A

20 April

Beijing officials disclose 339 formerly unreported SARS cases, and the cumulative number of SARS cases in China reaches 1,959. The traditional one-week May Day public holiday will be reduced by Chinese government.

The mayor of Beijing and the minister of health are dismissed from their jobs for their downplaying of SARS.

Singaporean health officials shut down a large wholesale fruit and vegetable market after identifying 3 SARS cases connected with the vegetable hawker.

23 April

Beijing authorities close all primary and secondary schools for two weeks.

A total of 2305 probable cases of SARS and 106 deaths are reported in China, among which the total number of cases in Beijing is 693.

In Singapore, the 8 probable and 14 suspect SARS cases can be traced back to the vegetable hawker.

WHO recommend travellers to Beijing, Shanxi and Toronto delay all but essential travel.

The cumulative number of probable SARS cases is 4288 with 251 deaths. China reports 106 deaths while Hong Kong reports 105.

The Hong Kong administration announced a financial relief package including income tax rebate and licensing fee waiver to recover the economy (The Legislative Council, 2019).

25 April

Outbreaks in Hanoi, Hong Kong, Singapore, and Toronto show signs of approaching peak.

28 April

Viet Nam is removed from the list of areas with recent local transmission and becomes the first country to successfully control the SARS outbreak.

The cumulative number of SARS cases outstrips 5000.

The Beijing municipal government required the closure of movie theatres, Internet cafes and other entertainment venues (Xu, 2003).

29 April

The China Securities Regulatory Commission declared the closure of stock markets and futures markets in Shanghai and Shenzhen until May 12 (Xu, 2003).

30 April

WHO removes its travel advice for Toronto.
China, with 3460 probable cases, has more SARS cases than other countries.

2 May

The cumulative number of SARS cases exceeds 6000.

3 May

WHO dispatches a team to Taiwan, which reports a cumulative number of 100 probable SARS cases.

7 May

WHO assesses that the case fatality rate of SARS ranges between 0% and 50% depending on the age cohort, with an overall case fatality ratio from 14% to 15%.

8 May

Travel advisories are extended to Tianjin, Inner Mongolia and Taipei.

11 May

The Ministry of Finance declares a waiver of and a reduction in taxes and administrative fees for industries affected by SARS (Lee and McKibbin, 2012).

13 May

Outbreaks in other areas show signs of containment.

14 May

Toronto is removed from the list of areas with recent local transmission.

17 May

The first global consultation on SARS concludes that containment measures suggested by WHO, such as early identification, isolation of patients, contact tracing and public education, are effective and supported by evidence.
Travel advice is extended to Hebei, China.

21 May

Travel advice is extended to all cities in Taiwan.

22 May

Health authorities in Canada report five new cases of acute respiratory disease in a hospital in

Toronto.

The cumulative number of SARS cases outstrips 8,000 around the globe.

23 May

Travel advice for Hong Kong and Guangdong is lifted.

Research teams in Hong Kong and China proclaim the identification of a SARS-like virus in the masked palm civet and racoon-dog, which are sold for consumption in southern China.

26 May

Toronto is put back on the list of areas with recent local transmission.

27 May

The World Health Assembly approves a resolution which requests all countries to disclose SARS cases instantaneously and transparently.

31 May

Singapore is removed from the list of areas with recent local transmission.

3 June

The number of new probable SARS cases in China is reduced to a weekly mean of more than two.

13 June

Travel advisories for Hebei, Inner Mongolia, Shanxi and Tianjin are lifted. Guangdong, Hebei, Hubei, Inner Mongolia, Jilin, Jiangsu, Shaanxi, Shanxi and Tianjin are removed from the list of areas with recent local transmission.

23 June

Hong Kong is removed from the areas with recent local transmission.

24 June

WHO lifts the travel advice for Beijing and removes Beijing from the list of areas with recent local transmission.

2 July

Toronto is removed from the list of areas with recent local transmission.

5 July

WHO removes Taiwan, which is the last area with recent local transmission, from the list of areas with recent local transmission.

WHO announces that SARS outbreaks have been controlled globally, but suggests proceeding with caution.

A.2 China and India Stock Market Indices

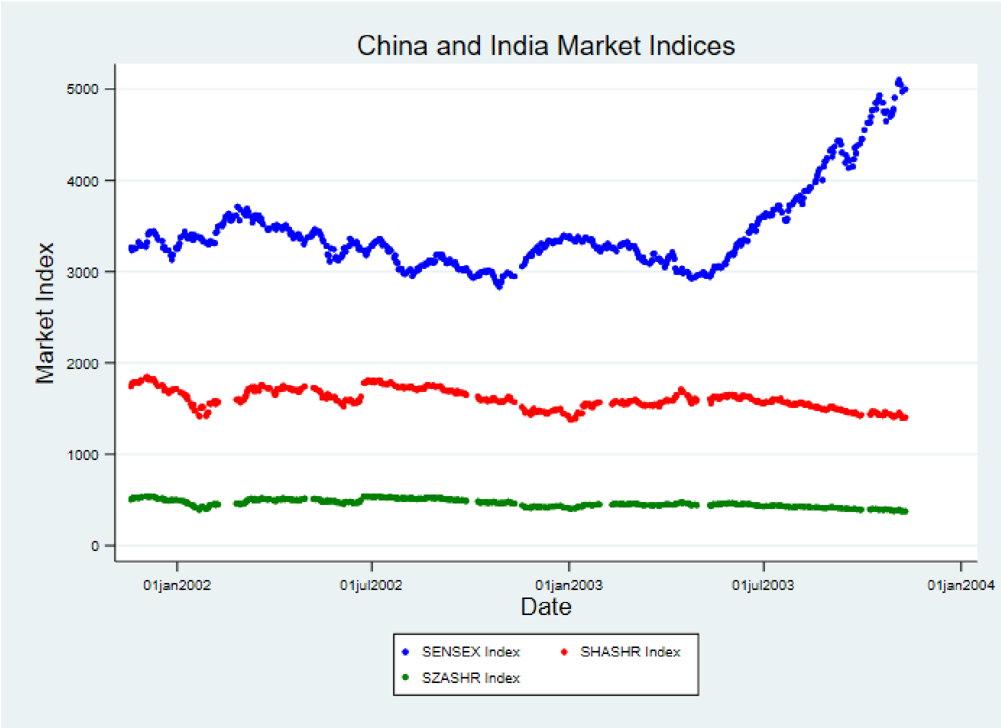

Figure A-1. A comparison between the trend in market indices in China and India.

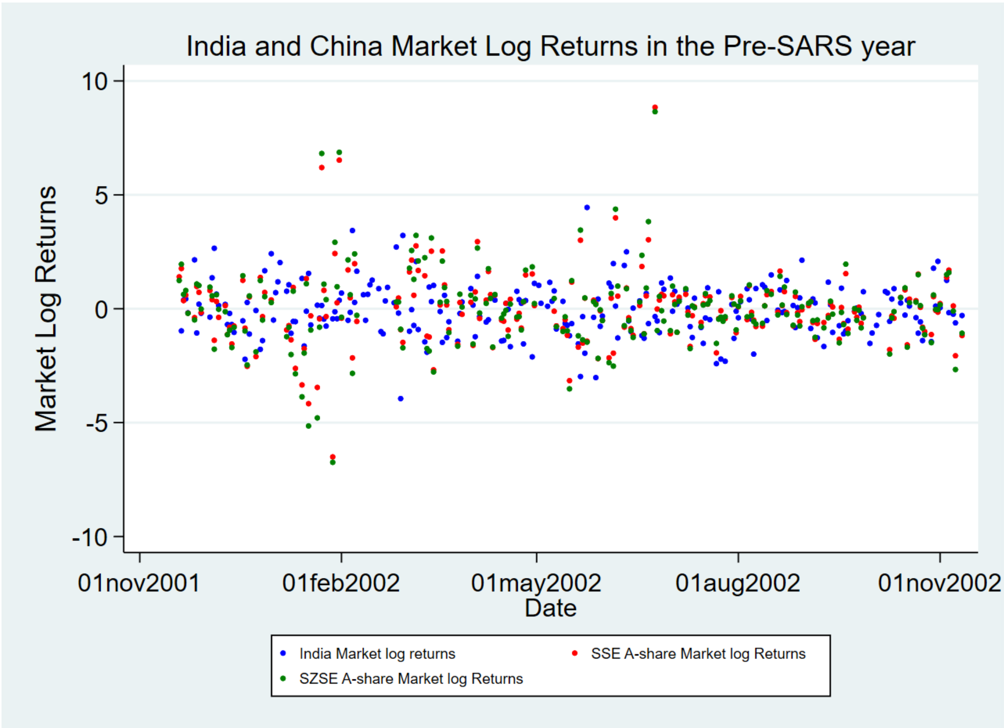

Figure A-2. A comparison between the trend in market returns in China and India.

A.3 Event Study Results

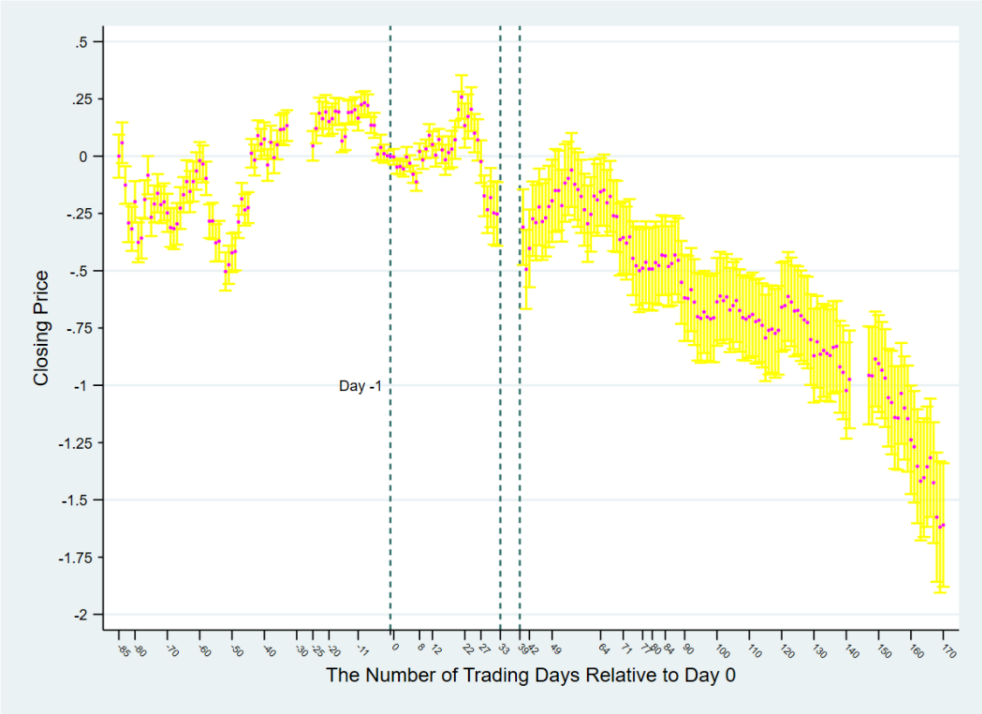

Figure A-3. The impact of SARS on A-share prices in consumer discretionary.

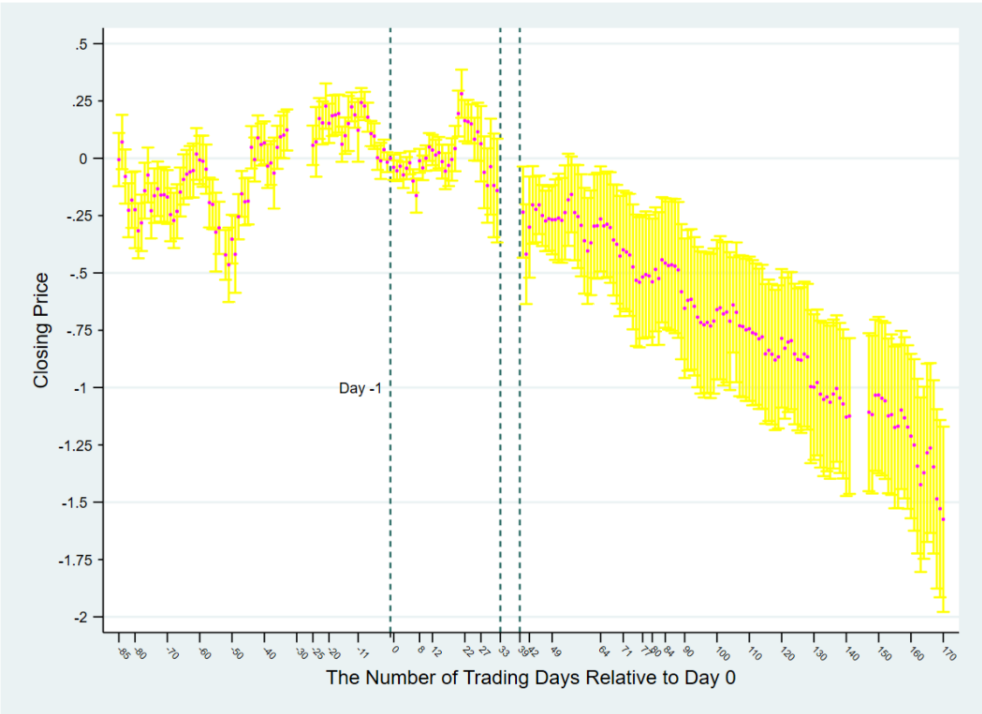

Figure A-4. The impact of SARS on A-share prices in consumer staples.

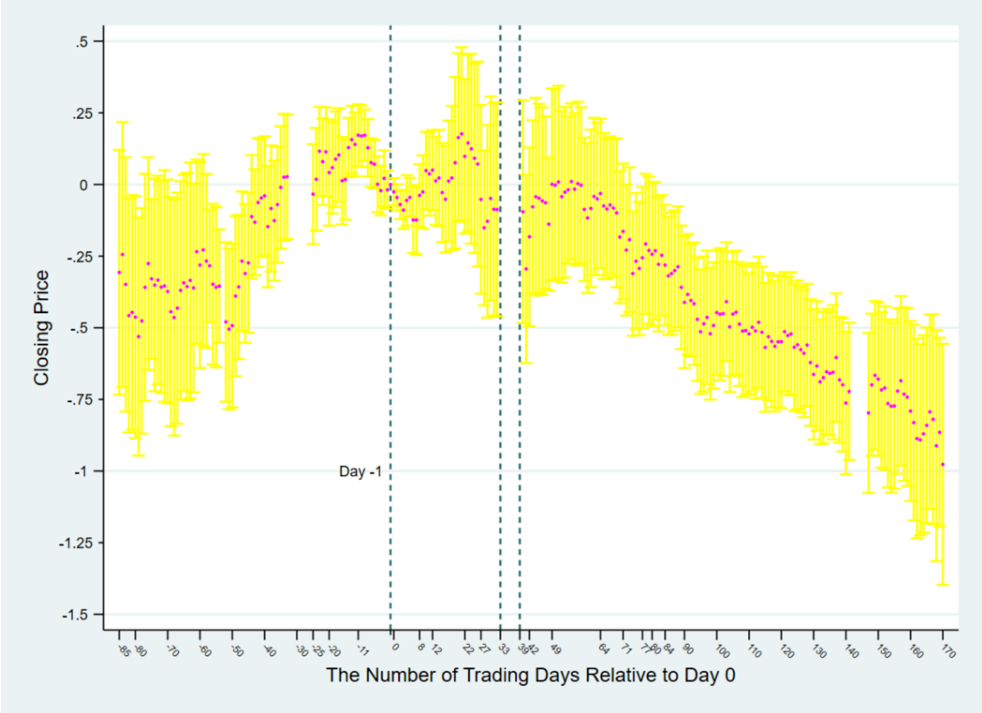

Figure A-5. The impact of SARS on A-share prices in energy.

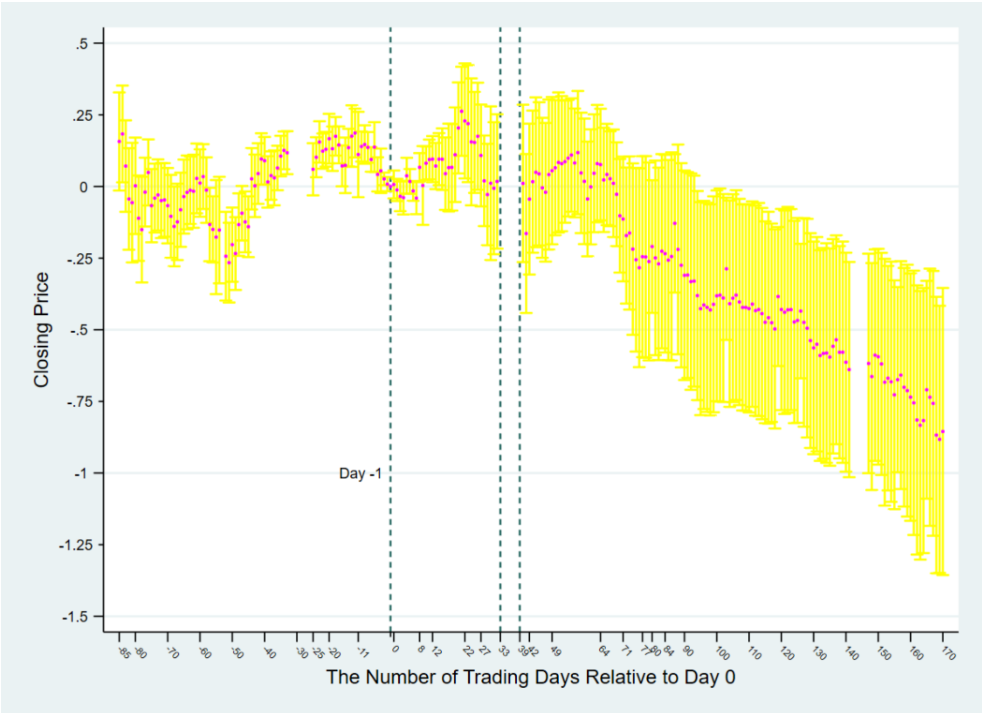

Figure A-6. The impact of SARS on A-share prices in financials.

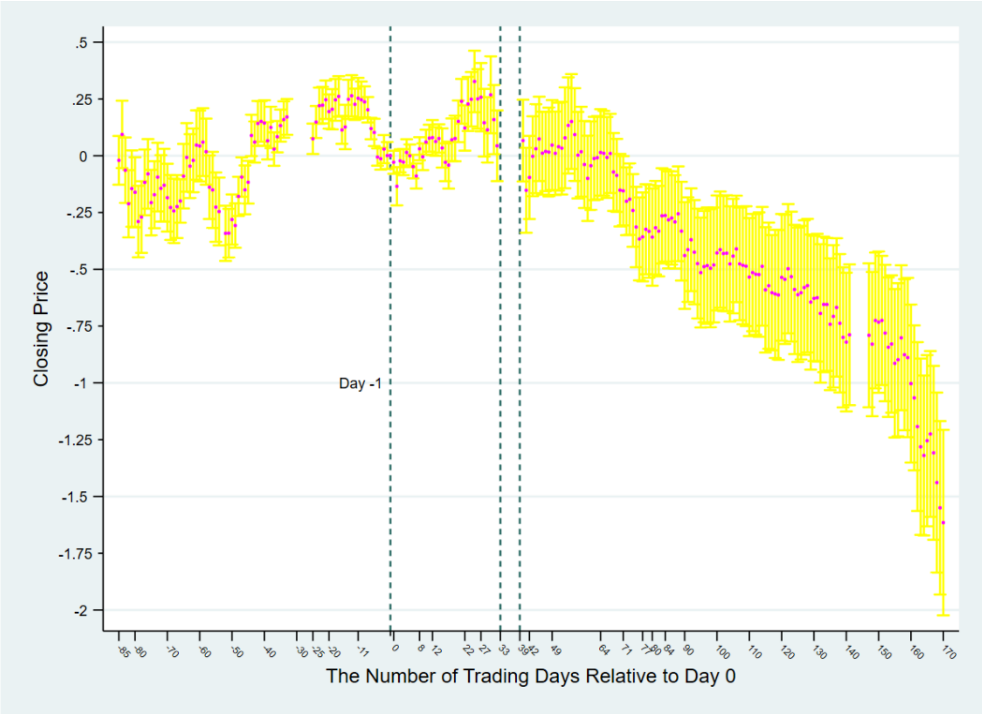

Figure A-7. The impact of SARS on A-share prices in health care.

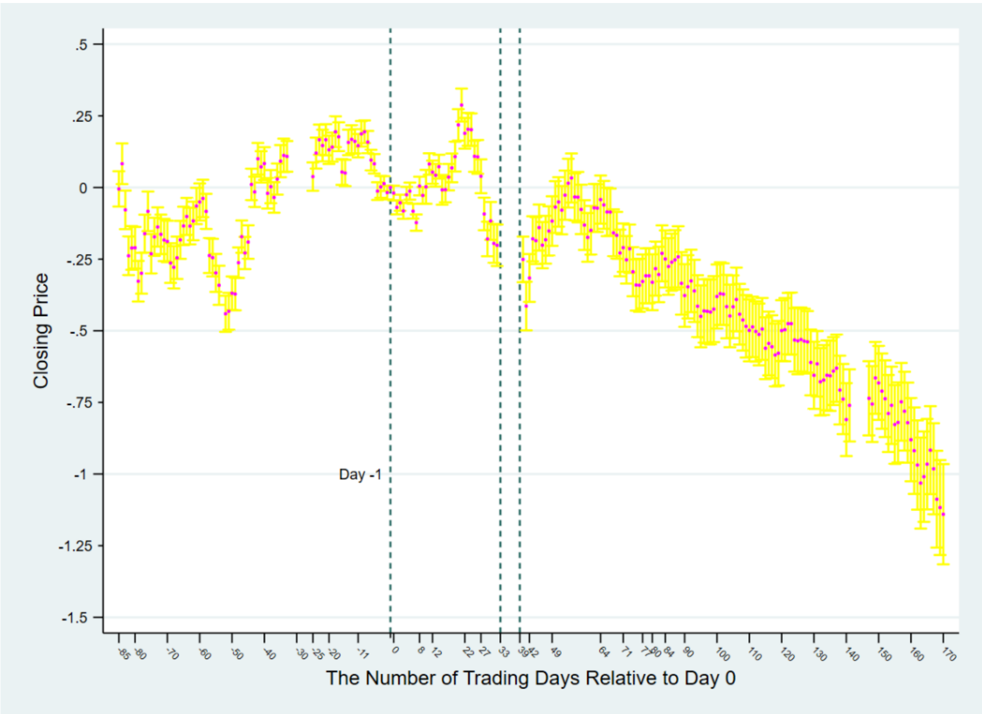

Figure A-8. The impact of SARS on A-share prices in industrials.

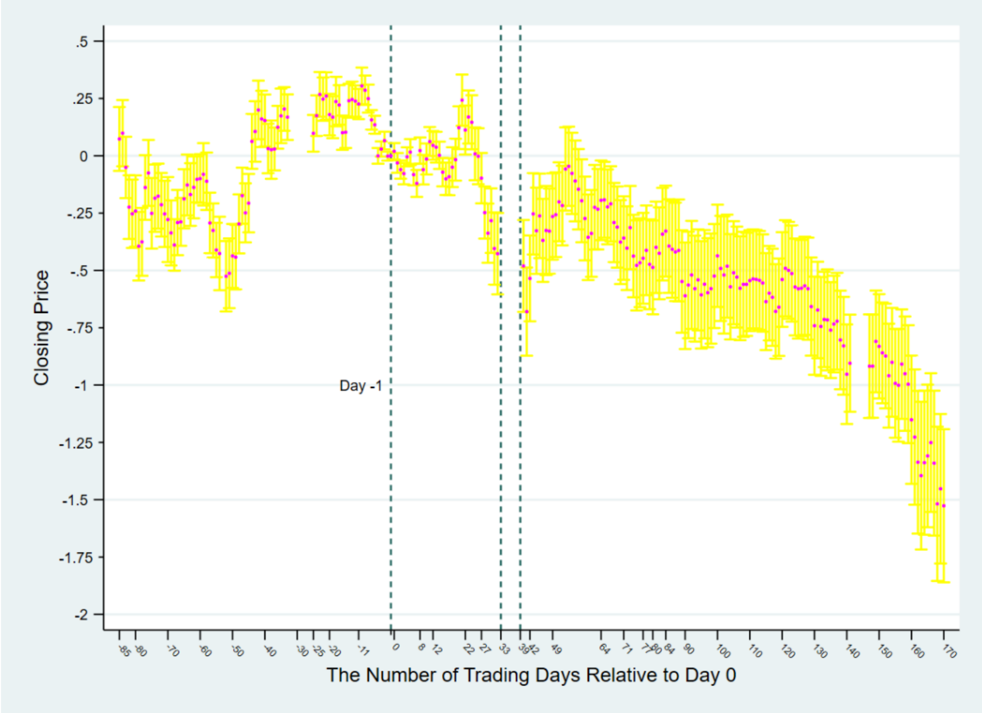

Figure A-9. The impact of SARS on A-share prices in information technology.

