Gender Empowerment as an Enforcer of Individuals' Choice between Education and Fertility: Evidence from 19th Century France

Abstract

Recent theoretical developments in growth models, triggered particularly by unified theories of growth, suggest that the child quantity-quality trade-off is a defining element in our explanation of a transition from Malthusian stagnation to a sustained growth path. This paper presents a model and derive a testable empirical framework to investigate the role of gender on the trade-off between education and fertility for 86 French counties during the 19th century. Endogeneity-mitigated mean- and median-based regressions offer robust empirical predictions for gender-empowered quality-quantity trade-off. In particular, we find the existence of a significant and negative association between education and fertility. Further, while gauging the effect of schooling on fertility, the short-run differences between male and female appear to be small whilst the long-run effects are large. From policy perspective, our results imply that it matters not just that parents educate their children, but specifically that they choose to educate girls.

Keywords: Gender difference; Cliometrics; Individuals' choice; Education; Fertility; Quantile regression; Unified growth theory; Nineteenth century France; Quality-Quantity trade-off.

JEL Codes: C22, C26, C32, C36, C81, C82, I20, J13, N01, N33.

1. Introduction

What explains transition of an economy from stagnation to a sustained growth path? Recent development of growth models, influenced in particular by unified growth theory (Galor and Weil, 1999, 2000; Galor, 2005, 2012), provide strong foundation to an empirical apparatus that considers gender inequality as a potential explanation of quality-quantity trade-off between fertility and education. Historical precedence in both developing and developed worlds reveals that the lack of empowerment in women via education, have often limited their choices of the number of children irrespective of economic circumstances. Questions may arise, for instance, how does gender-specific educational attainment impact fertility choices? Are there significant short-run and long-run differences between male and female of the effect of education on fertility? If so, does the size differential matter? To answer, it is important to characterize gender inequality as a choice function of an individual in a growth theoretic setting. Aligned with the existing social parameters and expectations, the gender inequality may then serve as a leading explanation of a skewed choice of either more education or more fertility (or even no fertility at all).[1] The current paper draws on the existing literature to develop a model and derive a testable empirical framework to study whether education and fertility are inversely related and whether gender inequality has an instrumental role in the nature of quality-quantity trade-off.

Our empirical investigation uses historical census data for 86 French counties in the nineteenth century. Like many Western countries, France too experienced major demographic changes over the past two centuries. Although resources were available, the number of offspring radically declined while formal education became accessible to a vast majority of the population. In the early 19th century, women were on average less trained than men and their education was often limited to specific knowledge related to household-related work and skills required for their future role within the household as mother and a wife. The feminization of education, via the implementation of laws and decrees, allowed girls to fill up a large part of their delay in schooling by the end of the 19th century.[2]

The reflections from the past, of course, have implications for the present. Despite a century having passed, a gender-driven individuals' choice have significant role in our effort towards a renewed understanding of a demography-economic growth nexus when both systems are facing

[1] Hazarika, Jha and Sarangi (2019), in a recent important work, argue that gender inequality is important in perceived well-being in pre-history in regions less endowed with ecological resources.
[2] See Perrin (2013) for a detailed description of the long-run and regional evolutions of education during the French development process.

unprecedented rise in uncertainty over their very existence and growth.[3] Very relevant to the modern day context, more so in the developing countries, it matters not just that parents educate their children, but specifically that they choose to educate girls.[4]

The contrasting evolution between the number of children and the average education level may lend credit to rational choice explanations, as questioned by de la Croix and Perrin (2018), according to which parents derive utility from both offspring quantity and quality (Becker, 1960; Becker and Lewis, 1973).[5] The child quantity-quality trade-off has been historically hailed as the main motivator of the celebrated transition from Malthusian stagnation to a sustained economic growth of recent times. The latter hypothesis has received both considerable theoretical attention (especially in a unified growth theoretic tradition following Galor and Weil (1999, 2000) and Galor (2005, 2012) and vigorous empirical analyses over the past decades. Lately, despite a renewed interest among researchers to uncover the existence of a possible causality[6] between quantity and quality of children, important questions remain: Are individual's choice for more (less) education or less (more) fertility naturally driven by their specific identities within a gender group (viz., male or female)? Within this proposed angle of gender-bias-driven quality-quantity trade-off, does a negative association between education and fertility decrease (increase) over the distribution of fertility and education?