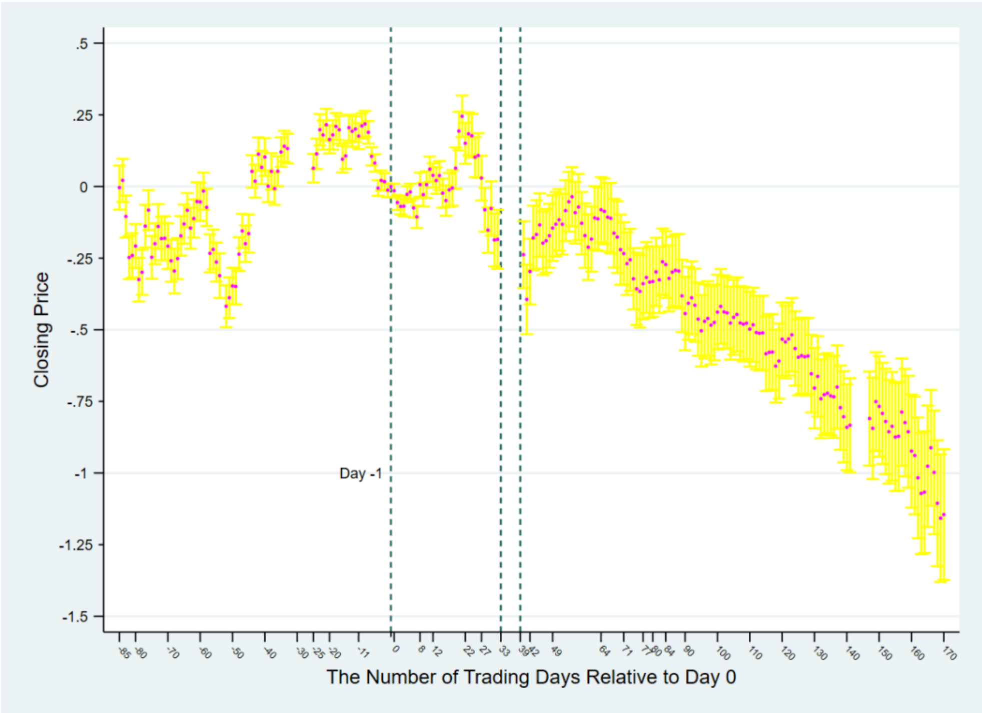

Figure A-10. The impact of SARS on A-share prices in materials.

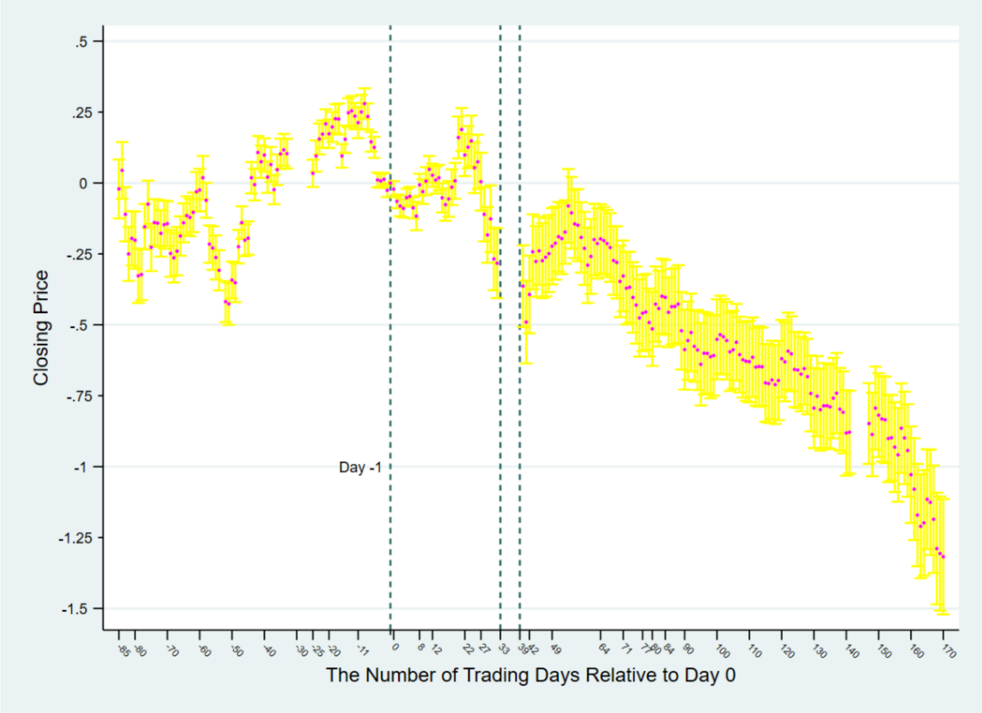

Figure A-11. The impact of SARS on A-share prices in real estate.

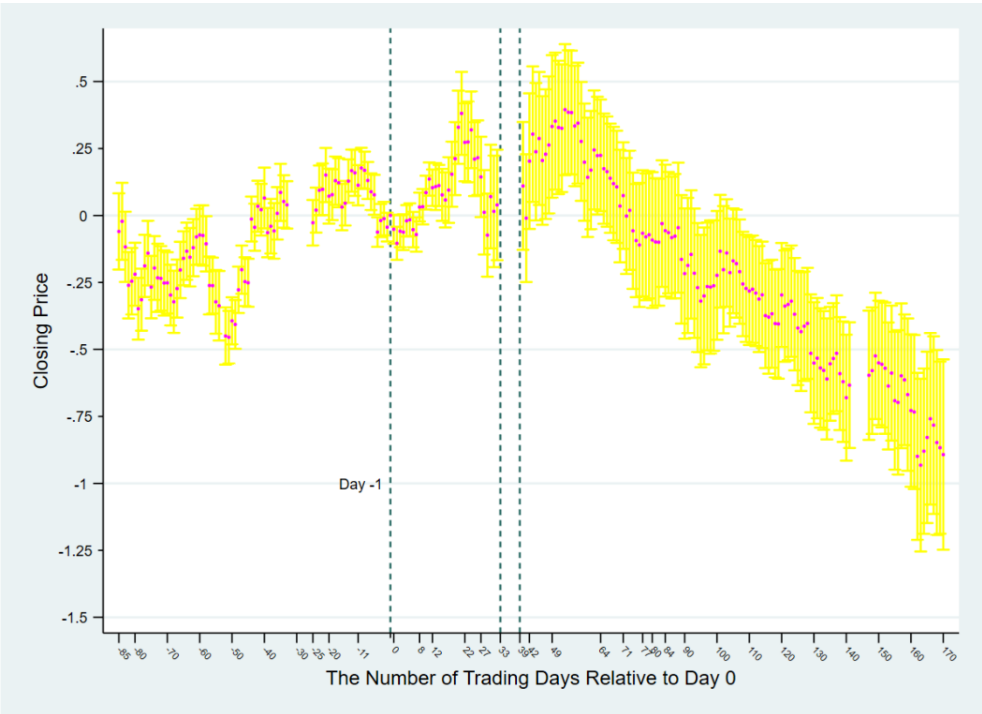

Figure A-12. The impact of SARS on A-share prices in utilities.

The following graphs show event study results over a longer time horizon from 18 November 2002 (Day -85) to 12 April 2004 (Day 280).

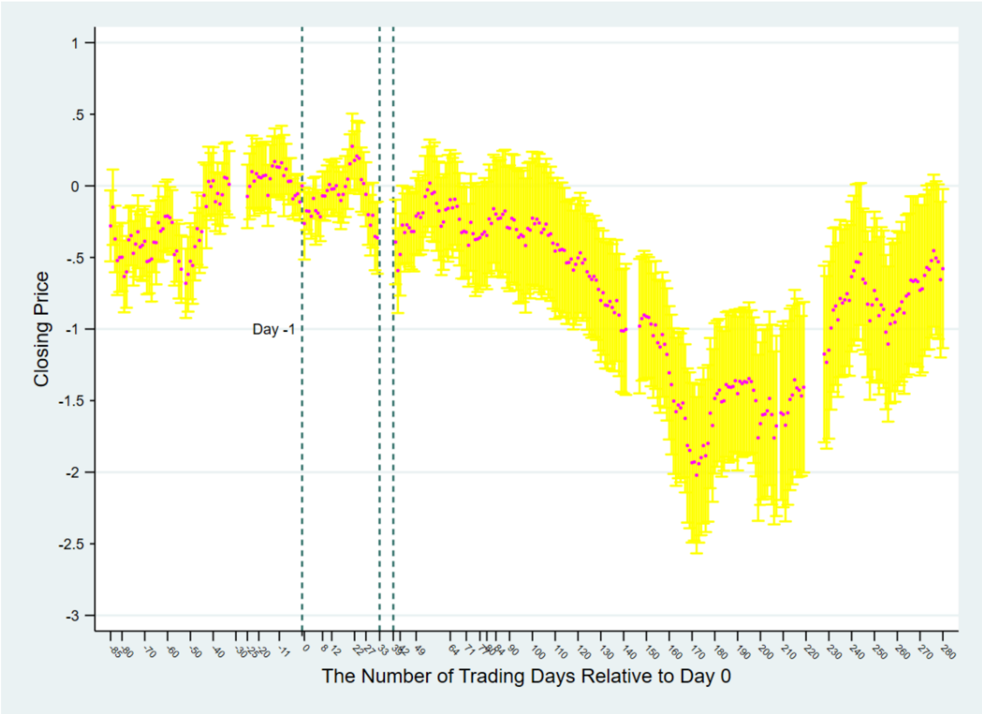

Figure A-13. Event study for communication services over a longer time horizon.

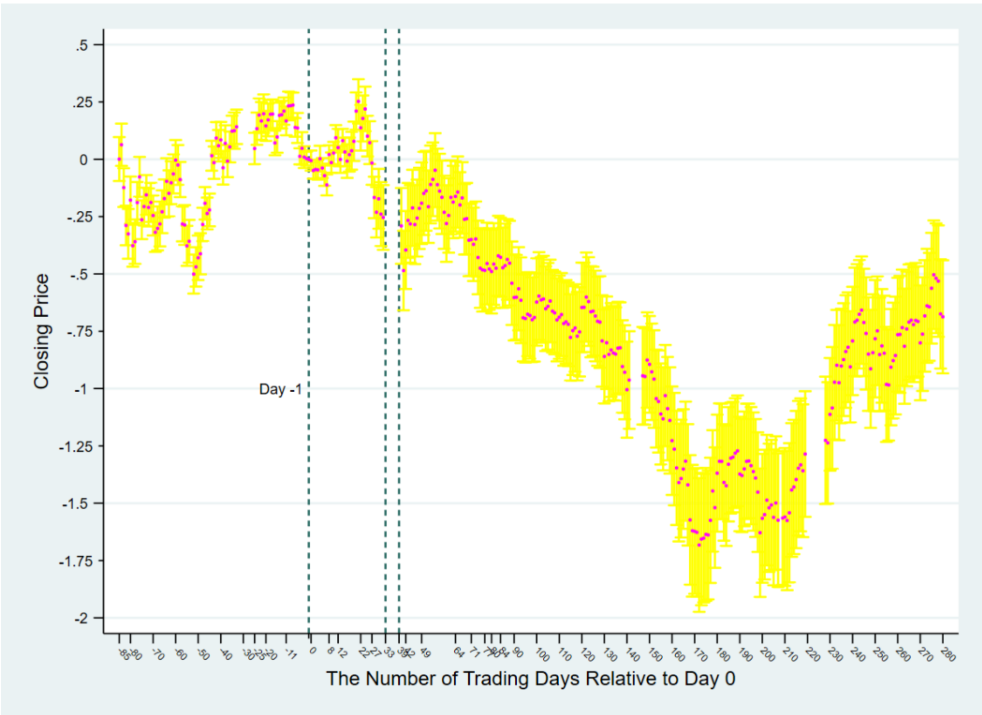

Figure A-14. Event study for consumer discretionary over a longer time horizon.

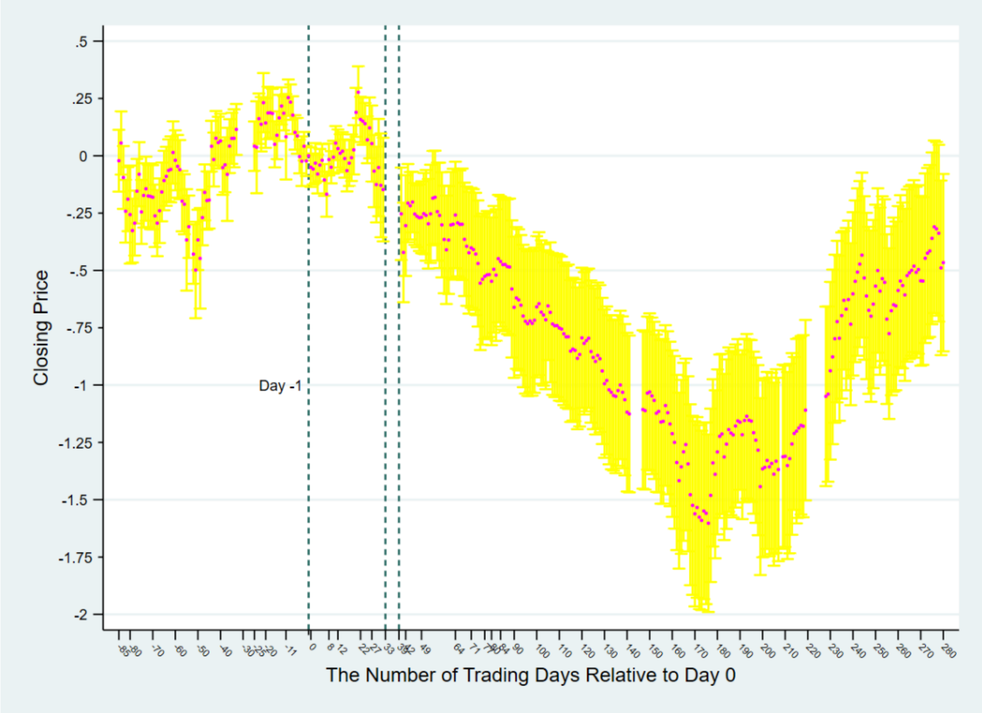

Figure A-15. Event study for consumer staples over a longer time horizon.

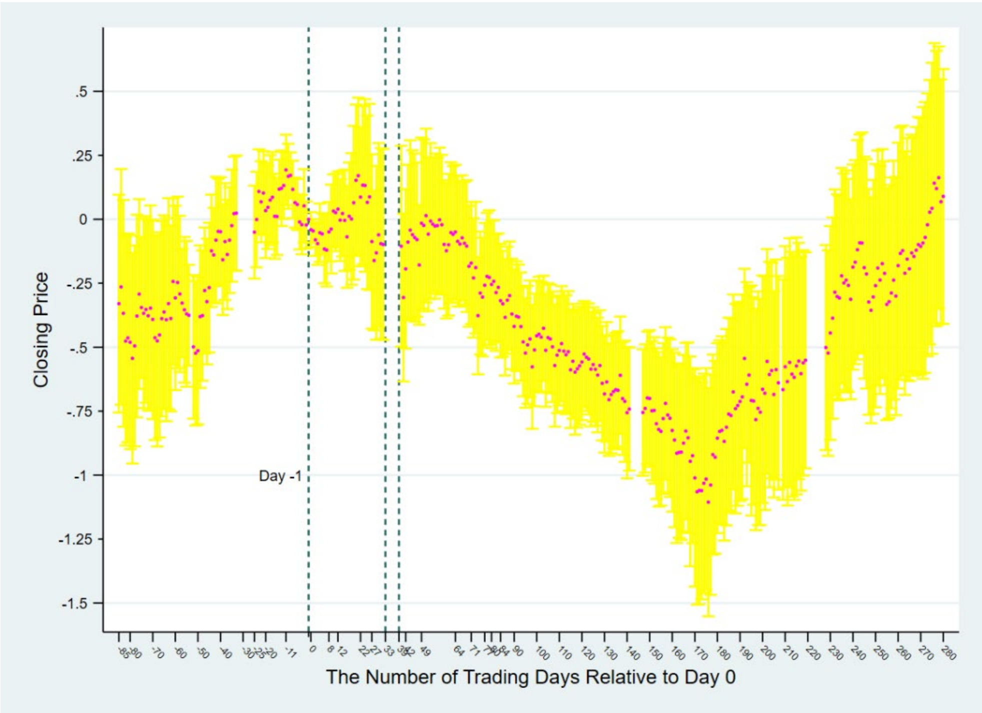

Figure A-16. Event study for energy over a longer time horizon.

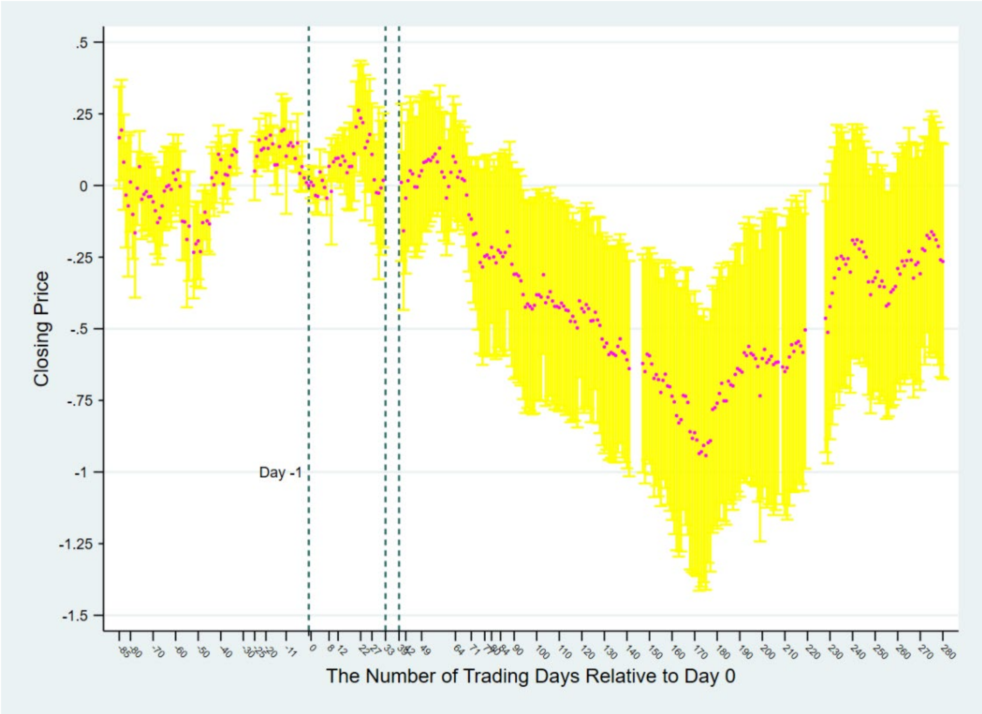

Figure A-17. Event study for financials over a longer time horizon.

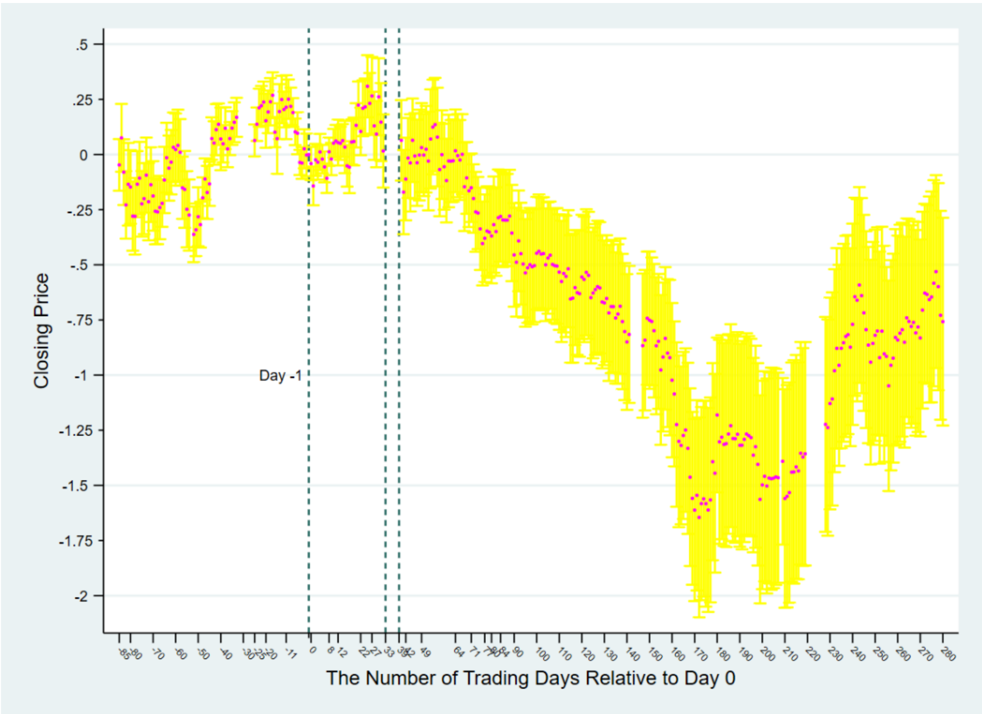

Figure A-18. Event study for health care over a longer time horizon.

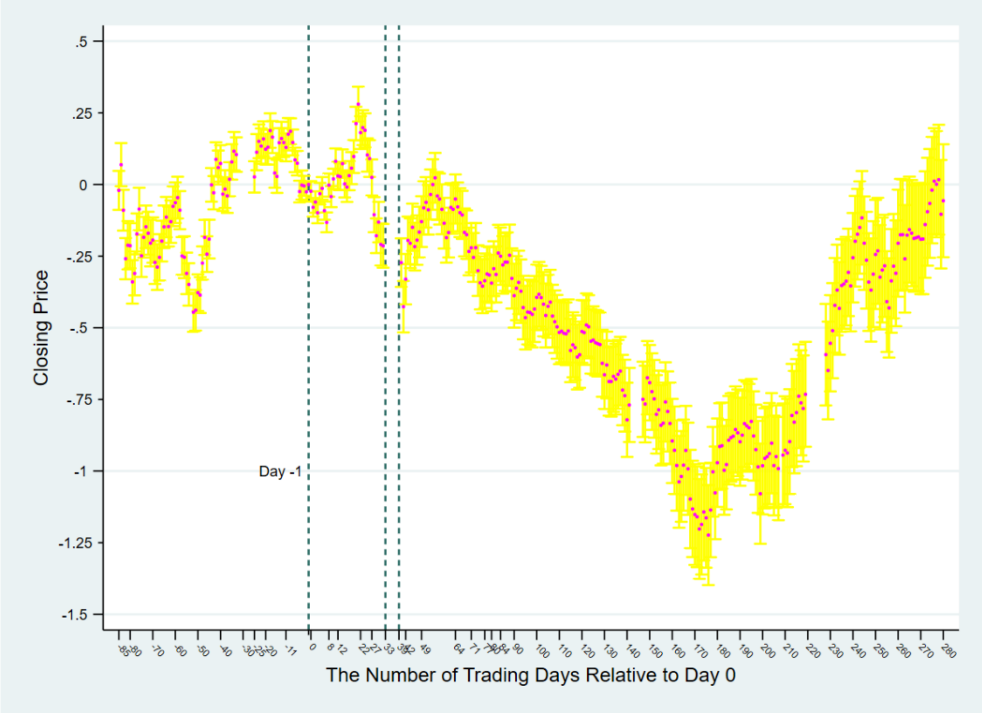

Figure A-19. Event study for industrials over a longer time horizon.

Figure A-20. Event study for information technology over a longer time horizon.

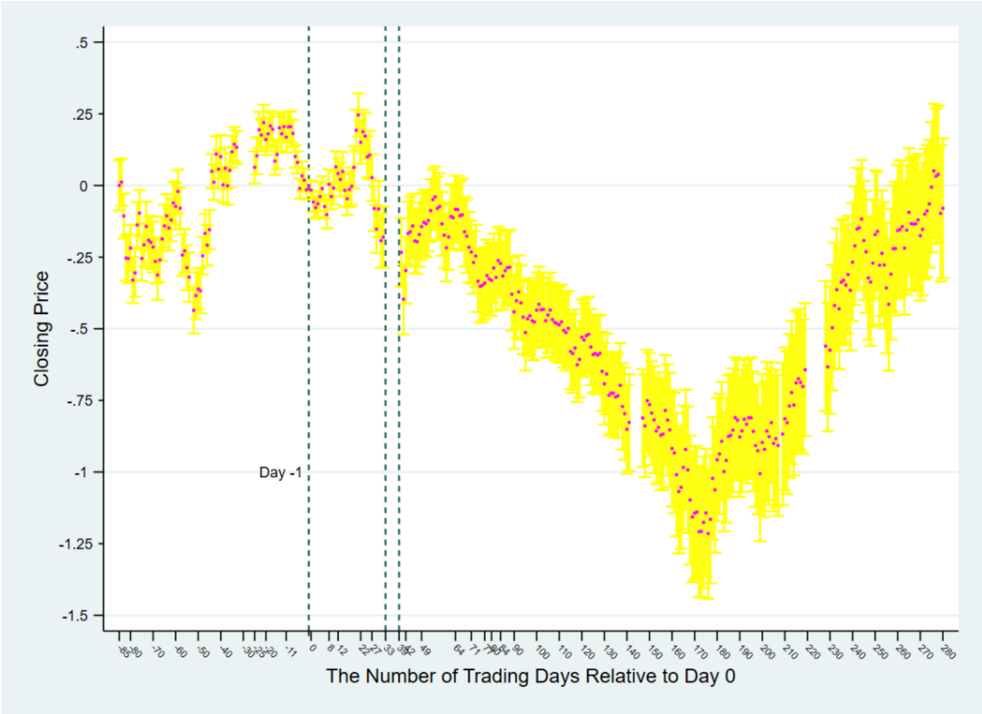

Figure A-21. Event study for materials over a longer time horizon.

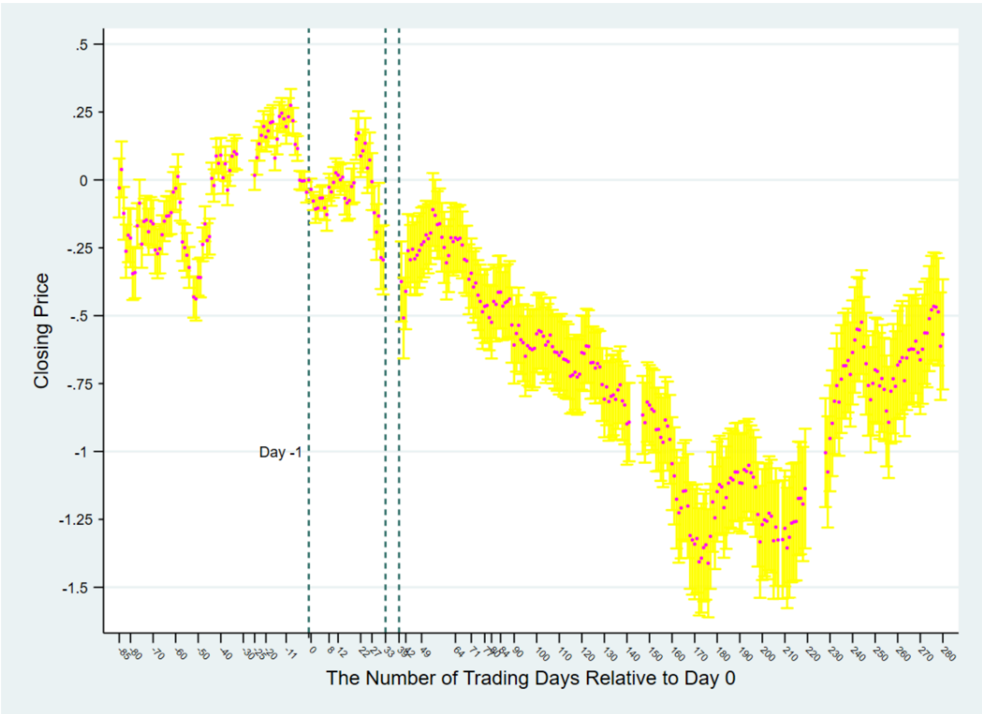

Figure A-22. Event study for real estate over a longer time horizon.

Figure A-23. Event study for utilities over a longer time horizon.

A.4 Cumulative Average Abnormal Returns

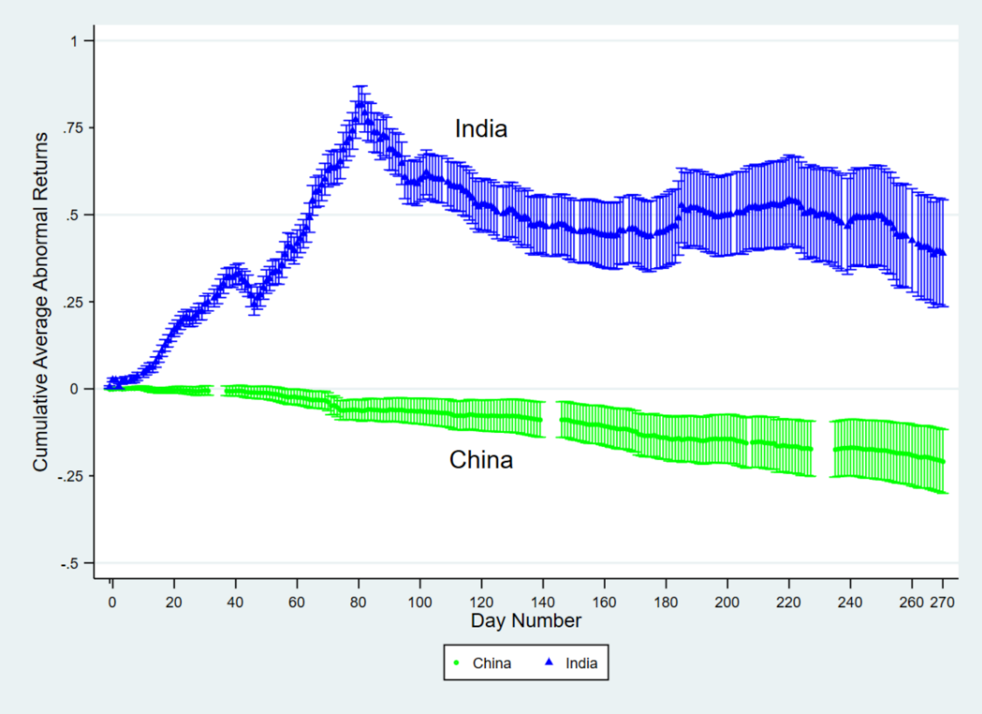

Figure A-24. Cumulative average abnormal returns from Day -1 (14/03/2003) to Day 270 (29/03/2004) during the placebo year for China and India.

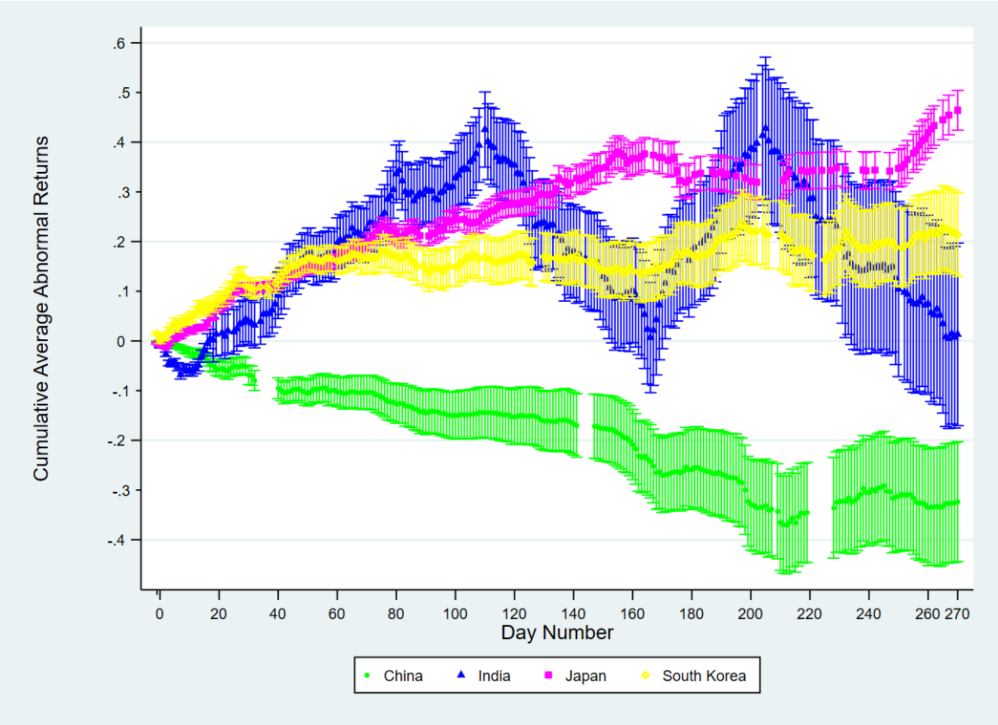

Figure A-25. Cumulative average abnormal returns from Day -1 (14/03/2003) to Day 270 (29/03/2004) in the SARS year for China, India, South Korea and Japan.

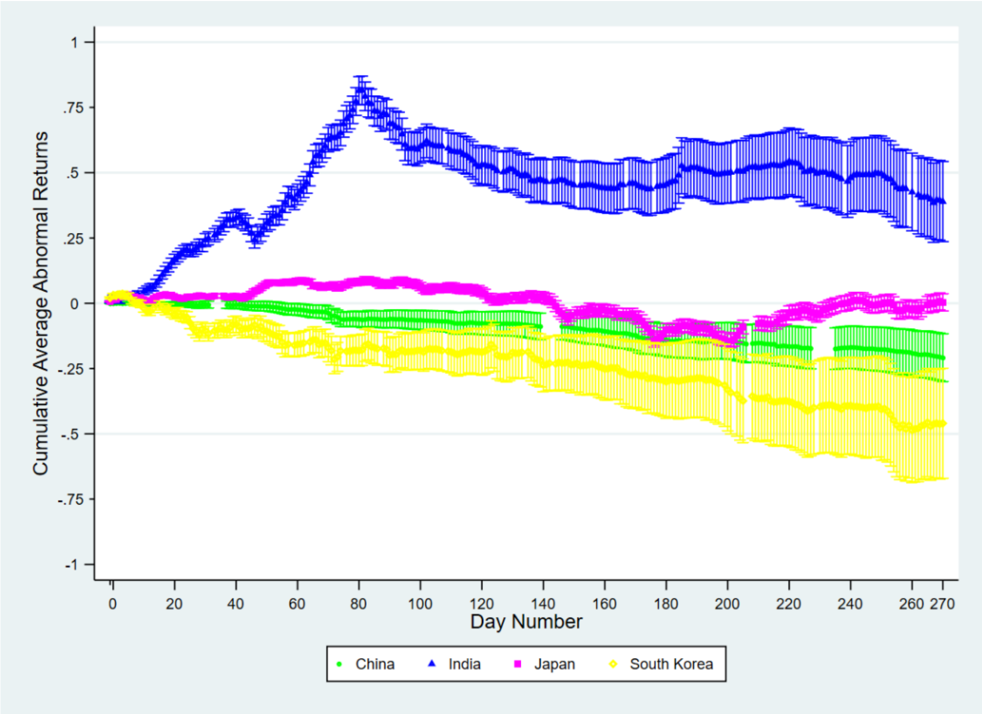

Figure A-26. Cumulative average abnormal returns from Day -1 (14/03/2003) to Day 270 (29/03/2004) in the placebo year for China, India, South Korea and Japan.

A.5 India-specific Difference-in-differences

Table A-1 The Impact of SARS on Indian Stock Returns (Using India-Specific DD)

	(1) Economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financials	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	.563*** (.0253)	1.109*** (.140)	.501*** (.0583)	.413*** (.0773)	.806*** (.111)	.493*** (.117)	.624*** (.0901)	.621*** (.0458)	.838*** (.0877)	.441*** (.0505)	-.0814 (.233)	.535* (.197)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.216*** (.0472)	.448 (.259)	-.416*** (.111)	.139 (.165)	.186 (.200)	-.146 (.205)	-.292* (.131)	-.222* (.0948)	-.209 (.166)	-.243* (.0970)	-1.233* (.480)	.254 (.528)
Post-period 2 (%)	.814*** (.0254)	1.295*** (.139)	.761*** (.0567)	.592*** (.0814)	.900*** (.118)	.668*** (.112)	.867*** (.0895)	.874*** (.0504)	1.244*** (.0848)	.696*** (.0502)	.396 (.235)	.575* (.263)
N	860209	29606	166393	64312	18272	77114	61829	152671	76750	186206	20384	6672

Notes: The dependent variable is the daily log returns. The DD compares return changes in the SARS year relative to the pre-SARS year. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-2 The Impact of SARS on Systematic Risk (Using Modified CAPM Based on India-specific DD)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
Risk Changes	-.228 (.242)	-.552*** (.0692)	-.0279 (.118)	-.328* (.147)	-.492*** (.125)	-.235* (.102)	-.567*** (.0803)	-.744*** (.123)	-.736*** (.0754)	-1.159*** (.300)	-.166 (.386)
Panel B: systematic risk changes for two post-periods											
Post-period 1	.985*** (.249)	.0232 (.105)	.246 (.181)	-.0693 (.155)	-.174 (.184)	.188 (.150)	.0228 (.113)	.444* (.175)	.0978 (.109)	.228 (.549)	-.136 (.268)
Post-period 2	-.481 (.251)	-.627*** (.0725)	.0208 (.120)	-.423* (.172)	-.557*** (.127)	-.385*** (.107)	-.642*** (.0845)	-.953*** (.123)	-.814*** (.0774)	-1.292*** (.304)	-.124 (.410)
N	29586	166276	64267	18257	77060	61777	152559	76697	186056	20370	6665

Notes: The adjusted CAPM compares changes in systematic risk in the SARS year relative to the pre-SARS year. It includes interaction terms between a dummy for SARS year and a dummy for post-period based on country-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

The India-specific DD estimates are displayed in Table A-1 to check whether India is a well-founded control group. The panel A in Table A-1 indicates that the real estate sector in India is a good control group when treating the post-period as a whole. Next, the analysis focuses on DD estimates when the post-treatment period is split into two sub-periods with the Chinese stock market closure period as a dividing line. Panel B in Table A-1 demonstrates that stock returns in the following Indian sectors can serve as reliable control groups in the first sub-period: communication services, consumer staples, energy, financials, information technology and utilities. The Indian real estate sector was also not affected by SARS in the second phase of the post-period and can be considered as a good control group.

As shown in Panel A of Table A-2, when focusing on the entire post-period, the systematic risk of the following Indian industries can be used as justifiable comparison groups: communication services, consumer staples and utilities. After dividing the whole post-treatment period into two parts, Panel B of Table A-2 demonstrates that the sectors listed below can be reasonable control groups: consumer discretionary, consumer staples, energy, financials, health care, industrials, materials, real estate and utilities in the first stage of the post-period; utilities, communication services and consumer staples in the second phase of the post-period.

A.6 Year-specific Difference-in-Differences Results for the Pre-SARS Year (Placebo Test)

Table A-3 The Impact of SARS on A-Share Returns (Using the Year-Specific DD for the Pre-SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	.0219 (.0223)	.510** (.160)	.0183 (.0518)	-.177* (.0713)	.225* (.103)	.324** (.0988)	.0590 (.0571)	-.0210 (.0476)	.388*** (.0771)	-.201*** (.0442)	-.357 (.185)	-.0438 (.183)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.0729 (.0389)	.170 (.269)	-.187 (.102)	-.0546 (.122)	.309* (.138)	.379* (.177)	-.159 (.0936)	-.101 (.0744)	-.0499 (.137)	-.194* (.0815)	-.216 (.269)	.0873 (.236)
Post-period 2 (%)	.263*** (.0218)	.715*** (.155)	.308*** (.0506)	-.0247 (.0705)	.325** (.0969)	.429*** (.108)	.242*** (.0559)	.250*** (.0486)	.707*** (.0745)	.0681 (.0409)	-.00302 (.205)	.0347 (.169)
N	605851	20602	105634	43879	13907	39591	43994	111568	53544	122848	34295	15989

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to India. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-4 The Impact of SARS on Systematic Risk (Using Modified CAPM Based on the Year-Specific DD for the Pre-SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
Risk Changes	.00788 (.109)	-.534*** (.0551)	-.312*** (.0895)	-.266** (.0959)	-.171 (.0992)	-.240** (.0764)	-.475*** (.0577)	-.183* (.0807)	-.627*** (.0586)	-.743*** (.219)	-.181 (.169)
Panel B: systematic risk changes for two post-periods											
Post-period 1	.623*** (.147)	.103 (.0876)	.116 (.150)	.314 (.175)	.293 (.162)	.244* (.121)	.174 (.0918)	.284* (.127)	.336*** (.0920)	.275 (.329)	.371 (.189)
Post-period 2	-.127 (.120)	-.641*** (.0579)	-.298*** (.0862)	-.410*** (.117)	-.240* (.101)	-.383*** (.0796)	-.558*** (.0619)	-.252** (.0805)	-.723*** (.0609)	-.836*** (.233)	-.316 (.233)
N	20582	105517	43834	13892	39537	43942	111456	53491	122698	34281	15982

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to India. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

A.7 Robustness Test Using Alternative Control Countries

A number of robustness checks are conducted by respectively using South Korea and Japan as control countries in both DD and DDD methods, the results of which are set out in appendices A.4 and A.9. The first set of robustness analyses focus on whether South Korea and Japan can be credible control groups compared with India. When studying the causal effect of SARS on A-share returns, the real estate in South Korea during the whole post-period is a valid control group for its Chinese counterparts, which is similar to using India as a control group, whereas in the case of Japan, the utilities can serve as a good comparison group. If the post-period is split into two sub-periods, the real estate during both sub-periods as well as the utilities in the second sub-period in South Korea appear to be reasonable control groups for the corresponding Chinese sectors, whilst in Japan, energy and health care before the Chinese stock market closure along with the utilities after the market closure can be good proxy for the counterfactual trend in A-share returns. Overall, the utilities in the second half of the post-period for all three countries can be a plausible control group for the Chinese stock market. However, in the first sub-period, more sectors in India can serve as valid control groups compared with South Korea and Japan.

When investigating the causal impact of SARS on the systematic risk of Chinese A-share market in the entire post-period, no sectors in South Korea can be convincing control groups for the corresponding Chinese industries, whereas in Japan, the communication services and real estate can act as good control groups. Furthermore, in addition to communication services and consumer staples in South Korea before the trading halt in China, South Korean financials and real estate after the Chinese stock market shutdown can be used as credible proxy for the counterfactual systematic risk of the A-share market. Therefore, there are also more Indian industries which can be employed as credible control groups in risk valuation.

The second robustness check compares findings obtained from the year-specific DD using South Korea and Japan as control groups. Some results are robust to the control group. In the placebo test, the parallel trend assumption in terms of A-share returns is satisfied for the following sectors using South Korea as a control group: energy and utilities for the entire post-period, as well as energy and utilities for the second half of the post-period. When employing Japan as the control group, the parallel trend assumption holds true for the industries specified below: communication services, consumer discretionary, energy, financials, industrials, real estate and all sectors combined for the whole post-period, consumer staples and health care before the stock market closure, together with communication services, consumer discretionary, financials, health care, industrials and real estate after the trading halt. In summary, compared with utilising

India as a control group, most sectors do not meet the common trend assumption when using South Korea as a control group, whereas the number of sectors that satisfy the parallel trend assumption employing Japan as a comparison group is comparable to that assigning India to the control group.

As for the risk valuation based on the year-specific DD, the financials (when using South Korea as a control group) and the utilities (when employing Japan as a control group) satisfy the parallel trend assumption for the entire post-period. Moreover, the communication services, financials and energy when using either South Korea or Japan as a control group before stock market closure meet the parallel trend assumption. In addition, the assumption also holds true for the following sectors: financials (when using South Korea as a control group) both before and after the stock market shutdown, the consumer staples, health care, industrials, materials, real estate before market closure (when assigning Japan to the control group), as well as the utilities (when Japan is the control group) before and after the closure of the stock market. Interestingly, when India is the control group, the sectors for which the parallel trend assumption holds true are similar to those when using Japan as the control group in the first half of the post-period. What's more, in the whole post-period and the second stage of the post-period, more sectors meet the parallel trend assumption when India is the control group compared with the case when South Korea or Japan is assigned to the comparison group.

Turning to the year-specific DD in the SARS year using either Japan or South Korea as the control group, the overall A-share stock market and all the sectors experienced a significant drop in A-share returns during the whole post-period regardless of the control country. More specifically, this decline in returns mostly occurred after the stock market closure time. These results are similar to those obtained from using India as a control group. As for risk valuation, over the post-period as a whole, the financials experienced a significant decline in systematic risk when South Korea is the control group, whereas the systematic risk of utilities significantly surged when Japan is used as the control group. Notably, the following results are robust to the choice of using either South Korea or Japan as the control group: the systematic risk of energy prior to the stock market closure and financials after the reopening of the stock market were not significantly affected by SARS, the former of which is consistent with the findings when India is the control group.

Finally, the robustness check analyses results of DDD which utilises South Korea and Japan as the control group. Specifically, when employing Japan as the control group, the DDD estimates indicate that the A-share returns for the entire economy and for all the sectors except utilities plummeted significantly while SARS had a null effect on A-share returns of the utilities. Moreover, the returns in utilities decreased significantly in the earlier stage of the post-period, but remain unchanged during the second phase of the post-period. Also, the overall stock market and all the sectors excluding health care and utilities experienced a significant decline in stock returns both in advance of and in the wake of stock market closure. In particular, SARS had a null impact on the stock returns of health care before the market closure, but the returns of health care decreased significantly afterwards. As for the case when South Korea is used as a control country, the impact of SARS on A-share returns was significantly negative for every sector and the entire A-share stock market. Besides, in both earlier and later phases of the post-period, A-share returns dropped significantly for each sector and all sectors combined. What’s more, the magnitude of the decline in A-share returns was much larger compared with using Japan or India as a control country, which is induced by the large increase in South Korea stock returns. According to Bloomberg News, the surge in South Korean stock returns is possibly caused by the economic recovery in U.S., which greatly boosted the sales of South Korea exports, and the new president’s economic policies, which were perceived to stimulate the nation’s economy. These results are partly consistent with those using India as a control country and confirm that the impact of SARS on A-share returns of the entire stock market and most sectors was significantly negative during the whole post-period, especially following the reopening of the stock market.

As for the risk analysis, when Japan is treated as the control country, all the sectors other than communication services and real estate experienced a significant increase in systematic risk and the surge in the risk kicked in until the later stage of the post-period. During the earlier phase of the post-period, the volatility in consumer discretionary and real estate fell off significantly, whereas the systematic risk of other sectors was not significantly influenced by SARS. When South Korea is the control group, besides financials which witnessed a significant decline in systematic risk, the systematic risk in other sectors soared significantly and the increase in systematic risk for these sectors took effect after the reopening of the stock market. In terms of financials, the market risk was not notably influenced by SARS in the second sub-period, but increased significantly over the first sub-period. These findings are also similar to those using India as a control country. Most sectors experienced an upsurge in systematic risk: consumer discretionary, energy, financials, industrials, information technology and materials, while the increase in market risk mainly happened following the trade resumption.

Given that the impact of SARS on A-share returns using South Korea as a control country is much larger than expected, another robustness check is conducted by winsorizing 10 percent of the observations in each tail of the distribution in order to examine whether the extreme outliers could influence the DD and DDD results. The results obtained from this robustness test demonstrate that after winsorization, the estimates using the modified CAPM are unchanged, whereas most DD or DDD estimates for changes in stock returns appear to be smaller. In addition, most DDD estimates regarding stock returns employing the winsorized data are still larger than one. This robustness check reveals that the estimates are unlikely to be driven by extreme values.

A.8 DD and DDD Results (Using South Korea as a Control Group)

Table A-5 and Table A-6 show results obtained from the country-specific DD and adjusted CAPM for South Korea. Table A-7 to Table A-10 display findings from the year-specific DD and adjusted CAPM using South Korea as a control group. The results of DDD and risk analysis based on DDD with South Korea as a control group are shown in Table A-11 and Table A-12.

Table A-5. The Impact of SARS on Stock Returns in South Korea (using the Country-specific DD)

	(1) economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financials	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	1.172*** (.0311)	1.108*** (.108)	1.133*** (.0698)	1.209*** (.119)	.681*** (.0910)	1.559*** (.117)	.838*** (.0717)	1.263*** (.0736)	1.445*** (.0904)	1.091*** (.0619)	.480 (.773)	.485* (.201)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	1.575*** (.0499)	1.208*** (.265)	1.479*** (.0977)	1.757*** (.241)	.920** (.193)	2.148*** (.198)	1.320*** (.121)	1.640*** (.122)	1.704*** (.171)	1.526*** (.0878)	1.607 (1.159)	.731* (.268)
Post-period 2 (%)	.978*** (.0291)	.970*** (.120)	1.009*** (.0663)	1.007*** (.0972)	.644*** (.0658)	1.275*** (.106)	.698*** (.0703)	1.019*** (.0745)	1.189*** (.0676)	.907*** (.0595)	.243 (.796)	.329 (.166)
N	225590	6002	40957	20517	2455	14393	16445	48519	18054	54532	423	3293

Notes: The dependent variable is the daily log returns. The DD compares return changes in the SARS year relative to the pre-SARS year. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-6. The Impact of SARS on Systematic Risk in South Korea (using Modified CAPM based on the Country-specific DD)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	-.460* (.162)	-.473*** (.0456)	-.455*** (.0563)	-.409** (.0939)	.277** (.0871)	-.468*** (.0550)	-.407*** (.0426)	-.442*** (.0771)	-.443*** (.0384)	-1.130** (.380)	-.247*** (.0430)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.189 (.223)	-.298*** (.0574)	-.146 (.0923)	-.445** (.0771)	.565*** (.0993)	-.390*** (.0693)	-.142* (.0652)	-.307** (.0989)	-.261*** (.0565)	-1.095* (.514)	-.342** (.0844)
Post-period 2	-.712** (.183)	-.611*** (.0585)	-.656*** (.0757)	-.377* (.0989)	.0794 (.0915)	-.539*** (.0688)	-.597*** (.0481)	-.544*** (.105)	-.575*** (.0482)	-.801 (.429)	-.232** (.0505)
N	5965	40702	20387	2443	14300	16343	48218	17940	54189	420	3272

Notes: The adjusted CAPM compares changes in systematic risk in the SARS year relative to the pre-SARS year. It includes interaction terms between a dummy for SARS year and a dummy for post-period based on country-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-7. The Impact of SARS on A-share Returns (using the Year-specific DD for the SARS Year)

	(1) economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financials	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	-.659*** (.0204)	-.713*** (.0888)	-.691*** (.0395)	-.723*** (.0767)	-.620*** (.0531)	-.761*** (.0798)	-.511*** (.0721)	-.670*** (.0493)	-.746*** (.0716)	-.584*** (.0438)	-.290*** (.0187)	-.495*** (.138)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.763*** (.0308)	-.746*** (.178)	-.818*** (.0604)	-.878*** (.101)	-.743*** (.0893)	-.597*** (.142)	-.555*** (.107)	-.740*** (.0777)	-.823*** (.0969)	-.744*** (.0668)	-.950*** (.0404)	-.360 (.200)
Post-period 2 (%)	-.535*** (.0202)	-.600*** (.0784)	-.574*** (.0382)	-.601*** (.0738)	-.545*** (.0568)	-.657*** (.0797)	-.499*** (.0696)	-.510*** (.0517)	-.580*** (.0810)	-.466*** (.0418)	.0188 (.0185)	-.462*** (.115)
N	345403	9984	53173	26658	7031	12577	25422	71678	27271	70594	26059	14956

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to South Korea. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-8. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on the Year-specific DD for the SARS Year)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	.0418 (.105)	-.0848* (.0378)	.0530 (.0493)	.134* (.0575)	-.347*** (.0896)	-.0574 (.0481)	-.00885 (.0375)	.121 (.0710)	.0135 (.0342)	.424*** (.0306)	.138* (.0590)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.323* (.138)	-.337*** (.0488)	-.201*** (.0593)	.0884 (.0894)	-.543*** (.123)	-.316*** (.0647)	-.273*** (.0471)	-.132 (.0830)	-.207*** (.0422)	.708*** (.0433)	.0674 (.0885)
Post-period 2	.366** (.106)	.115* (.0458)	.262*** (.0645)	.132 (.0651)	-.180 (.0908)	.0942 (.0609)	.210*** (.0437)	.279*** (.0819)	.181*** (.0409)	.242*** (.0323)	.178* (.0764)
N	9947	52918	26528	7019	12484	25320	71377	27157	70251	26056	14935

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to South Korea. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-9. The Impact of SARS on A-share Returns (using the Year-specific DD for the Pre-SARS Year)

	(1) economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financials	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	.620*** (.0257)	.500** (.167)	.613*** (.0646)	.538*** (.103)	.125 (.111)	.999*** (.0954)	.478*** (.0593)	.654*** (.0621)	.845*** (.0855)	.598*** (.0443)	.342*** (.0173)	-.0109 (.0988)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	1.066*** (.0429)	.763** (.234)	.981*** (.0844)	.994*** (.200)	.456* (.219)	1.635*** (.158)	.840*** (.111)	1.134*** (.106)	1.221*** (.164)	1.066*** (.0779)	1.084*** (.0396)	.412** (.139)
Post-period 2 (%)	.548*** (.0251)	.479** (.173)	.601*** (.0660)	.454*** (.0966)	.149 (.0855)	.845*** (.106)	.414*** (.0545)	.571*** (.0585)	.740*** (.0857)	.523*** (.0448)	.382*** (.0163)	-.139 (.116)
N	327326	9084	51893	25331	6611	12161	23958	66708	25315	66577	25308	14380

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to South Korea. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-10. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on the Year-specific DD for the Pre-SARS Year)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	-.435** (.135)	-.519*** (.0391)	-.396*** (.0462)	-.327*** (.0752)	-.0718 (.0646)	-.406*** (.0466)	-.413*** (.0368)	-.339*** (.0569)	-.393*** (.0317)	-.651*** (.0225)	-.184** (.0635)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.317 (.181)	-.439*** (.0574)	-.245* (.0946)	-.239 (.140)	.0792 (.109)	-.418*** (.0613)	-.300*** (.0554)	-.253** (.0879)	-.294*** (.0504)	-.208*** (.0310)	-.285*** (.0602)
Post-period 2	-.459** (.137)	-.528*** (.0442)	-.419*** (.0490)	-.359*** (.0661)	-.115 (.0654)	-.394*** (.0491)	-.436*** (.0384)	-.367*** (.0627)	-.409*** (.0338)	-.573*** (.0238)	-.152* (.0683)
N	9084	51893	25331	6611	12161	23958	66708	25315	66577	25308	14380

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to South Korea. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-11. The Impact of SARS on A-share Returns (using DDD)

	(1) economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financial s	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DDD estimates for the entire post-period												
DDD estimate (%)	-1.298*** (.0332)	-1.293*** (.155)	-1.303*** (.0727)	-1.291*** (.128)	-.769*** (.117)	-1.761*** (.127)	-.998*** (.0805)	-1.361*** (.0801)	-1.608*** (.0995)	-1.203*** (.0673)	-.643*** (.0273)	-.501* (.194)
Panel B: DDD estimates for two post-periods												
Post-period 1 (%)	-1.832*** (.0534)	-1.542*** (.299)	-1.793*** (.104)	-1.891*** (.248)	-1.198*** (.209)	-2.230*** (.226)	-1.400*** (.136)	-1.879*** (.131)	-2.043*** (.180)	-1.810*** (.101)	-2.034*** (.0566)	-.771** (.263)
Post-period 2 (%)	-1.108*** (.0314)	-1.171*** (.164)	-1.177*** (.0693)	-1.088*** (.111)	-.724*** (.0981)	-1.505*** (.129)	-.925*** (.0805)	-1.127*** (.0812)	-1.341*** (.0791)	-1.016*** (.0646)	-.378*** (.0258)	-.344* (.165)
N	672729	19068	105066	51989	13642	24738	49380	138386	52586	137171	51367	29336

Notes: The dependent variable is the daily log returns. The DDD compares return changes in China relative to South Korea during the SARS year compared with the pre-SARS year. Panel A and B show results for the entire post-period and two sub-periods respectively. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-12. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on DDD)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	.482** (.174)	.432*** (.0533)	.449*** (.0700)	.464*** (.106)	-.275* (.107)	.349*** (.0700)	.406*** (.0525)	.460*** (.0903)	.410*** (.0485)	1.076*** (.0365)	.323*** (.0560)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.00224 (.236)	.102 (.0699)	.0416 (.117)	.327* (.148)	-.622*** (.160)	.102 (.0899)	.0267 (.0768)	.122 (.114)	.0857 (.0698)	.915*** (.0547)	.354*** (.100)
Post-period 2	.827*** (.195)	.641*** (.0652)	.682*** (.0887)	.493*** (.117)	-.0650 (.109)	.488*** (.0839)	.648*** (.0579)	.646*** (.116)	.594*** (.0575)	.816*** (.0384)	.331*** (.0644)
N	19031	104811	51859	13630	24645	49278	138085	52472	136828	51364	29315

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to South Korea in the SARS year compared to the pre-SARS year. It includes interaction terms of 3 dummies for China, post-period and SARS year respectively based on DDD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

A.9 DD and DDD Results (Using Japan as a Control Group)

Table A-13 and Table A-14 show results obtained from the country-specific DD and modified CAPM for Japan. Table A-15 to Table A-18 summarise findings from the year-specific DD and modified CAPM using Japan as a control group. The results of DDD and risk analysis based on DDD with Japan as a control group are demonstrated in Table A-19 and Table A-20.

Table A-13. The Impact of SARS on Stock Returns in Japan (using the Country-specific DD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	.279*** (.00857)	.516*** (.0542)	.215*** (.0182)	.102*** (.0201)	.182* (.0647)	.258*** (.0299)	.133*** (.0338)	.241*** (.0153)	.552*** (.0252)	.288*** (.0216)	.348*** (.0593)	.0158 (.0286)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	.141*** (.0120)	.332*** (.0759)	.103*** (.0276)	.112** (.0339)	.0976 (.119)	.159*** (.0435)	.0164 (.0498)	.134*** (.0223)	.219*** (.0361)	.100** (.0331)	.265** (.0816)	.428*** (.0389)
Post-period 2 (%)	.266*** (.00917)	.491*** (.0596)	.215*** (.0195)	.0958*** (.0211)	.207** (.0687)	.187*** (.0367)	.154*** (.0364)	.228*** (.0165)	.533*** (.0266)	.272*** (.0231)	.325*** (.0637)	-.0587 (.0336)
N	845596	23898	177389	70027	6175	43294	31799	249989	124930	95316	14819	7960

Notes: The dependent variable is the daily log returns. The DD compares return changes in the SARS year relative to the pre-SARS year. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-14. The Impact of SARS on Systematic Risk in Japan (using Modified CAPM based on the Country-specific DD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	-.0681 (.0818)	-.275*** (.0359)	-.328*** (.0412)	-.646** (.206)	-.315*** (.0674)	-.350*** (.0613)	-.415*** (.0302)	-.293*** (.0459)	-.465*** (.0397)	-.155 (.104)	-.177** (.0613)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.103 (.128)	.00301 (.0474)	-.0646 (.0620)	-.129 (.285)	-.323*** (.0866)	-.108 (.0912)	-.122** (.0417)	-.116 (.0626)	-.150* (.0588)	.203 (.166)	-.153 (.0916)
Post-period 2	-.0849 (.0798)	-.325*** (.0370)	-.363*** (.0426)	-.695** (.232)	-.318*** (.0690)	-.388*** (.0633)	-.469*** (.0310)	-.322*** (.0468)	-.547*** (.0431)	-.205 (.103)	-.159* (.0636)
N	17140	127110	50325	4476	30876	22808	178822	90277	68291	10815	5662

Notes: The adjusted CAPM compares changes in systematic risk in the SARS year relative to the pre-SARS year. It includes interaction terms between a dummy for SARS year and a dummy for post-period based on country-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-15. The Impact of SARS on A-share Returns (using the Year-specific DD for the SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	-.301*** (.00753)	-.534*** (.0434)	-.324*** (.0174)	-.200*** (.0225)	-.119* (.0518)	-.296*** (.0415)	-.247*** (.0281)	-.258*** (.0151)	-.417*** (.0223)	-.251*** (.0177)	-.496*** (.0414)	-.102** (.0329)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	-.245*** (.0124)	-.399*** (.0734)	-.297*** (.0280)	-.233*** (.0397)	-.0578 (.0857)	-.0364 (.0815)	-.0837 (.0476)	-.241*** (.0251)	-.345*** (.0387)	-.202*** (.0314)	-.392*** (.0716)	-.193*** (.0495)
Post-period 2 (%)	-.264*** (.00775)	-.475*** (.0482)	-.283*** (.0182)	-.168*** (.0228)	-.109 (.0566)	-.288*** (.0434)	-.246*** (.0291)	-.221*** (.0154)	-.342*** (.0232)	-.216*** (.0182)	-.462*** (.0430)	-.0895* (.0358)
N	672943	19285	124997	53036	9160	27659	33668	176835	84409	92627	33968	17299

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to Japan. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-16. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on the Year-specific DD for the SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	-.123 (.0878)	.0601 (.0325)	.113** (.0395)	.202* (.0980)	.0417 (.0725)	.0703 (.0547)	.182*** (.0328)	.206*** (.0516)	.181*** (.0386)	-.119 (.0806)	.193*** (.0460)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.0410 (.110)	-.0751 (.0429)	-.00245 (.0545)	-.0475 (.173)	.0545 (.108)	-.0892 (.0706)	.0346 (.0431)	.222*** (.0647)	.0469 (.0484)	-.151 (.109)	.0119 (.0744)
Post-period 2	-.0732 (.0908)	.131*** (.0332)	.148*** (.0424)	.248* (.0991)	.0234 (.0703)	.122* (.0580)	.228*** (.0339)	.234*** (.0526)	.231*** (.0403)	-.0647 (.0798)	.239*** (.0432)
N	18767	121122	51522	9017	26732	32975	171413	81628	90564	33622	17122

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to Japan. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-17. The Impact of SARS on A-share Returns (using the Year-specific DD for the Pre-SARS Year)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	economy -wide	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: DD estimates for the entire post-period												
DD estimate (%)	.0135 (.00728)	.0564 (.0499)	-.0310 (.0166)	-.0805*** (.0212)	.123 (.0663)	.0414 (.0336)	-.0823** (.0301)	.00862 (.0145)	.125*** (.0243)	.0616*** (.0172)	-.0811 (.0504)	-.0831*** (.0238)
Panel B: DD estimates for two post-periods												
Post-period 1 (%)	.115*** (.0108)	.183* (.0733)	.0724** (.0255)	.0556 (.0351)	.256* (.101)	.231*** (.0475)	.0147 (.0450)	.142*** (.0223)	.0732* (.0351)	.109*** (.0248)	.197** (.0665)	.328*** (.0413)
Post-period 2 (%)	.0274*** (.00764)	.0871 (.0546)	-.00219 (.0171)	-.0700** (.0226)	.154* (.0712)	-.00460 (.0441)	-.0278 (.0309)	.0135 (.0149)	.158*** (.0253)	.0691*** (.0184)	-.101 (.0530)	-.130*** (.0266)
N	619792	17679	116501	48463	8202	25980	31066	163021	75053	85328	31795	16704

Notes: The dependent variable is the daily log returns. The DD compares return changes in China relative to Japan. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods divided by stock market closure. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage terms. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-18. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on the Year-specific DD for the Pre-SARS Year)

	(1) Communication Services	(2) Consumer Discretionary	(3) Consumer Staples	(4) Energy	(5) Financials	(6) Health Care	(7) Industrials	(8) Information Technology	(9) Materials	(10) Real Estate	(11) Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	-.205* (.0870)	-.174*** (.0307)	-.207*** (.0415)	-.503** (.152)	-.278*** (.0641)	-.162*** (.0450)	-.230*** (.0285)	-.103* (.0433)	-.253*** (.0318)	-.204** (.0677)	-.0612 (.0742)
Panel B: systematic risk changes for two post-periods											
Post-period 1	.0535 (.121)	.125** (.0471)	.0361 (.0766)	-.0726 (.193)	-.214 (.126)	.0865 (.0833)	.0331 (.0419)	.294*** (.0640)	.0668 (.0538)	.246 (.130)	-.156 (.124)
Post-period 2	-.265** (.0933)	-.224*** (.0314)	-.238*** (.0434)	-.567** (.171)	-.311*** (.0658)	-.215*** (.0452)	-.293*** (.0303)	-.189*** (.0451)	-.339*** (.0342)	-.271*** (.0649)	-.0238 (.0799)
N	11439	70097	30275	6646	14489	22768	97276	43181	60366	28137	14583

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to Japan. It includes interaction terms between a dummy for China and a dummy for post-period based on year-specific DD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-19. The Impact of SARS on A-share Returns (using DDD)

	(1) economy -wide	(2) Communication Services	(3) Consumer Discretionary	(4) Consumer Staples	(5) Energy	(6) Financial s	(7) Health Care	(8) Industrials	(9) Information Technology	(10) Materials	(11) Real Estate	(12) Utilities
Panel A: DDD estimates for the entire post-period												
DDD estimate (%)	-.317*** (.0104)	-.590*** (.0623)	-.294*** (.0231)	-.124*** (.0288)	-.223** (.0781)	-.338*** (.0443)	-.170*** (.0397)	-.270*** (.0207)	-.546*** (.0326)	-.310*** (.0252)	-.418*** (.0618)	-.0154 (.0367)
Panel B: DDD estimates for two post-periods												
Post-period 1 (%)	-.359*** (.0161)	-.582*** (.107)	-.368*** (.0366)	-.290*** (.0512)	-.325* (.131)	-.267** (.0962)	-.101 (.0616)	-.383*** (.0333)	-.417*** (.0518)	-.309*** (.0408)	-.582*** (.0873)	-.518*** (.0558)
Post-period 2 (%)	-.295*** (.0109)	-.562*** (.0674)	-.282*** (.0244)	-.104*** (.0308)	-.240** (.0819)	-.286*** (.0535)	-.223*** (.0423)	-.242*** (.0213)	-.506*** (.0337)	-.284*** (.0263)	-.369*** (.0658)	.0424 (.0424)
N	1292735	36964	241498	101499	17362	53639	64734	339856	159462	177955	65763	34003

Notes: The dependent variable is the daily log returns. The DDD compares return changes in China relative to Japan during the SARS year compared with the pre-SARS year. Panel A and B show results for the entire post-period and two sub-periods respectively. The parentheses show standard errors clustered by firm. The estimates are expressed in percentage. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Table A-20. The Impact of SARS on Systematic Risk of Chinese Sectors (Modified CAPM based on DDD)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Financials	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
Panel A: systematic risk changes for the entire post-period											
risk changes	.0908	.235***	.323***	.701**	.316***	.231**	.414***	.311***	.432***	.101	.253***
	(.109)	(.0453)	(.0588)	(.212)	(.0921)	(.0752)	(.0431)	(.0663)	(.0495)	(.110)	(.0715)
Panel B: systematic risk changes for two post-periods											
Post-period 1	-.0876	-.199**	-.0400	.0112	.265	-.181	.00672	-.0693	-.0261	-.383*	.165
	(.156)	(.0622)	(.0949)	(.308)	(.152)	(.108)	(.0585)	(.0859)	(.0718)	(.173)	(.109)
Post-period 2	.199	.355***	.389***	.812**	.332***	.337***	.521***	.424***	.566***	.220*	.259**
	(.111)	(.0470)	(.0633)	(.239)	(.0916)	(.0798)	(.0448)	(.0694)	(.0533)	(.109)	(.0760)
N	30206	191219	81797	15663	41221	55743	268689	124809	150930	61759	31705

Notes: The adjusted CAPM compares changes in systematic risk in Chinese stock market relative to Japan in the SARS year compared to the pre-SARS year. It includes interaction terms of 3 dummies for China, post-period and SARS year respectively based on DDD. The dependent variable is the daily log returns. Panel A and B respectively show results for the whole post-period as well as the first and second post-periods split by stock market closure. The parentheses show standard errors clustered by firm. *, ** and *** indicate significance levels at 0.05, 0.01 and 0.001 respectively. The last row shows the number of observations in each regression.

Appendix B Chapter 4 Formulae

B.1 Geodetic Distance

The geodetic distance between two geographic coordinates is estimated based on the following Haversine formula (Robusto, 1957; Shylaja, 2015; Movable Type Scripts, 2021):

$$d = Rc$$

In this formula, R is the radius of the earth and

$$c = 2\tan^{-1}\frac{\sqrt{a}}{\sqrt{1-a}}$$

where

$$a = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos\varphi_1 \cos\varphi_2 \sin^2\left(\frac{\Delta\lambda}{2}\right)$$

$$\Delta\lambda = \lambda_2 - \lambda_1$$

$$\Delta\varphi = \varphi_2 - \varphi_1.$$

φ_1 and λ_1 denote the latitude and longitude at the starting point respectively while φ_2 and λ_2 indicate the latitude and longitude at the ending point on Earth.

Appendix C Chapter 4 Figures and Tables

C.1 Choropleth Maps about Distribution of Observations

The choropleth maps in C.1.1 below respectively show the distribution of the non-missing observations from 1998 to 2004 with respect to US counties exposed to wildfires in FIRESTAT dataset, US counties in birth data as well as US counties in the treated groups after merging FIRESTAT with birth data. Correspondingly, the choropleth maps in C.1.2 show the distribution of the non-missing observations between 2000 and 2010 in terms of US counties exposed to wildfires in FIRESTAT dataset, US counties in BRFSS data as well as US counties in the treated groups after merging FIRESTAT with BRFSS. In Figure C-11, Figure C-12 and Figure C-15, counties are treated when they lie within a 50-kilometre radius of the point of origin of wildfires which burned at least 5 total acres. In addition, the start date of pregnancy is calculated as gestational age subtracted from date of birth in Figure C-11 and 9 months before the date of birth in Figure C-12 respectively. The colours in Figure C-9 and Figure C-13 denote the number of non-missing observations in the maximum total acres burned over the corresponding time window while the colours in Figure C-11, Figure C-12 and Figure C-15 represent different values of the number of non-missing observations in the treatment status. Figure C-10 and Figure C-14 separately visualises how the number of non-missing values in birth weight and general physical health varies across US counties.

C.1.1 Natality Data

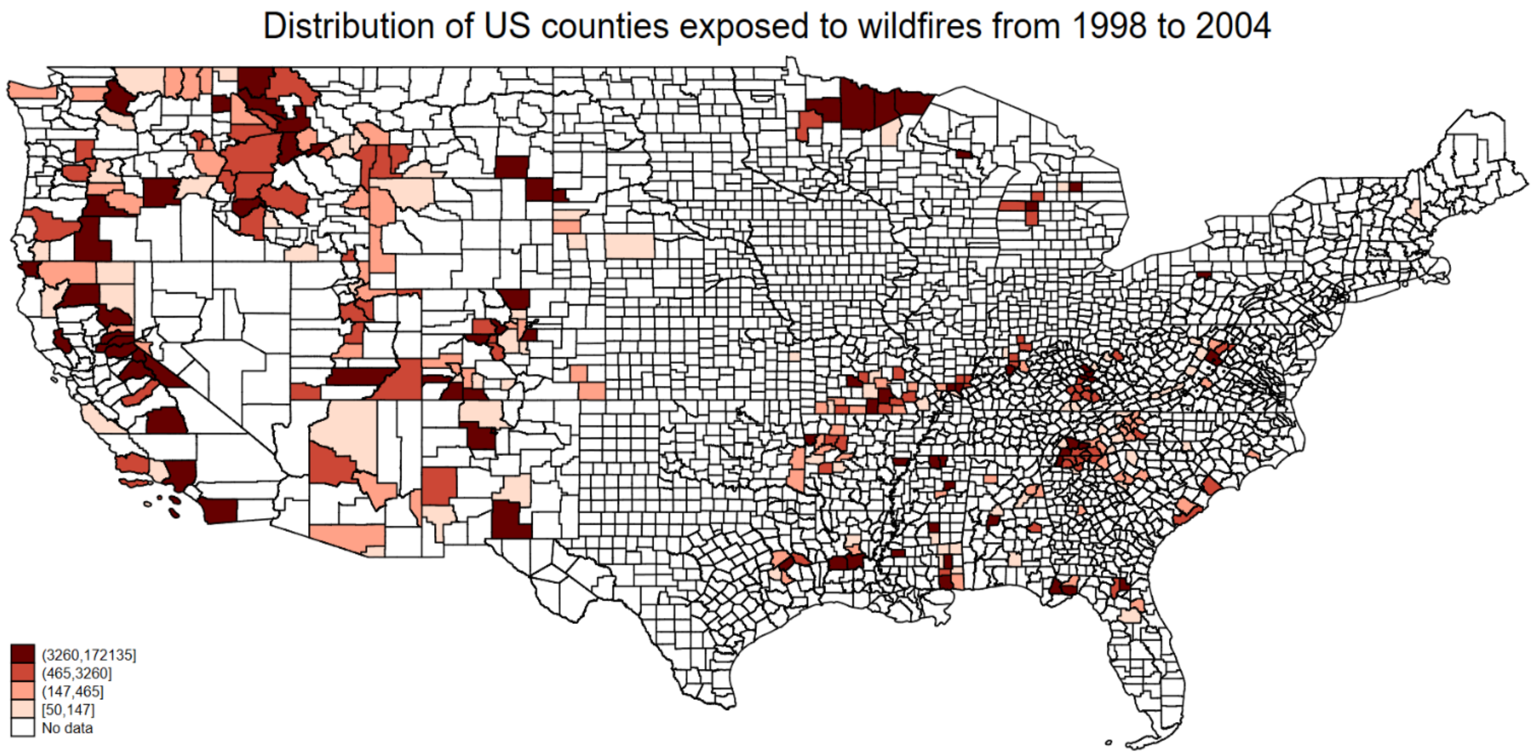

Figure C-1. The distribution of US counties exposed to any wildfires from 1998 to 2004.

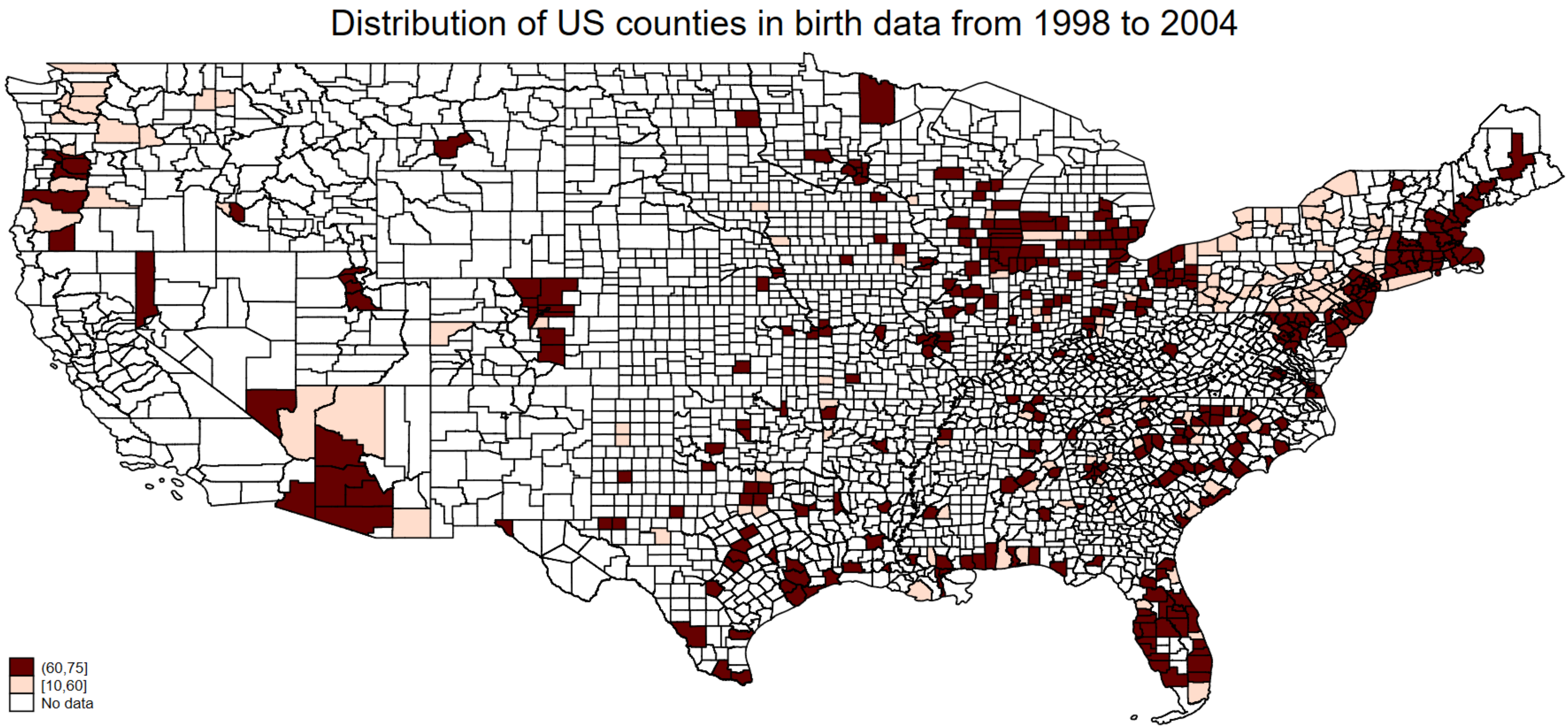

Figure C-2. The distribution of US counties in natality data from 1998 to 2004.

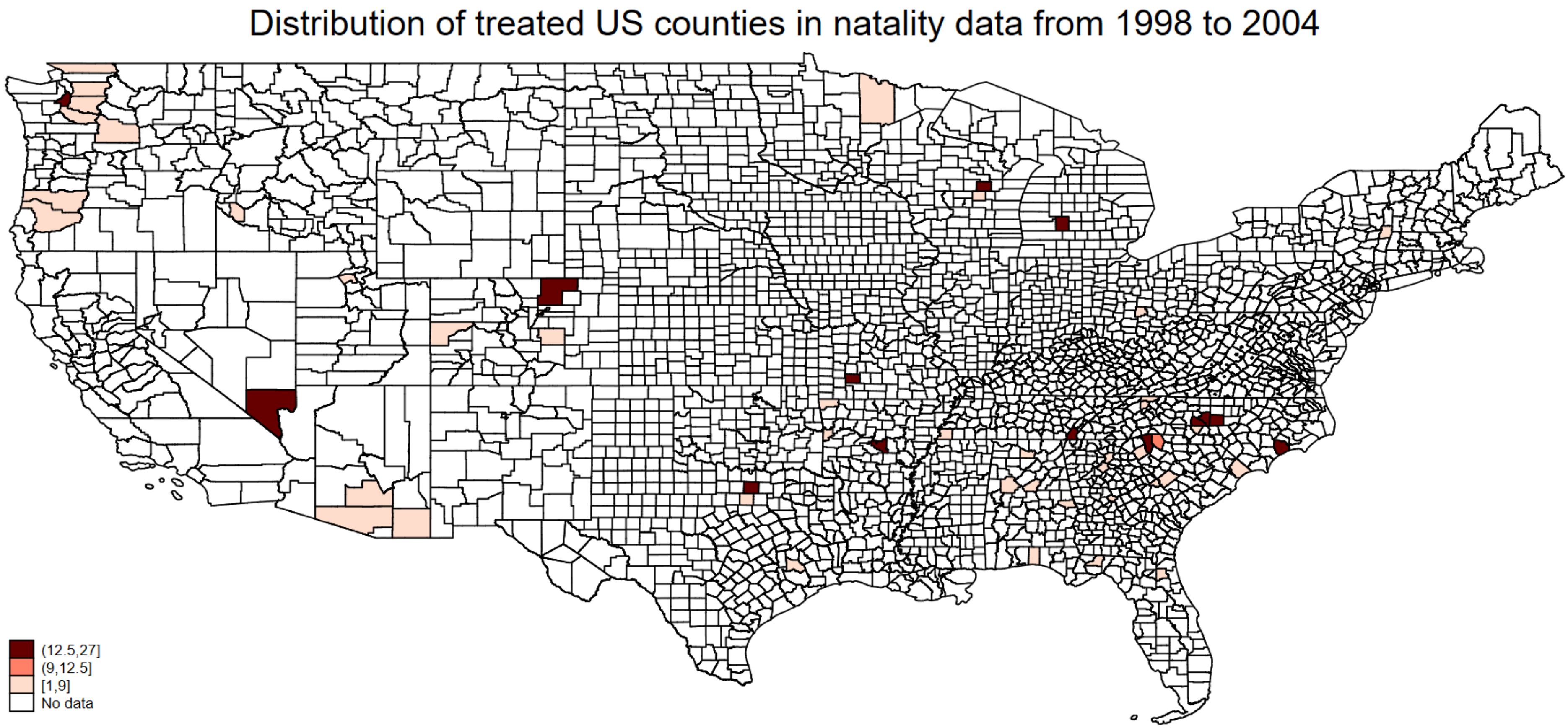

Figure C-3. The distribution of the treated US counties in natality data from 1998 to 2004 with gestational age subtracted from date of birth as the start date of pregnancy.

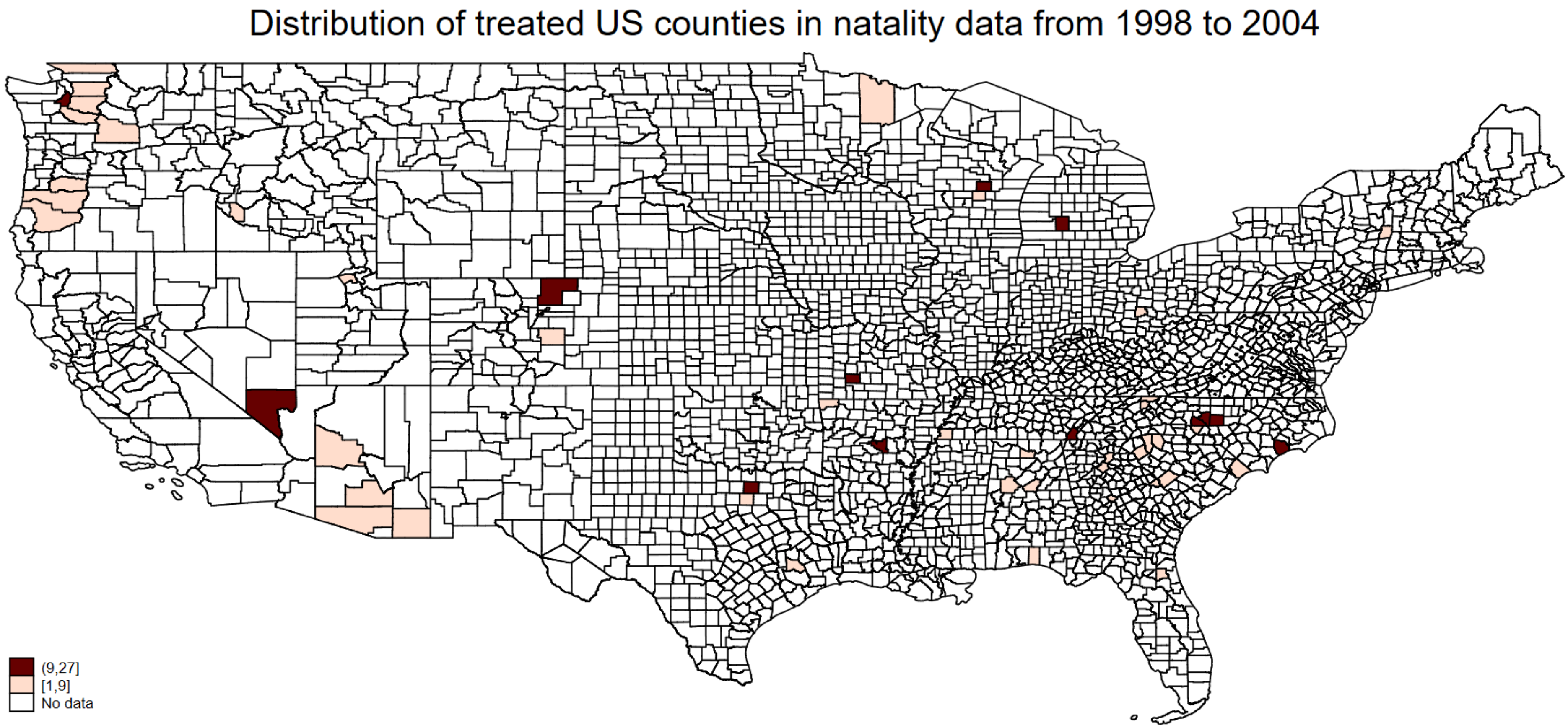

Figure C-4. The distribution of the treated US counties in natality data from 1998 to 2004 with 9 months subtracted from date of birth as the start date of pregnancy.

C.1.2 BRFSS

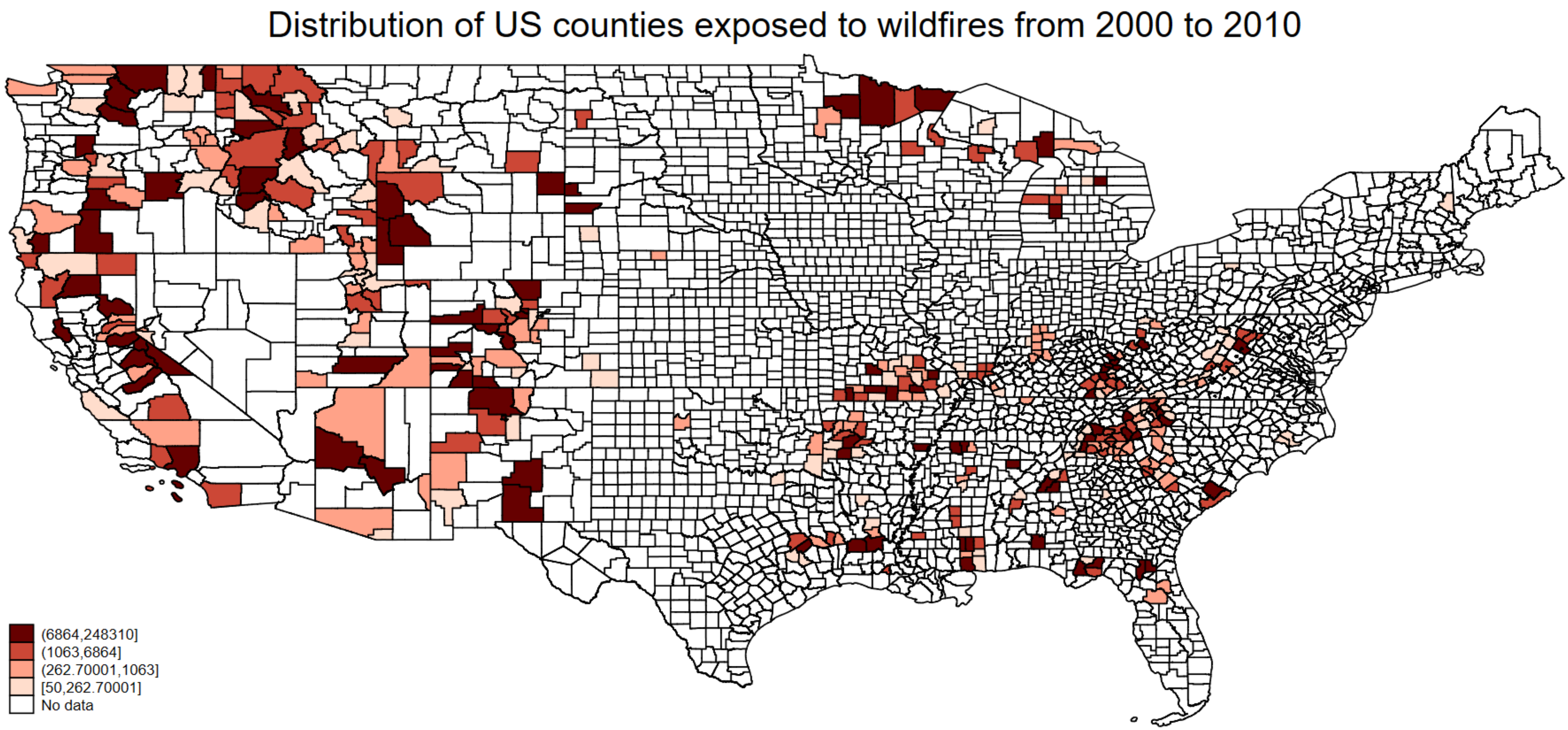

Figure C-5. The distribution of US counties exposed to any wildfires from 2000 to 2010.

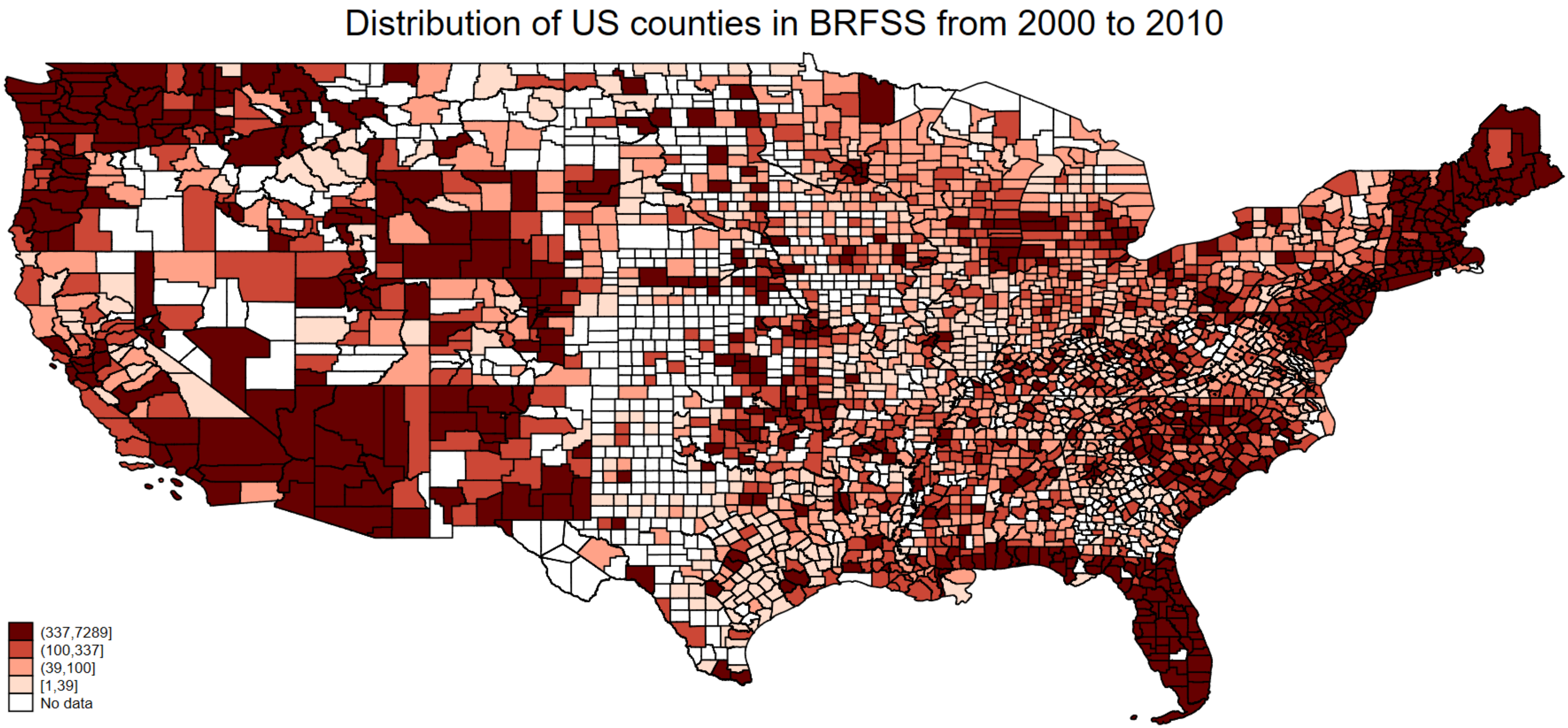

Figure C-6. The distribution of US counties in BRFSS from 2000 to 2010.

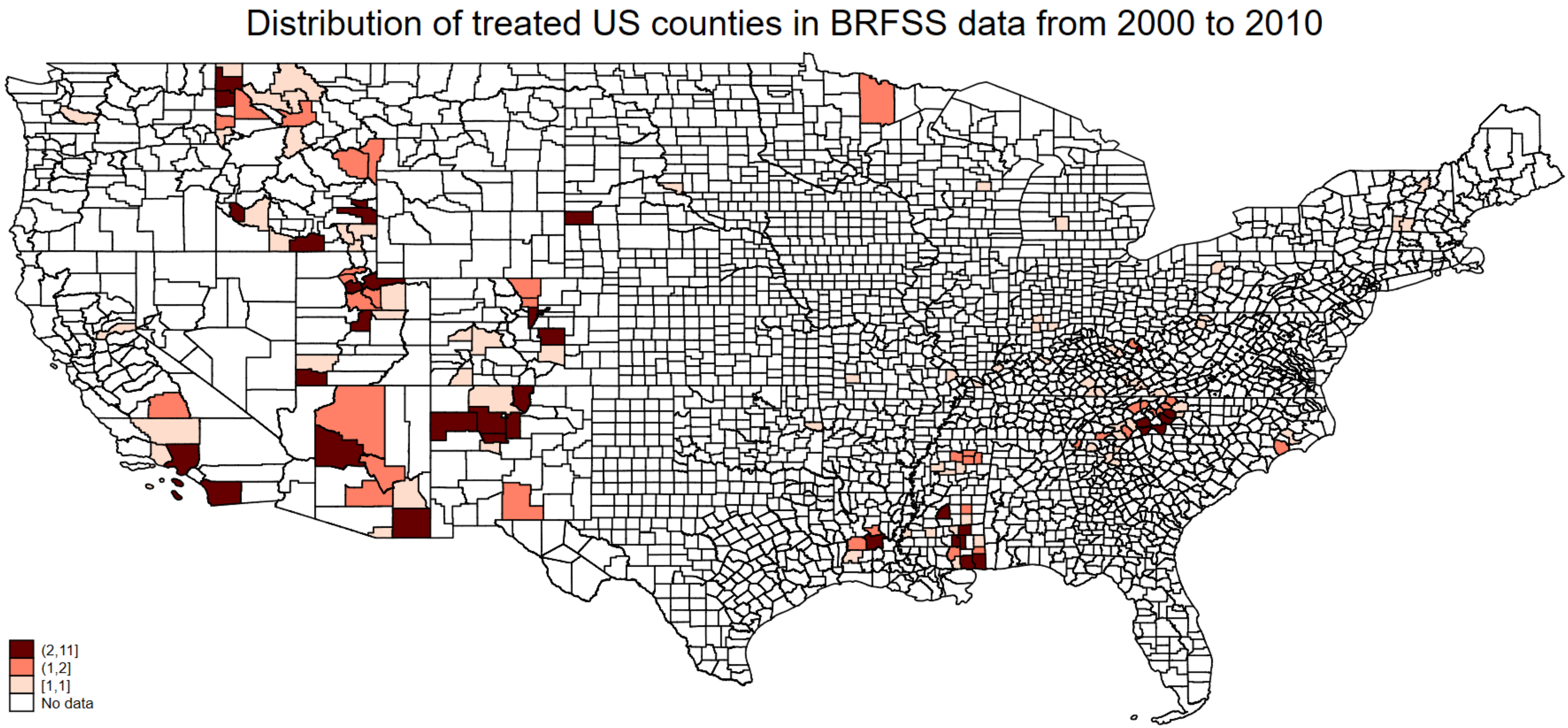

Figure C-7. The distribution of the treated US counties in BRFSS from 2000 to 2010.

C.2 The Effect of Wildfires on Birth Outcomes

C.2.1 The Impact of the Five Largest Wildfires on Birth Outcomes

Table C-1. The effect of the five largest wildfires on birth weight and gestational age (robustness test)

Birth outcomes	(1) Birth weight	(2) Low birth weight	(3) Macrosomia
The largest wildfire			
ATT	-0.00548	-0.000000173	-0.00000563*
	(-0.83)	(-0.05)	(-2.21)
Number of observations	419601	419601	419601
The second largest wildfire			
ATT	-0.000193	0.00000438	-0.00000303
	(-0.03)	(1.34)	(-0.89)
Number of observations	828169	828169	828169
The third largest wildfire			
ATT	0.0167	-0.00000692	-0.00000384
	(1.03)	(-1.01)	(-0.56)
Number of observations	233925	233925	233925
The fourth largest wildfire			
ATT	.0116	-.00000313	.00000227
	(.00616)	(.00000206)	(.00000358)
Number of observations	1177894	1177894	1177894
The fifth largest wildfire			
ATT	-.0108	.00000414	-.00000139
	(.0211)	(.00000753)	(.0000130)
Number of observations	206148	206148	206148

Note. The dependent variables include birth weight, a dummy for low birth weight and a dummy for macrosomia. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * p < 0.05, ** p < 0.01, *** p < 0.001. The start date of pregnancy is 9 months subtracted from date of birth. All estimates satisfy the parallel trend assumption.

Table C-2. The effect of the five largest wildfires on congenital anomalies (robustness test)

Birth outcomes	(1) Heart malformations	(2) Other circulatory/respiratory anomalies	(3) Omphalocele	(4) Cleft lip
The largest wildfire				
ATT	-0.00000181	0.000000781	0.000000396	-0.000000315
	(-1.99)	(1.75)	(1.51)	(-0.97)
Number of observations	823150	823150	823150	823150
The second largest wildfire				
ATT	0.000000138	-0.000000346	0.000000223	-0.000000152
	(0.36)	(-1.71)	(0.89)	(-0.47)
Number of observations	823150	823150	823150	823150
The third largest wildfire				
ATT	-0.000000228	-0.00000201	0.000000309	0.000000800
	(-0.23)	(-1.51)	(0.52)	(0.90)
Number of observations	215027	215027	232811	232811
The fourth largest wildfire				
ATT	0.000000123	0.000000847	-7.71e-08	-0.000000103
	(0.32)	(0.98)	(-0.47)	(-0.31)
Number of observations	1178545	1178545	1178545	1178545
The fifth largest wildfire				
ATT	-0.000000198	0.00000223	-0.00000149	-0.000000509
	(-0.11)	(1.14)	(-1.75)	(-0.48)
Number of observations	204531	204531	204531	204531

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth. All estimates satisfy the parallel trend assumption.

Table C-3. The effect of the five largest wildfires on birth weight and gestational age (placebo test)

Birth outcomes	(1) Birth weight	(2) Low birth weight	(3) Macrosomia	(4) Gestational age	(5) Preterm birth
The largest wildfire					
ATT	-.00702 (.00674)	.00000372 (.00000282)	-.000000583 (.00000271)	-.000123* (.0000561)	.0000118* (.00000458)
Number of observations	395756	395756	395756	395955	395955
The second largest wildfire					
ATT	.000215 (.00953)	-.000000539 (.00000364)	.00000471 (.00000351)	-.00000188 (.0000450)	.00000129 (.00000451)
Number of observations	806526	806526	806526	806793	806793
The third largest wildfire					
ATT	.00453 (.0135)	.0000125* (.00000510)	.0000149* (.00000695)	-.0000377 (.0000794)	.0000148 (.0000116)
Number of observations	223313	223313	223313	223391	223391
The fourth largest wildfire					
ATT	-.00577 (.00599)	-.000000153 (.00000259)	-.00000346 (.00000303)	-.0000280 (.0000410)	.00000191 (.00000413)
Number of observations	1138447	1138447	1138447	1139253	1139253
The fifth largest wildfire					
ATT	-.00159 (.0245)	-.0000145 (.00000839)	.000000797 (.00000894)	.000154 (.0000906)	-.0000146 (.0000192)
Number of observations	189866	189866	189866	190026	190026

Note. The dependent variables include birth weight, a dummy for low birth weight, a dummy for macrosomia, gestational age and an indicator for preterm birth. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth.

Table C-4. The effect of the five largest wildfires on congenital anomalies (placebo test)

Birth outcomes	(1) Heart malformations	(2) Other circulatory/respiratory anomalies	(3) Omphalocele	(4) Cleft lip
The largest wildfire				
ATT	-.000000397 (.000000524)	-.00000134 (.000000667)	-.000000634 (.000000332)	.000000250 (.000000447)
Number of observations	362999	362999	377548	377548
The second largest wildfire				
ATT	.000000570 (.000000355)	-.000000654* (.000000257)	-.000000168 (.000000201)	-7.03e-08 (.000000278)
Number of observations	800178	800178	800178	800178
The third largest wildfire				
ATT	.000000693 (.00000120)	-.000000469 (.000000358)	-.000000380 (.000000586)	-.000000439 (.000000741)
Number of observations	221379	221379	221379	221379
The fourth largest wildfire				
ATT	.000000263 (.000000299)	.000000242 (.000000286)	.000000226 (.000000222)	2.65e-08 (.000000279)
Number of observations	1136946	1136946	1136946	1136946
The fifth largest wildfire				
ATT	.00000173 (.000000987)	.00000954 (.00000636)	.00000204* (.000000961)	-.00000137 (.00000138)
Number of observations	186313	186313	186313	186313

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth.

Table C-5. The effect of the five largest wildfires on birth weight and gestational age (placebo test for robustness check)

Birth outcomes	(1) Birth weight	(2) Low birth weight	(3) Macrosomia
The largest wildfire			
ATT	-.000874	.00000290	.000000576
	(.00745)	(.00000318)	(.00000232)
Number of observations	398081	398081	398081
The second largest wildfire			
ATT	.00986	-.00000445	.00000630
	(.00852)	(.00000389)	(.00000350)
Number of observations	805798	805798	805798
The third largest wildfire			
ATT	.00931	.00000630	.0000147
	(.0118)	(.00000614)	(.00000770)
Number of observations	223899	223899	223899
The fourth largest wildfire			
ATT	-.0113**	.00000205	-.00000368
	(.00409)	(.00000216)	(.00000294)
Number of observations	1141042	1141042	1141042
The fifth largest wildfire			
ATT	-.00655	-.00000620	.000000722
	(.0189)	(.00000761)	(.00000889)
Number of observations	190385	190385	190385

Note. The dependent variables include birth weight, a dummy for low birth weight and a dummy for macrosomia. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth.

Table C-6. The effect of the five largest wildfires on congenital anomalies (placebo test for robustness check)

Birth outcomes	(1) Heart malformations	(2) Other circulatory/respiratory anomalies	(3) Omphalocele	(4) Cleft lip
The largest wildfire				
ATT	-5.44e-08	-.00000165**	-.000000630*	.000000192
	(.000000482)	(.000000572)	(.000000308)	(.000000385)
Number of observations	364182	364182	379705	379705
The second largest wildfire				
ATT	.000000156	-.000000420	-.000000259	-2.53e-08
	(.000000391)	(.000000262)	(.000000206)	(.000000271)
Number of observations	799573	799573	799573	799573
The third largest wildfire				
ATT	.000000392	-.00000130	-.000000604	-7.74e-08
	(.00000111)	(.000000727)	(.000000556)	(.000000828)
Number of observations	222079	222079	222079	222079
The fourth largest wildfire				
ATT	.000000386	.000000311	.000000293	.000000166
	(.000000377)	(.000000317)	(.000000247)	(.000000268)
Number of observations	1139696	1139696	1139696	1139696
The fifth largest wildfire				
ATT	.00000164	.00000830	.00000175*	-.00000170
	(.00000106)	(.00000522)	(.000000810)	(.00000122)
Number of observations	187007	187007	187007	187007

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates in DD regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth.

C.2.2 The Impact of Multiple Large Wildfires on Birth Outcomes

Table C-7. The effect of multiple large wildfires (which burned at least 50 acres) on birth outcomes

Birth outcomes	Low birth weight	Heart malformations	Omphalocele	Cleft lip
ATT	-.00722*** (.00129)	.000355 (.000224)	-.00000947 (.0000173)	-.000803 (.000539)
Number of observations	15946339	15233583	15793638	15793638
Parallel trend	Yes	Yes	Yes	Yes

Note. The dependent variables include a dummy for low birth weight as well as dummies for heart malformations, omphalocele and cleft lip. Standard errors are clustered by county. The covariates in TWFE regression include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth. The last row shows whether the parallel trend assumption is satisfied.

C.2.3 $DID_{+,t}$ Estimators

Table C-8. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 1)

	Birth Weight and Length of Gestation				
Birth outcomes	Birth weight	Low birth weight	Macrosomia	Gestational age	Preterm birth
wildfire size >=50 acres and distance<=20 km:					
ATT	-1.794 (19.766)	-.00194 (.00827)	.00758 (.00585)	.00239 (.0641)	.0175 (.0111)
Number of observations	2314	2314	2314	2314	2314
Parallel trend	Yes	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:					
ATT	7.690 (20.646)	-.0119 (.00875)		.0603 (.0947)	-.00211 (.0139)
Number of observations	2161	2161		2161	2161
Parallel trend	Yes	Yes		Yes	Yes
wildfire size >=5 acres and distance<=20 km:					
ATT	17.529 (12.335)	-.00311 (.00365)	.00656 (.00443)	.112* (.0544)	-.00270 (.00745)
Number of observations	4242	4242	4242	4242	4242
Parallel trend	Yes	Yes	Yes	Yes	Yes

Note. The dependent variables include birth weight, a dummy for low birth weight, a dummy for macrosomia, gestational age and an indicator for preterm birth. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth. The estimation is conducted using "did_multiplegt" in Stata 17.

Table C-9. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 1)

	Congenital Anomalies			
Birth outcomes	Heart malformations	Other circulatory or respiratory anomalies	Omphalocele	Cleft lip
wildfire size >=50 acres and distance<=20 km:				
ATT	.00158 (.00137)	-.00215 (.00176)	-.000194 (.000137)	-.000885 (.000793)
Number of observations	2246	2246	2314	2314
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	-.00174 (.00132)	-.00143 (.000989)	.000111 (.000276)	-.00130 (.00096)
Number of observations	2042	2042	2161	2161
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:				
ATT	.000393 (.000830)	-.00135 (.00158)	.000395 (.000461)	-.000868 (.000596)
Number of observations	4109	4109	4242	4242
Parallel trend	Yes	Yes	Yes	Yes

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth. The estimation is conducted using “did_multiplegt” in Stata 17.

Table C-10. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 1 & Alternative Starting Date of Pregnancy)

	Birth Weight and Length of Gestation		
Birth outcomes	Birth weight	Low birth weight	Macrosomia
wildfire size >=50 acres and distance<=20 km:			
ATT			-.000537 (.00819)
Number of observations			2329
Parallel trend			Yes
wildfire size >=50 acres and distance<=50 km:			
ATT	-15.120 (14.275)	.00629 (.00639)	
Number of observations	1867	1867	
Parallel trend	Yes	Yes	
wildfire size >=5 acres and distance<=20 km:			
ATT	7.470 (10.196)		.00151 (.00790)
Number of observations	3841		3841
Parallel trend	Yes		Yes
wildfire size >=5 acres and distance<=50 km:			
ATT	1.631 (10.076)	.0000575 (.00466)	
Number of observations	5331	5331	
Parallel trend	Yes	Yes	

Note. The dependent variables include birth weight, a dummy for low birth weight and a dummy for macrosomia. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * p < 0.05, ** p < 0.01, *** p < 0.001. The start date of pregnancy is 9 months subtracted from date of birth. The estimation is conducted using "did_multiplegt" in Stata 17.

Table C-11. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 1 & Alternative Starting Date of Pregnancy)

	Congenital Anomalies			
Birth outcomes	Heart malformations	Other circulatory or respiratory anomalies	Omphalocele	Cleft lip
wildfire size >=50 acres and distance<=20 km:				
ATT	-.000895 (.00191)	.000870 (.00107)	-.000101 (.000144)	-.000805 (.000816)
Number of observations	1869	1869	2329	2329
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	.0000663 (.000269)	.00110 (.00106)	-.000261 (.000705)	-.00109 (.00107)
Number of observations	1507	1507	1867	1867
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:				
ATT	-.000728 (.000920)	-.000253 (.000604)	-.000725 (.000526)	.000084 (.000660)
Number of observations	3381	3381	3841	3841
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=50 km:				
ATT	-.000265 (.000850)	-.000136 (.000594)	-.000423* (.000195)	-.000877* (.000439)
Number of observations	4819	4819	5331	5331
Parallel trend	Yes	Yes	Yes	Yes

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth. The estimation is conducted using “did_multiplegt” in Stata 17.

Table C-12. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 2)

	Birth Weight and Length of Gestation				
Birth outcomes	Birth weight	Low birth weight	Macrosomia	Gestational age	Preterm birth
wildfire size >=50 acres and distance<=20 km:					
ATT	10.378	-.00537	.00633	.0276	.00169
	(13.306)	(.00478)	(.00356)	(.0455)	(.00665)
Number of observations	8208	8208	8208	8208	8208
Parallel trend	Yes	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:					
ATT	-2.644	-.00249	-.000159	.000722	-.00267
	(5.534)	(.00220)	(.00347)	(.0242)	(.00358)
Number of observations	13167	13167	13167	13167	13167
Parallel trend	Yes	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:					
ATT	-7.800	.00820	.00724	-.0116	.0116
	(20.232)	(.0134)	(.00447)	(.124)	(.0203)
Number of observations	9083	9083	9083	9083	9083
Parallel trend	Yes	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=50 km:					
ATT	3.00692	.00343	.00422	-.0406	.00797
	(8.738)	(.00596)	(.00407)	(.0543)	(.00863)
Number of observations	11947	11947	11947	11947	11947
Parallel trend	Yes	Yes	Yes	Yes	Yes

Note. The dependent variables include birth weight, a dummy for low birth weight and a dummy for macrosomia. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth. The estimation is conducted using “did_multiplegt” in Stata 17.

Table C-13. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 2)

	Congenital Anomalies			
Birth outcomes	Heart malformations	Other circulatory or respiratory anomalies	Omphalocele	Cleft lip
wildfire size >=50 acres and distance<=20 km:				
ATT	.000544 (.000866)	-.000357 (.000795)	.000158 (.000266)	-.0000153 (.0004)
Number of observations	7919	7919	8208	8208
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	-.000247 (.000399)	-.000518 (.000422)	.0000798 (.000140)	.000133 (.000501)
Number of observations	12737	12737	13167	13167
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:				
ATT	-.000127 (.000390)	-.000325 (.000511)	-.000135 (.000327)	-.000428 (.000581)
Number of observations	8738	8738	9083	9083
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=50 km:				
ATT	-.000138 (.000411)	.000102 (.000512)	-.0000179 (.000105)	-.000181 (.000307)
Number of observations	11519	11519	11947	11947
Parallel trend	Yes	Yes	Yes	Yes

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is gestational age subtracted from date of birth. The estimation is conducted using “did_multiplegt” in Stata 17.

Table C-14. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 2 & Alternative Starting Date of Pregnancy)

	Birth Weight and Length of Gestation		
Birth outcomes	Birth weight	Low birth weight	Macrosomia
wildfire size >=50 acres and distance<=20 km:			
ATT	-7.098 (8.981)		.00301 (.00597)
Number of observations	8200		8200
Parallel trend	Yes		Yes
wildfire size >=50 acres and distance<=50 km:			
ATT	-6.325 (5.563)	.00205 (.00226)	-.00178 (.00302)
Number of observations	12602	12602	12602
Parallel trend	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:			
ATT	4.288 (7.171)		.00369 (.00498)
Number of observations	8285		8285
Parallel trend	Yes		Yes
wildfire size >=5 acres and distance<=50 km:			
ATT	1.528 (7.648)	.000170 (.00228)	.00356 (.00416)
Number of observations	11376	11376	11376
Parallel trend	Yes	Yes	Yes

Note. The dependent variables include birth weight, a dummy for low birth weight and a dummy for macrosomia. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * p < 0.05, ** p < 0.01, *** p < 0.001. The start date of pregnancy is 9 months subtracted from date of birth. The estimation is conducted using "did_multiplegt" in Stata 17.

Table C-15. The Effect of Wildfires on Birth Outcomes at the County Level (Pre-Period Definition 2 & Alternative Starting Date of Pregnancy)

	Congenital Anomalies			
Birth outcomes	Heart malformations	Other circulatory or respiratory anomalies	Omphalocele	Cleft lip
wildfire size >=50 acres and distance<=20 km:				
ATT	-.000826	-.000203	-.000105	2.41e-06
	(.000516)	(.000755)	(.0000913)	(.000377)
Number of observations	7560	7560	8200	8200
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	-.000088	-.000154	-.000239	-.000763*
	(.000208)	(.000393)	(.000141)	(.000348)
Number of observations	11951	11951	12602	12602
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=20 km:				
ATT	-9.02e-06	.000351	-.000364	.000285
	(.000402)	(.000507)	(.000253)	(.000333)
Number of observations	7607	7607	8285	8285
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=50 km:				
ATT	.000303	-.000404	-.000276	-.0000792
	(.000247)	(.000399)	(.000157)	(.000315)
Number of observations	10665	10665	11376	11376
Parallel trend	Yes	Yes	Yes	Yes

Note. The dependent variables include dummies for heart malformations, other circulatory/respiratory anomalies, omphalocele and cleft lip. Standard errors are clustered by county. The covariates include fetal sex, access to prenatal care, plurality, total birth order, diabetes, chronic hypertension and pregnancy-associated hypertension, tobacco use during pregnancy, maternal age, race, education levels and resident status. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The start date of pregnancy is 9 months subtracted from date of birth. The estimation is conducted using “did_multiplegt” in Stata 17.

C.2.4 Dynamic Causal Effects of Wildfires on Birth Outcomes

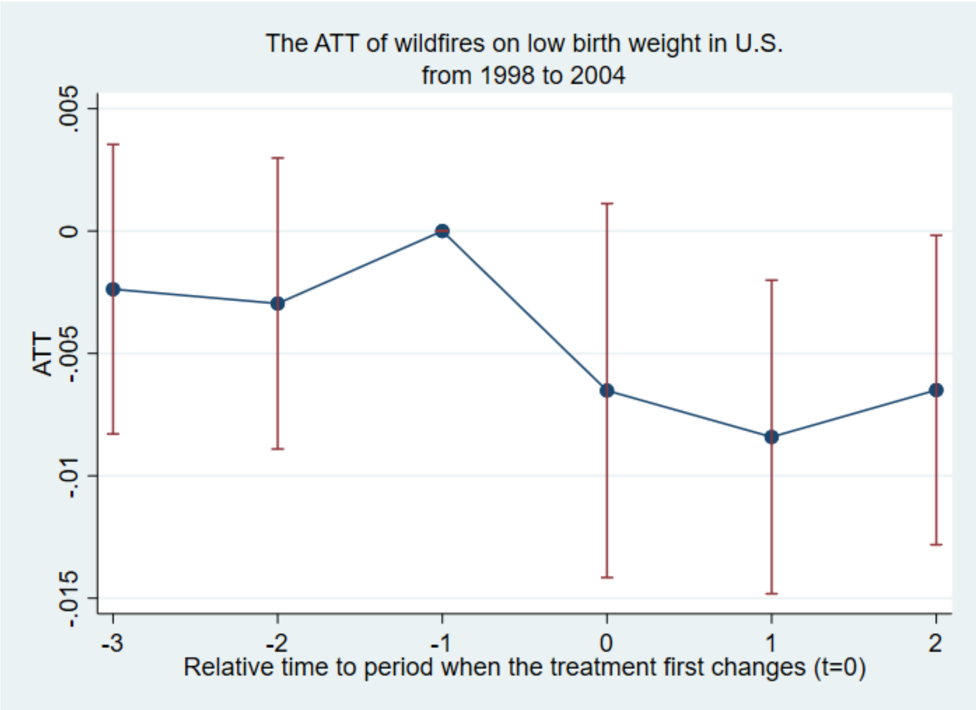

Figure C-8. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 20 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

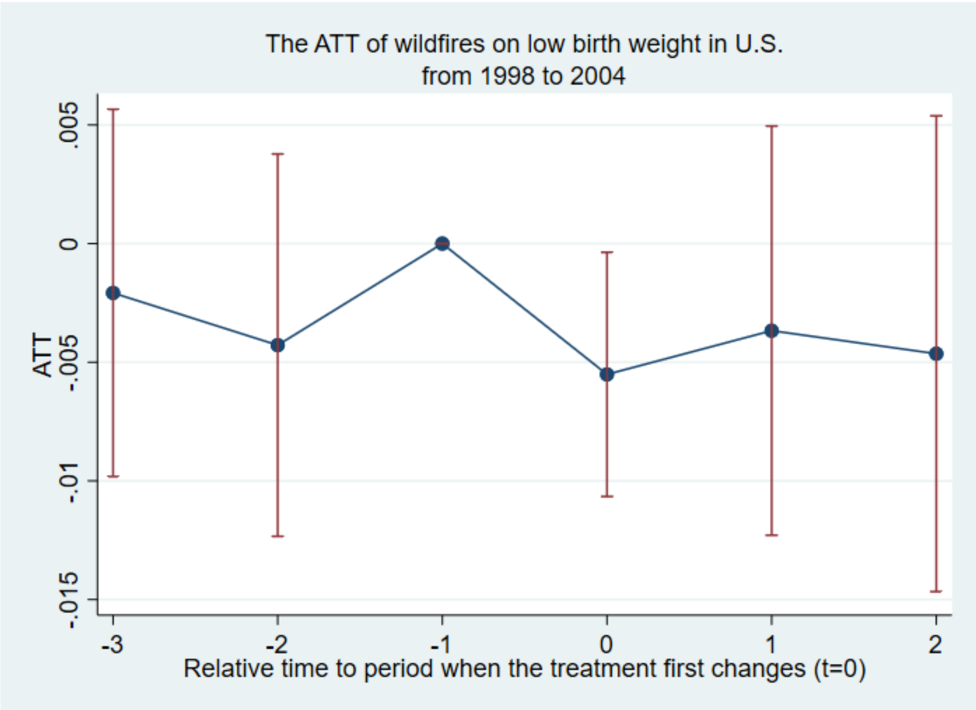

Figure C-9. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 20 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

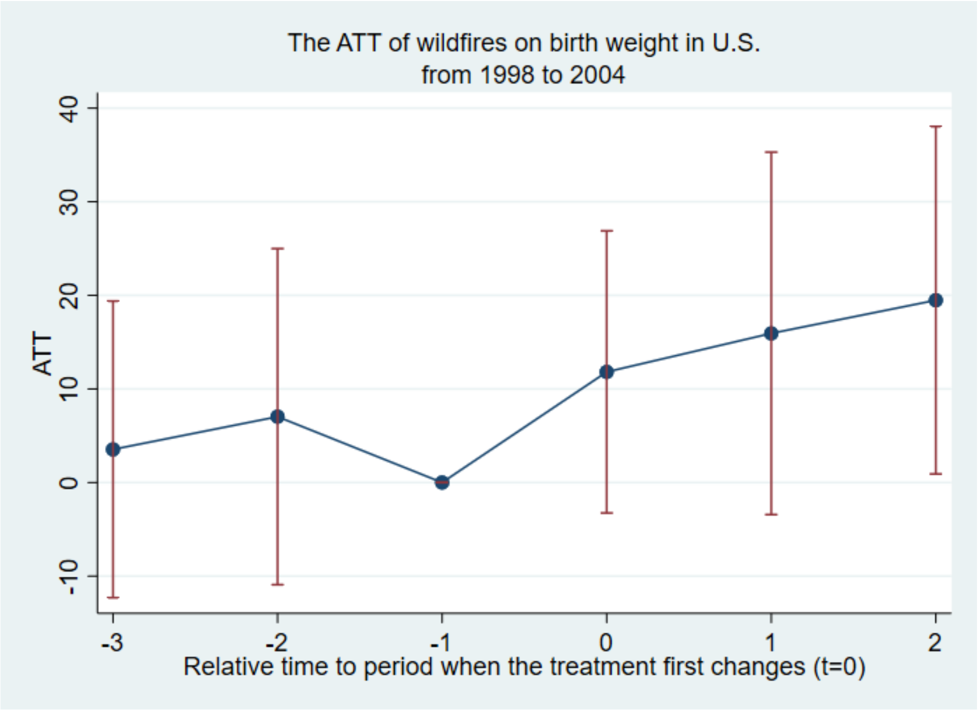

Figure C-10. The dynamic effect of wildfires on birth weight at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 20 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

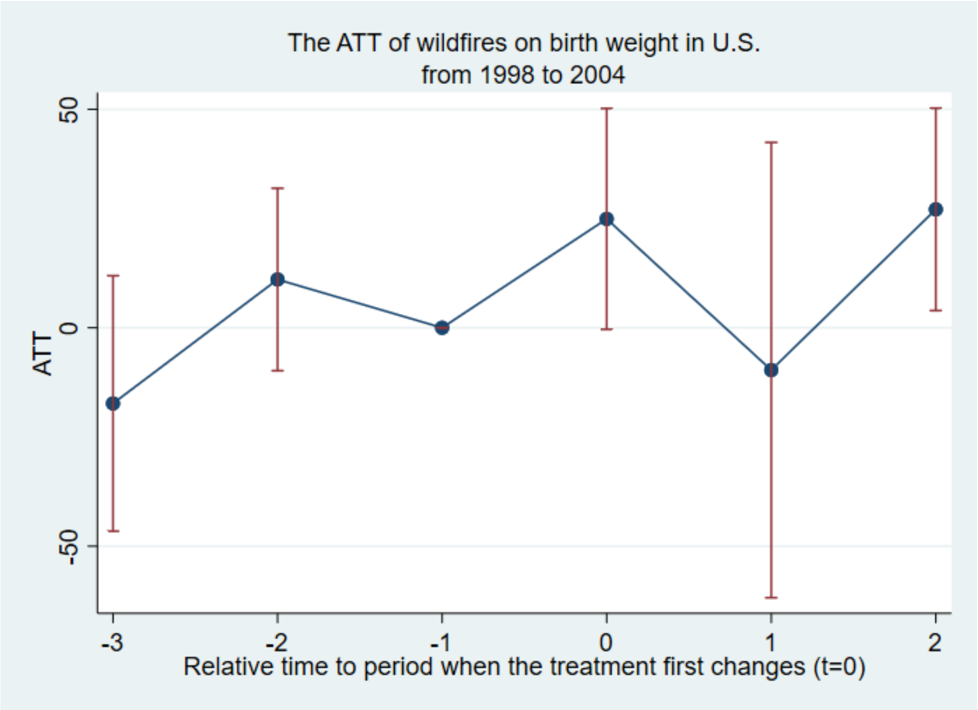

Figure C-11. The dynamic effect of wildfires on birth weight at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 20 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

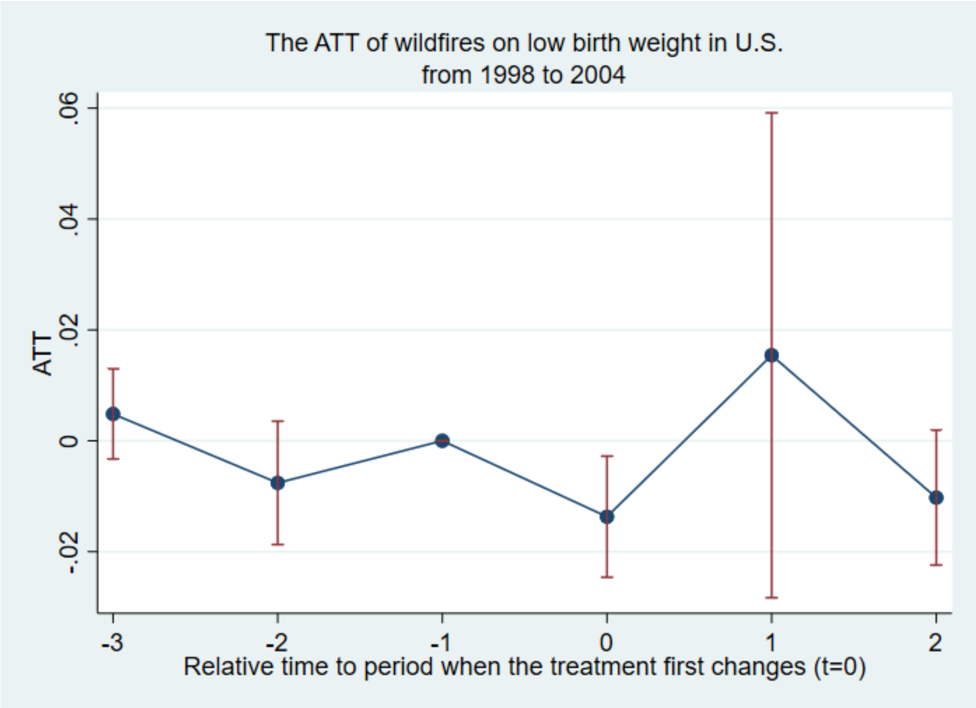

Figure C-12. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 20 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

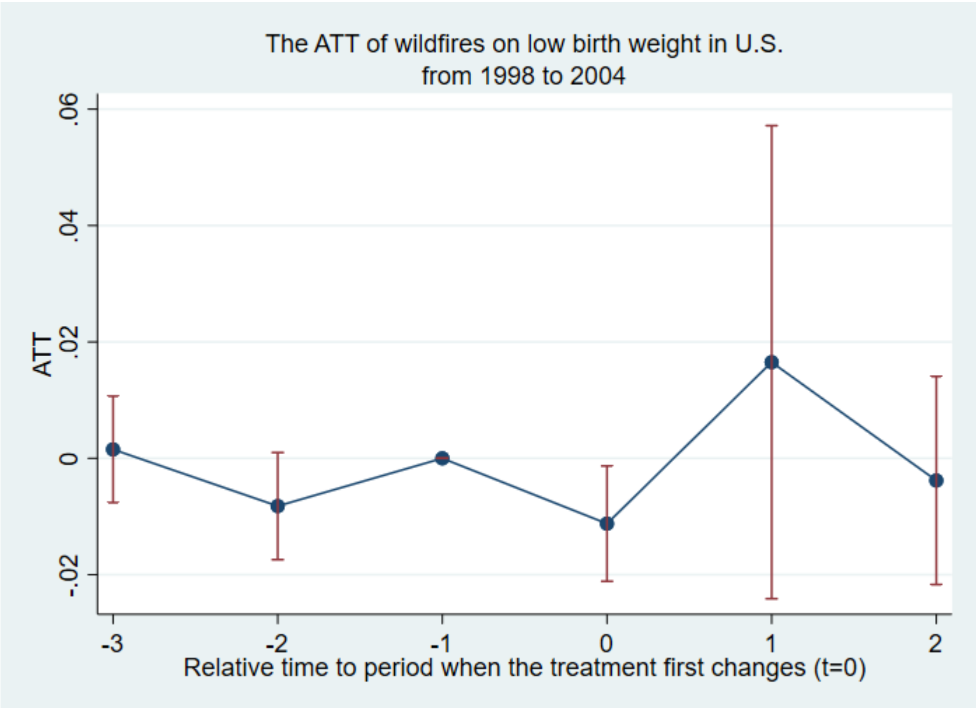

Figure C-13. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 20 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

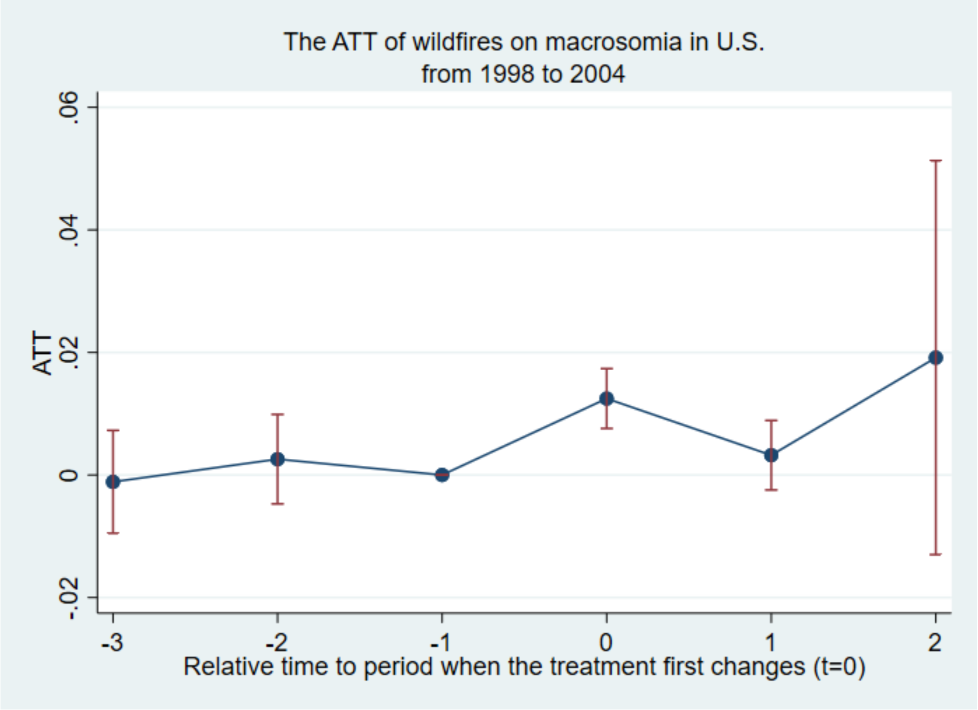

Figure C-14. The dynamic effect of wildfires on macrosomia at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 20 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

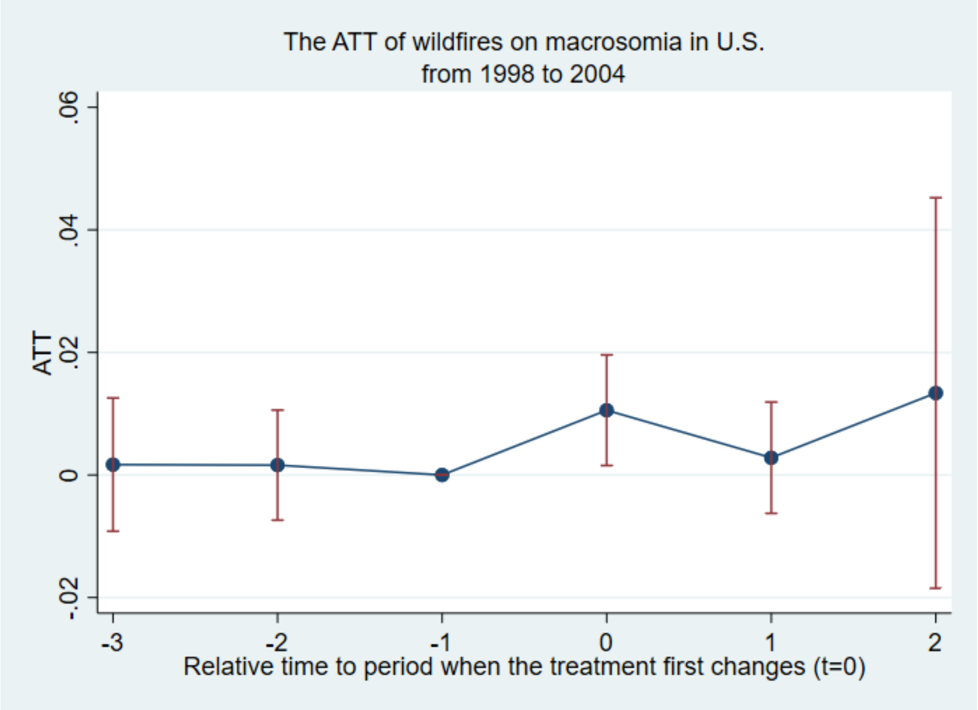

Figure C-15. The dynamic effect of wildfires on macrosomia at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 20 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

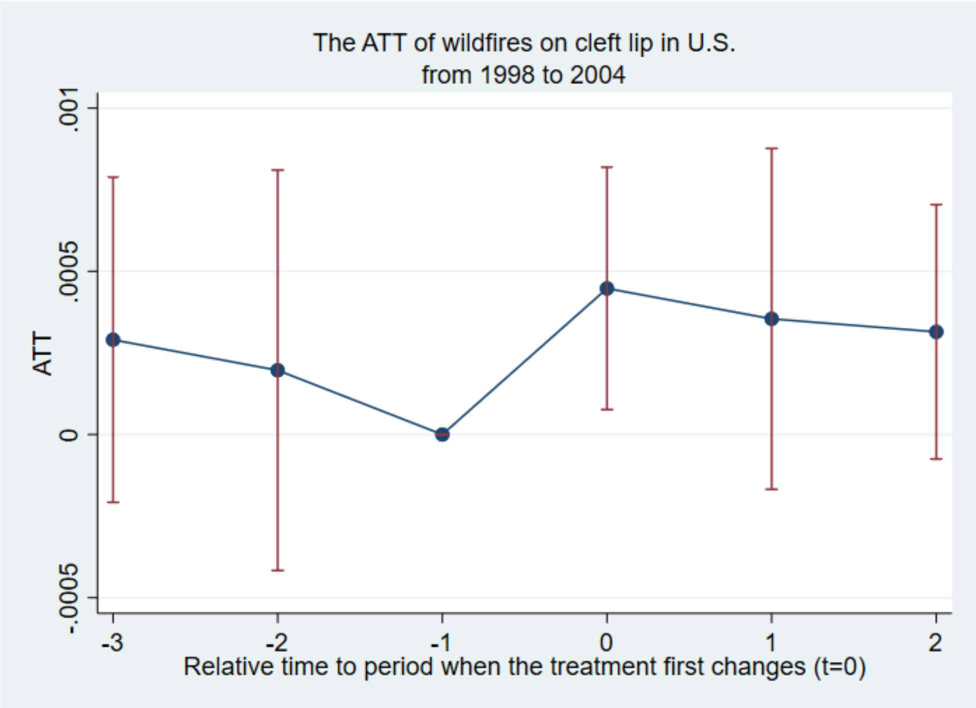

Figure C-16. The dynamic effect of wildfires on cleft lip at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

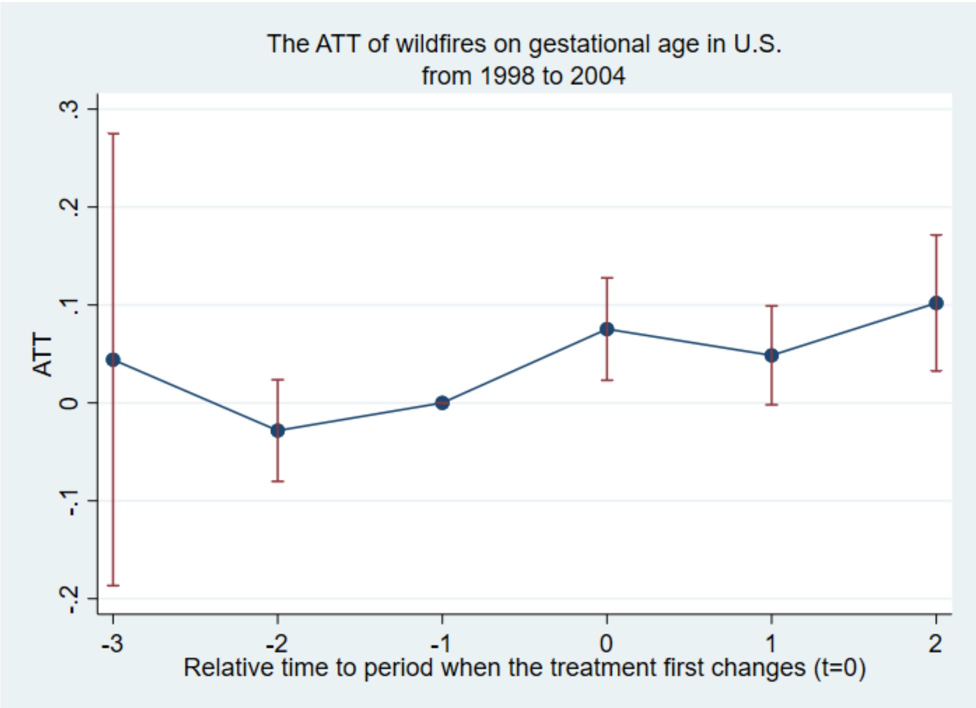

Figure C-17. The dynamic effect of wildfires on gestational age at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 50 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

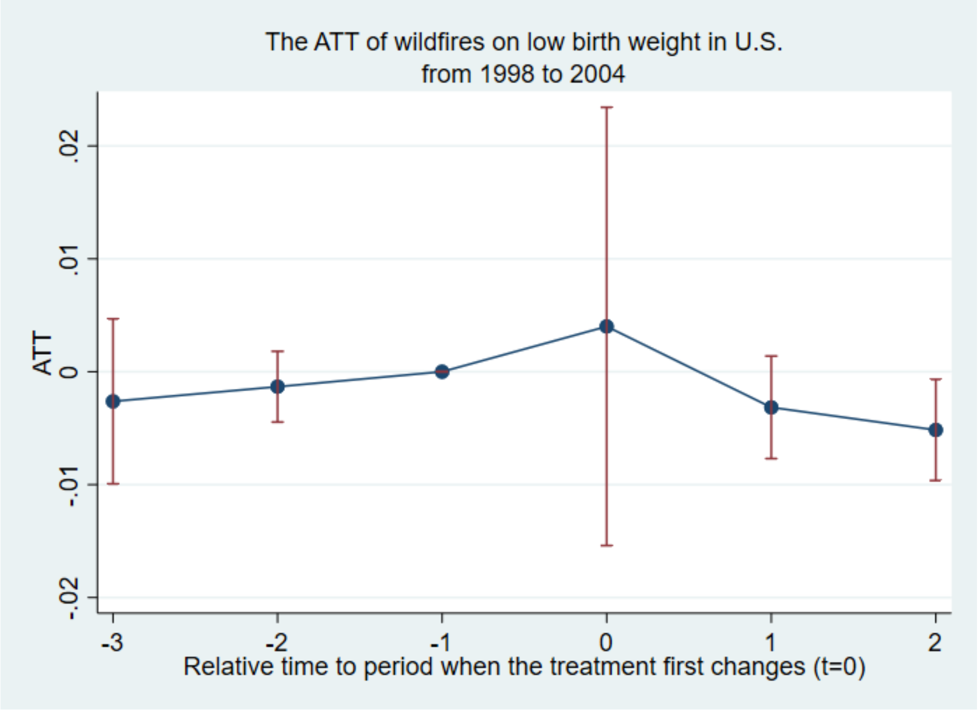

Figure C-18. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

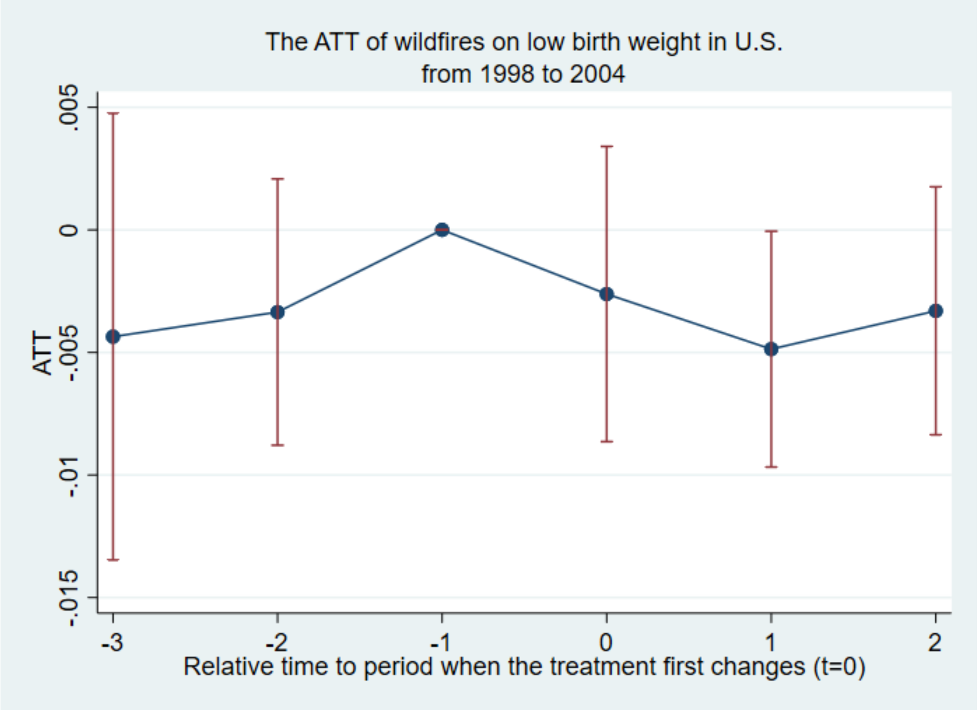

Figure C-19. The dynamic effect of wildfires on low birth weight at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

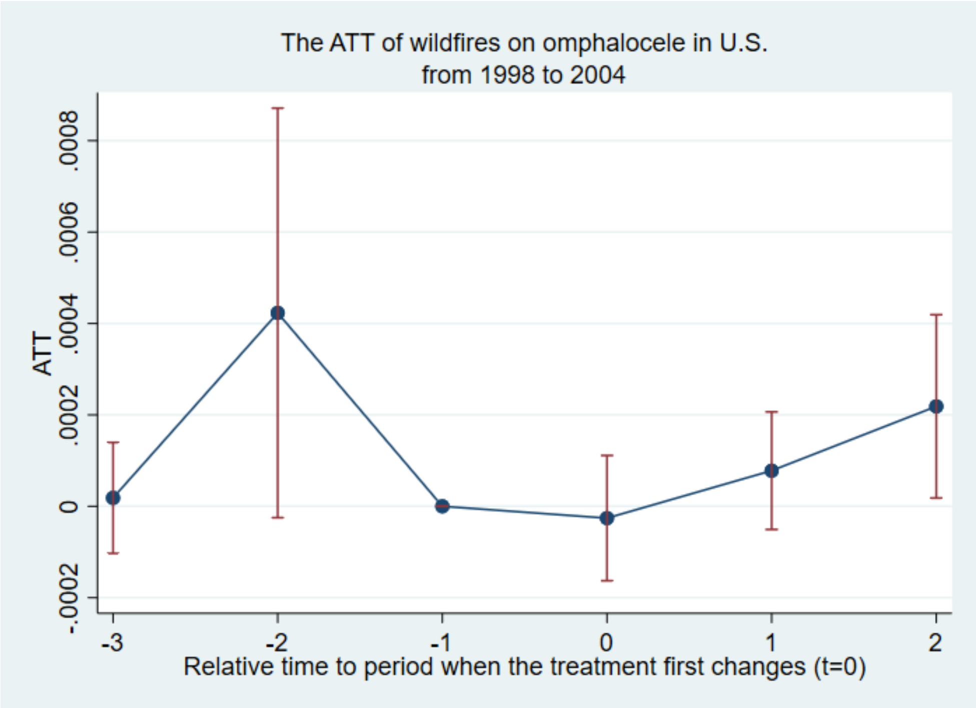

Figure C-20. The dynamic effect of wildfires on omphalocele at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

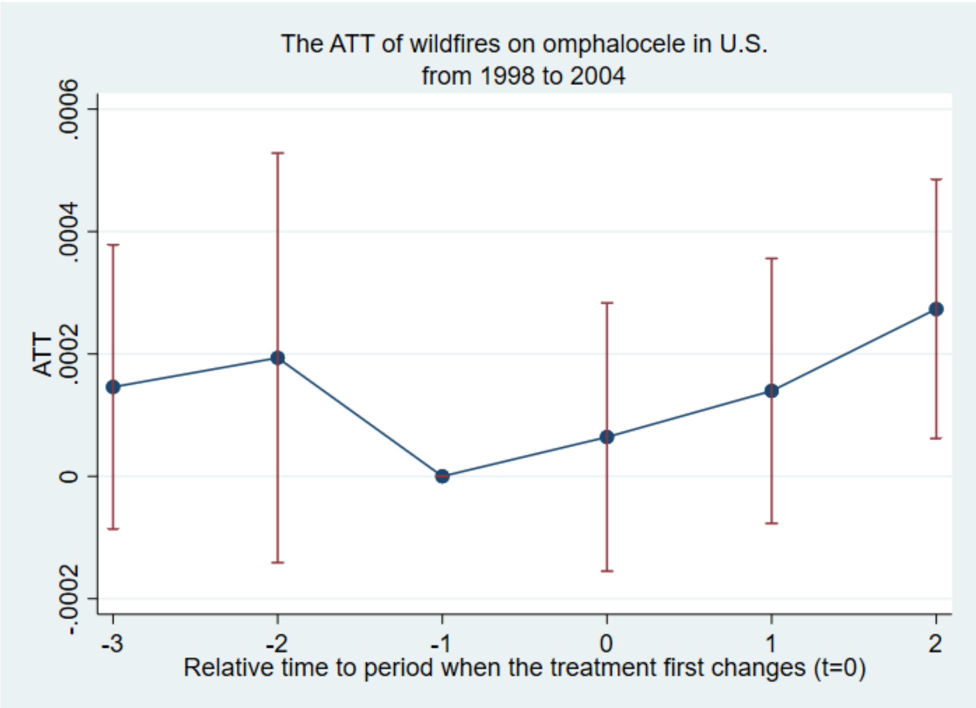

Figure C-21. The dynamic effect of wildfires on omphalocele at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 50 and 50 separately. The start date of pregnancy is calculated by subtracting gestational age from date of birth.

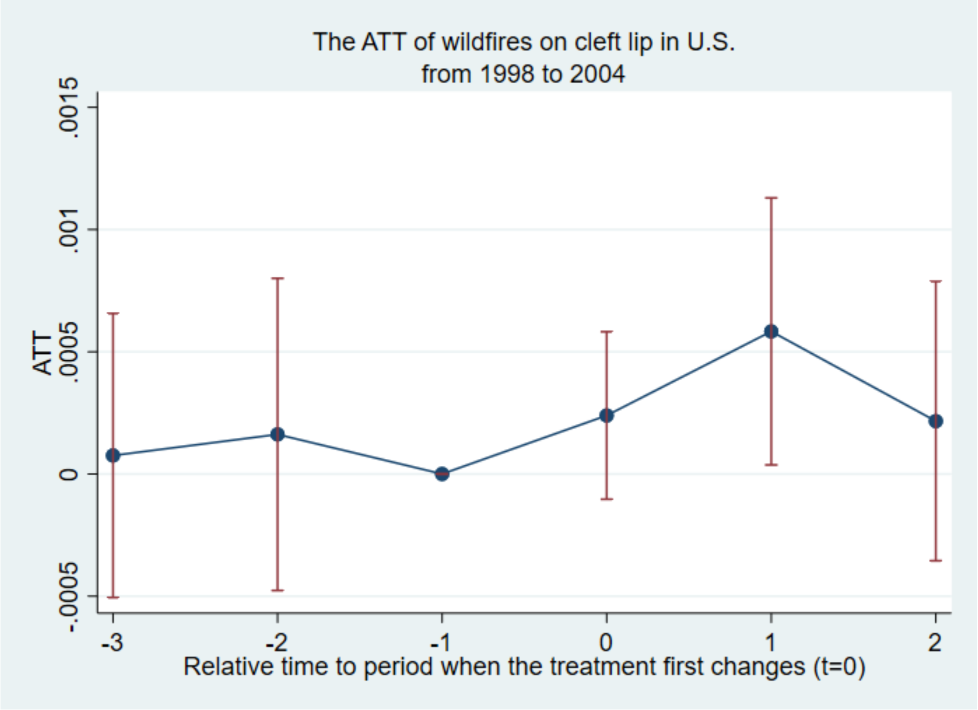

Figure C-22. The dynamic effect of wildfires on cleft lip at the county-level in US.

Notes: The state-specific trends are not considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting 9 months from date of birth.

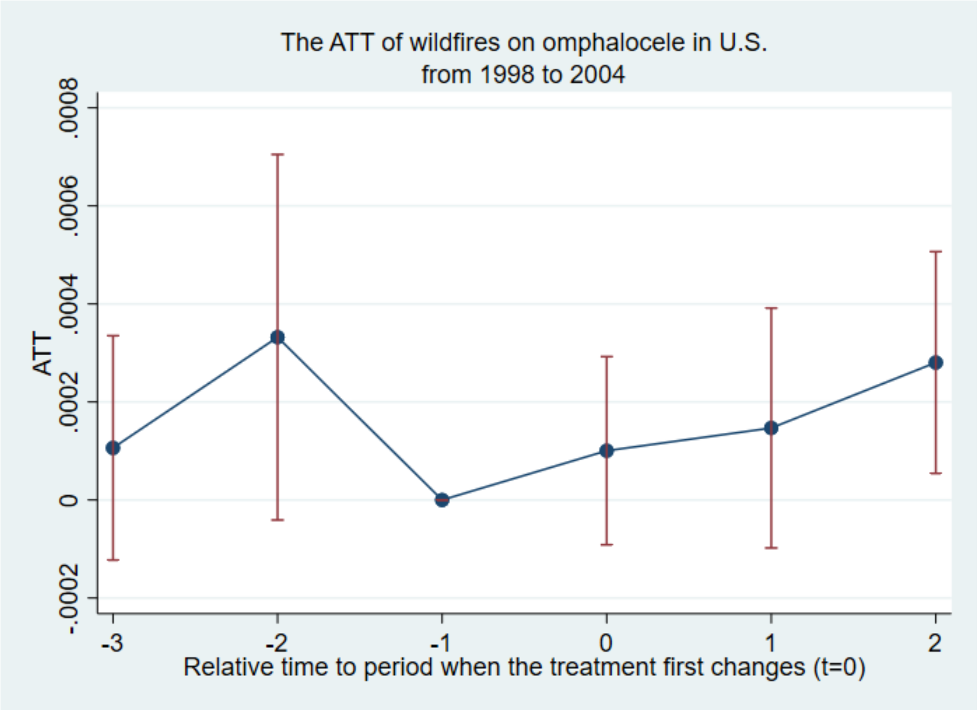

Figure C-23. The dynamic effect of wildfires on omphalocele at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 50 and 5 separately. The start date of pregnancy is calculated by subtracting 9 months from date of birth.

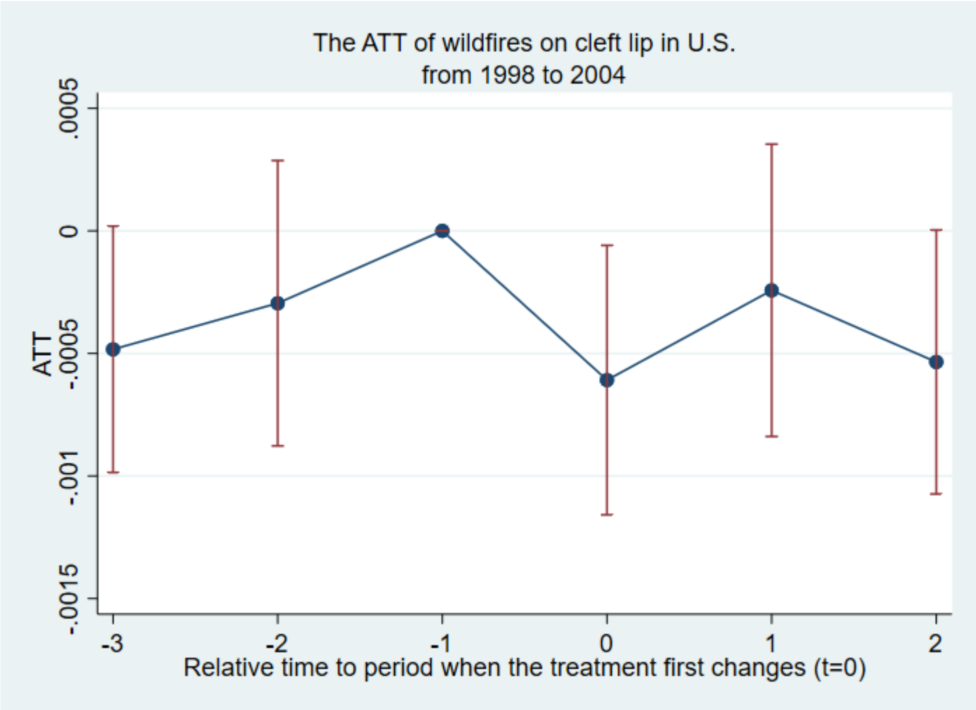

Figure C-24. The dynamic effect of wildfires on cleft lip at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 50 and 50 separately. The start date of pregnancy is calculated by subtracting 9 months from date of birth.

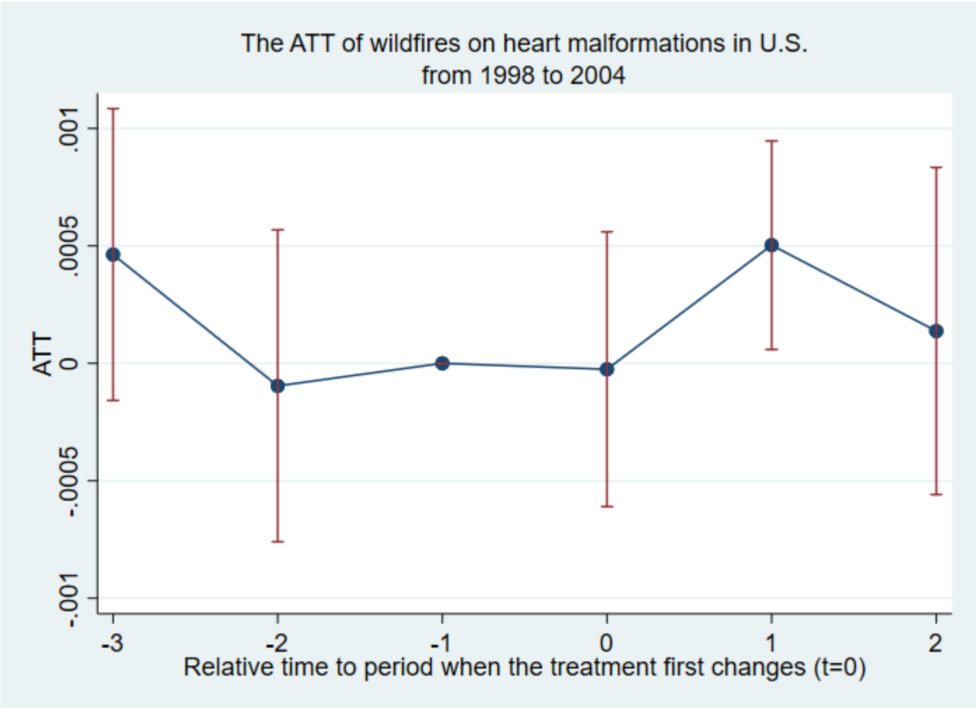

Figure C-25. The dynamic effect of wildfires on heart malformations at the county-level in US.

Notes: The state-specific trends are considered. The cutoffs for distance and wildfire size are 50 and 50 separately. The start date of pregnancy is calculated by subtracting 9 months from date of birth.

C.3 The Effect of Wildfires on the Elderly's Health Outcomes at the County Level ($DID_{+,t}$ Estimator)

Table C-16. The effect of wildfires on health outcomes of the elderly at the county level with wildfire size >=5 acres and distance<=50 km (pre-period definition 1, time window: 2 and 3 months before and after-wildfires).

Health Outcomes	Participate in exercises
3-month time window:	
ATT	-.00117 (.210)
Number of observations	161
Parallel trend	Yes
2-month time window:	
ATT	-.0130 (.168)
Number of observations	191
Parallel trend	Yes

Note. The dependent variable is a dummy for whether a person took part in any physical activities in the last 30 days. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The estimation is conducted using "did_multiplegt" in Stata 17. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table C-17. The effect of wildfires on health outcomes of the elderly at the county level (pre-period definition 2, time window: 3 months pre- and post-wildfire).

Health Outcomes	Number of days physical health not good	Number of days mental health not good	Participate in exercises	Often have asthma symptoms
wildfire size >=5 acres & distance<=20 km:				
ATT	.649 (3.254)	-.420 (2.567)	-.174 (.273)	
Number of observations	175	175	175	
Parallel trend	Yes	Yes	Yes	
wildfire size >=50 acres & distance<=20 km:				
ATT		2.550 (3.165)	-.297 (.222)	.197 (.345)
Number of observations		156	156	156
Parallel trend		Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	1.164 (3.395)	1.068 (2.226)	-.134 (.178)	
Number of observations	338	338	338	
Parallel trend	Yes	Yes	Yes	
wildfire size >=5 acres and distance<=50 km:				
ATT		-3.080 (1.976)	.0810 (.177)	.0506 (.148)
Number of observations		489	489	489
Parallel trend		Yes	Yes	Yes

Note. The dependent variables include in the last 30 days, the number of days physical health not good, the number of days mental health not good, a dummy for whether a person took part in any physical activities and a dummy for whether an individual had any symptoms of asthma more than twice a week. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The estimation is conducted using "did_multiplegt" in Stata 17. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table C-18. The effect of wildfires on health outcomes of the elderly at the county level (pre-period definition 2, time window: 2 months pre- and post-wildfire).

Health Outcomes	Number of days physical health not good	Number of days mental health not good	Participate in exercises	Often have asthma symptoms
wildfire size >=5 acres & distance<=20 km:				
ATT	.147 (3.674)	-.573 (2.259)	-.246 (.258)	
Number of observations	174	174	174	
Parallel trend	Yes	Yes	Yes	
wildfire size >=50 acres & distance<=20 km:				
ATT	3.661 (4.373)	4.0117 (3.242)	-.222 (.236)	.226 (.290)
Number of observations	161	161	161	161
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=50 acres and distance<=50 km:				
ATT	2.895 (3.299)	.880 (2.176)	-.0364 (.165)	.0882 (.177)
Number of observations	383	383	383	383
Parallel trend	Yes	Yes	Yes	Yes
wildfire size >=5 acres and distance<=50 km:				
ATT				-.0366 (.112)
Number of observations				482
Parallel trend				Yes

Note. The dependent variables include in the last 30 days, the number of days physical health not good, the number of days mental health not good, a dummy for whether a person took part in any physical activities and a dummy for whether an individual had any symptoms of asthma more than twice a week. Standard errors are clustered by county. The covariates in DD regression include age, gender, race, marital status, a dummy for whether a person has children in the household, education and employment status. The estimation is conducted using "did_multiplegt" in Stata 17. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix D Chapter 4 The Relationship between Distance and Air Quality Index (AQI)

D.1 Empirical Method

The U.S. counties in the sample are divided into the treated and the control groups. The treatment status of each county is assigned based on the geodesic distance between the centroid of each county and the point of origin of each wildfire for the following reasons. As discussed in section 4.2, air pollutants released from wildfires and psychological responses have been found to be related to adverse birth outcomes and negative health impact on adults. Firstly, it has been suggested that the distance between counties and wildfires as well as wind direction can affect concentrations of air pollutants emitted from fires, but in previous literature, there is no consensus on the exact distance the air pollutants can travel (Lazaridis *et al.*, 2008; Carbajal, Pineda-Martinez and Vicente, 2015; Gosteva, Yakubailik and Shaparev, 2020; Rogers, Ditto and Gentner, 2020). Secondly, individuals in close proximity to wildfires are more likely to suffer from mental health problems (Johnston *et al.*, 2021; Silveira *et al.*, 2021), which can exert a detrimental effect on pregnant women and older adults according to 4.2. However, the specific threshold for distance to wildland fires within which health outcomes of human beings are deleteriously affected is inconsistent in previously published studies. As a result, further empirical evidence is required to determine the cut-off points of distance. Due to the unavailability of high frequency data about mental health at county level, this section only assesses the correlation between air pollution levels measured by air quality index (AQI) and distance to wildfires. Corresponding to the time window of natality data, the sample covers the time period from 1998 to 2004.

The sample of counties exposed to wildfires consists of those whose distance to the point of origin of wildfires is not larger than 500 kilometres because the long-range transport of air pollutants is expected to minimally influence the air quality of counties outside of the threshold. This study initially identifies the neighbouring counties within 500 kilometres to wildfires and calculates the great-circle distance from each county to the point of wildfire origin. Distance values are then broken down into 20-kilometre bins. Furthermore, given that air quality effects of wildland fires are heterogeneous depending on the sizes of wildfires, the sample is divided into quintiles based on total acres burned by wildfires, so that the relationship between distance and air pollution levels is evaluated for each quintile.

For the purpose of combining air quality indices (AQI) with panel data of counties exposed to wildfires, the daily AQI are collapsed to weekly means. AQI, which were measured at the monitor stations nearest to each exposed county and were collected four weeks before and after the start dates of wildfires, are subsequently joined to the panel data.

The following regression specification is used to estimate the correlation between distance to wildfires and AQI:

$$AQI_{it} = \alpha_1 dist_{it} + \alpha_2 post_{it} + \alpha_3 dist_{it} post_{it} + \gamma_i + \delta_t + \varepsilon_{it} \qquad \text{(D-1)}$$

where AQI_{it} is the weekly average AQI in county i at week t. $dist_{it}$ denotes the geodetic distance between county i and the point of origin of the wildfire at week t. $post_{it}$ is a dummy variable equal to one for air quality following the occurrence of wildfires and zero otherwise. Given the variation in air pollution levels caused by county-specific and seasonal factors, the regression also controls for county and week fixed effects, γ_i and δ_t. The standard errors are clustered by county on account of possible correlations between AQIs throughout the time period within a county.

The estimator α_3 is the coefficient of interest, which estimates how the effect of wildfires on AQI varies by distance between each county and the wildfire locations. Finally, the relationship between AQI and distance is visualised in graphs to identify the threshold of distance within which counties can be assigned to the treated groups.

D.2 Results

This empirical analysis investigates how AQIs change with the distance following occurrence of wildfires, which pinpoints the cutoff of distance within which wildfires can induce more severe air pollution so that the counties within such a radius are assigned to the treated groups. Given that wildfires of different sizes have disparate effects on AQI, the sample of wildfires is divided into quintiles based on the total acres burned by wildfires as shown in Table D-1. Since the first and the second quintiles are identical, both of them are categorised into quintile 1. The sample covers the time period between 1998 and 2004.

The results obtained from the regression D-1 are displayed in Figure D-1, Figure D-2, Figure D-3 and Figure D-4, which correspond to wildfires categorised into quintile 4, quintile 1, quintile 3 and quintile 5 respectively. The horizontal axis in these figures represents 20-kilometre distance bins. Figure D-2 indicates that there is no evidence to suggest that counties nearer to wildfires categorised in quintile 1 tend to be more polluted than those further away from wildfires. In addition, AQIs in counties exposed to wildfires in the first quintile fluctuate around zero. The trends shown in Figure D-3 and Figure D-4 illustrate that for wildfires in the third and fifth quintile, there has been a surge in AQI in exposed counties within the 50-kilometre radius of the point of origin of wildfires whereas the AQI decreased steadily as the distance is larger than 250 kilometres. Similarly, as shown in Figure D-1, there has been a gradual decline in AQI when the distance is larger than 250 kilometres for wildfires grouped in the fourth quintile. Figure D-3, Figure D-4 and Figure D-1 also indicate that the impact of wildfires categorised in quintile 3, 4 and 5 on AQI fades out for counties outside of the 420-kilometre radius of wildfires. These results imply that smaller wildfires in the first quintile which burned at most 0.1 acres have a minor impact on air quality in the neighbouring counties, whereas counties exposed to larger wildfires in the third, fourth and fifth quintile experienced more severe air pollutions.

This paper adopts various cutoff distances and wildfire sizes, some of which can be used as a robustness test. Besides using large wildfires and the 20-kilometre distance as a threshold in 4.4.1 and 4.4.2, the thresholds for distance are chosen as 20 km and 50 km while the cutoffs for wildfire sizes are selected as 5 and 50 total acres burned when assigning treatment status to counties in 4.4.3.

Table D-1. The interval of total acres burned in each quintile

Quintile	Total acres burned
1 and 2	[0, 0.1]
3	[0.11, 0.3]
4	[0.31, 3]
5	[3.1, 280059]

Notes: The table shows the interval of total acres burned corresponding to each quintile of wildfire size.

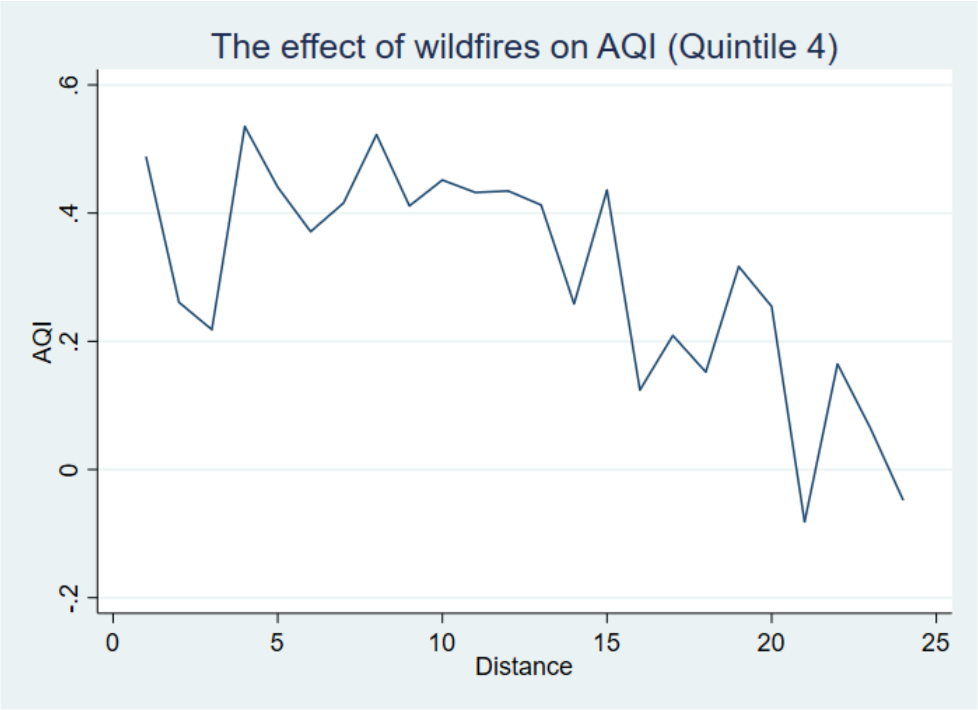

Figure D-1. The relationship between AQI and distance for wildfires in quintile 4.

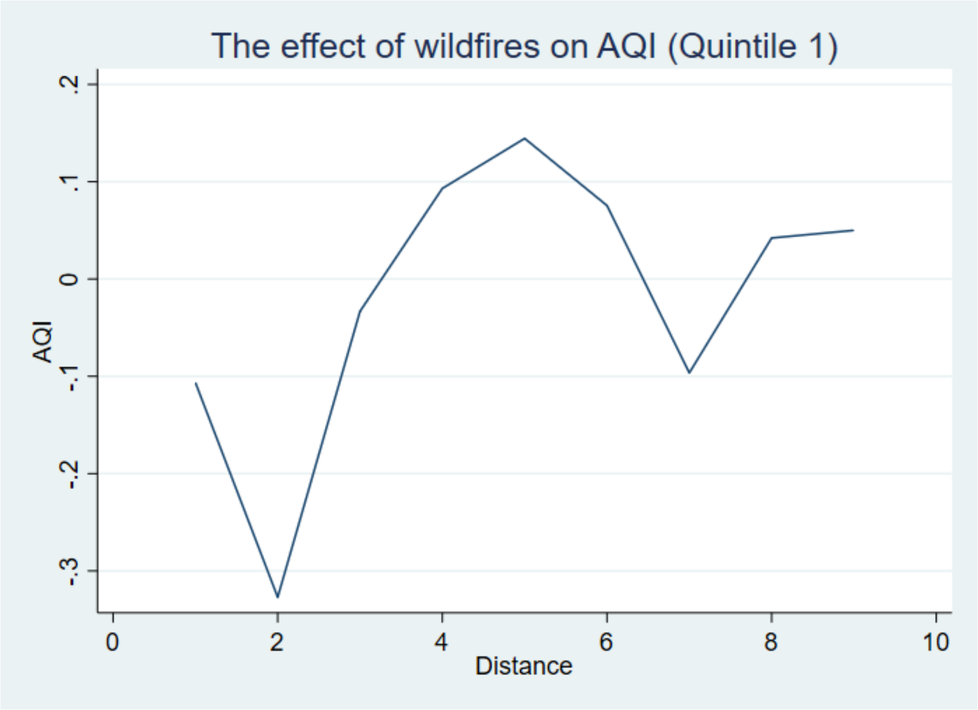

Figure D-2. The relationship between AQI and distance for wildfires in quintile 1.

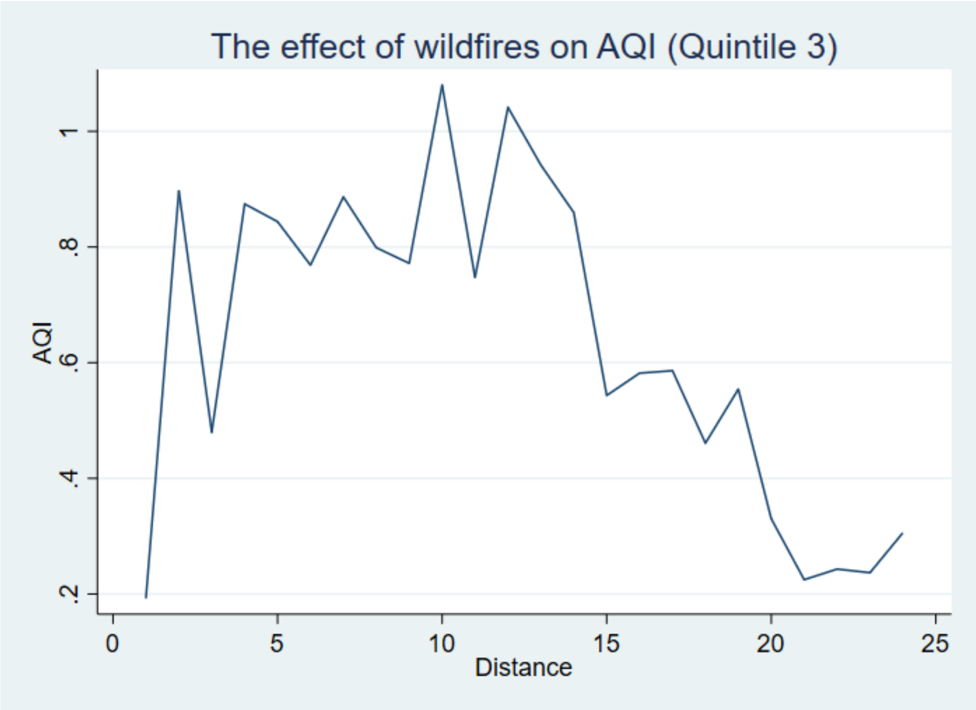

Figure D-3. The relationship between AQI and distance for wildfires in quintile 3.

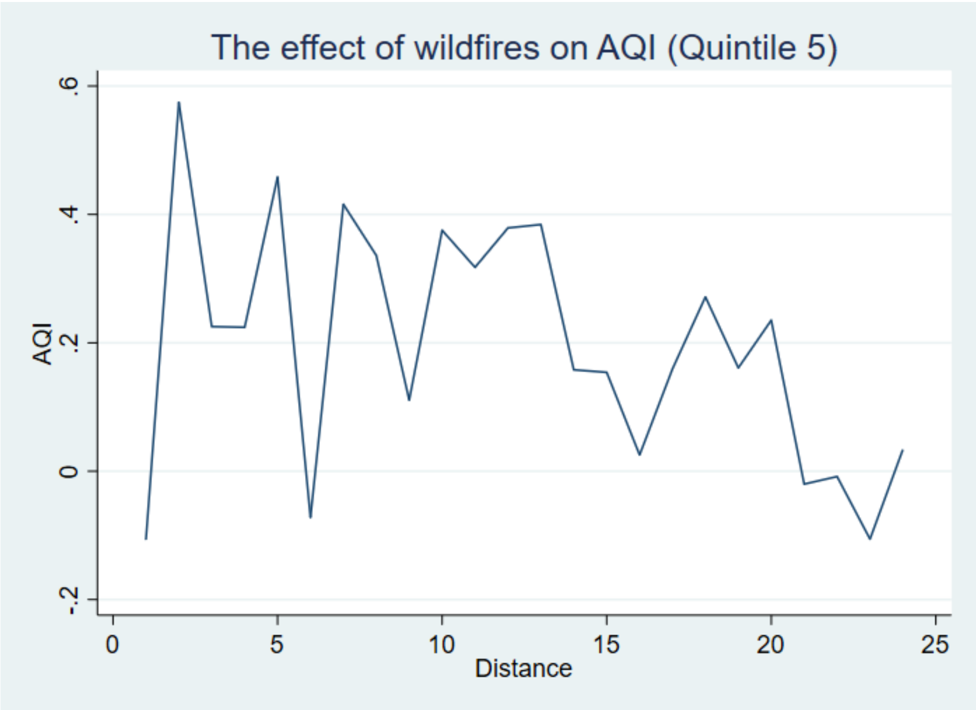

Figure D-4. The relationship between AQI and distance for wildfires in quintile 5.

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