The main purpose of the current article is to contribute to the burgeoning literature about the relationship between education and fertility[7] by modelling choice of gender-specific individuals for quality and quantity of children. As we expect heterogeneous effects, we exploit the recent development in quantile regression literature to account for full distributional effects of changes in educational status (of boys and girls/men and women) on fertility transition. Women's education and gender differences are crucial factors to explain transition to a sustained growth. It is particularly due to the dual relationship between education and fertility (via the quantity-quality trade-off) that eventually stimulates the long-term process of human capital accumulation. We, therefore, consider both the short-run and the long-run nexus between education and fertility.

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[3] A series of natural events, including the current pandemic situation, which has triggered world-wide deaths of population, have also unleashed an almost irreversible financial uncertainty, and thus fast-pacing an already severe problem of hunger and poverty. Individuals may now be faced with a difficult choice of producing progenies amidst a severe financial difficulty. In our view, which can be a subject of new research, the world demographic growth may fall below a replacement level as the death of 'human capital' during this pandemic will begin re-defining individuals' choice.

[4] Many thanks to an anonymous referee for providing important insights whilst formalising the problem.

[5] See Doepke (2015) for a thorough presentation of Gary Becker's theory and its developments.

[6] Cinnirella (2019) provides an exhaustive review of literature on the relationship between parental investments in children's education and fertility.

[7] See for instance, Becker et al. (2010, 2012), Fernihough (2017) for studies about Prussia, Ireland, respectively; Clark and Cummins (2016), Klemp and Weisdorf (2019) for studies about England; Murphy (2015), Bignon and García-Peñalosa (2016), Diebolt et al. (2017), de la Croix and Perrin (2018) for studies about France.

For our empirical exercise, we use county-level data collected from diverse publications of the *Service de la Statistique Générale de la France*. Our dataset covers information about aggregated individual-level behavior for 86 French counties (*départements*).[8] The French development process occurred at different speed across time and space. The typology of French department in the 19th century reveals the existence of five groups of counties reflecting the diversity of local developments (Perrin and Benaim, 2019). On the one hand, prosperous counties are characterized by a dynamic industry, gender equality, high education, fertility control within marriage, and low fertility rates. On the other hand, 'backward' counties, heavily dependent on agriculture, present strong gender inequalities, poorly educated population controlling nuptiality and experiencing high fertility rates.

The typology highlights the coexistence of different stages of development, as well as different traditions and norms,[9] at the regional level. While estimating the effects of education on fertility, for instance, accounting for heterogeneity in the effects can capture these dynamics and may unravel differential effects over the distribution of fertility. Indeed, it is possible that there is an underlying systematic education effects heterogeneity shaped by the population composition of people receiving education. Females with a high propensity for education can secure high economic returns via low rates of intermittent labor force participation and low levels of fertility. Moreover, there is a sociological angle to the explanation; many non-economic factors predict educational attainment because not only rational cost-benefit analysis, but also cultural and social norms and circumstance may govern educational attainment levels.

Bidirectional causality between child quantity (more or less fertility) and child quality (less or more education) may arise in our estimation because as educational quality rises, people may have less time for bearing children. Conversely, as people have more children, it may also impact their ability to spend enough resources for education. To mitigate endogeneity issues, we have employed instrumental variable regression strategy, instrumenting both education and fertility in the respective regressions. Our results for 19th century France provide robust evidence of a significant association between quantity and quality of children; we find that between male and female schooling, the short-run the differences are small, but in the long run the effects of male and female schooling on future fertility are large. Furthermore, it appears that the fertility transition in France was significantly pronounced in counties with higher female endowment in human capital.

[8] 1851 France consists of current metropolitan French *départements* except Alpes-Maritimes, Savoie and Haute-Savoie.

[9] Recent studies have highlighted the importance to account for the role played by different culture and norms to understand the diffusion of the fertility transition (Spolaore and Wacziarg, 2014; Daudin et al., 2016, de la Croix and Perrin, 2018), and the role played by family systems for economic development (see Carmichael et al., 2016, for an introduction; Diebolt et al., 2017, for an empirical investigation of mid-nineteenth century France).

The rest of the paper is planned as follows. Section 2 provides a theoretical discussion of the relationships between education and fertility. Section 3 describes data and presents distributional characteristics. Section 4 discusses our empirical construct and the methodological approach. Section 5 presents and discusses results. Finally, Section 6 concludes with the implications of main findings of the paper.

2. Theoretical framework

In this section, we present a theoretical underpinning of gender-driven differential effects in quality-quantity trade-off. We draw on existing theoretical contribution and present a simple model of quantity-quality trade-off in fertility and education in the context of gender. Several mechanisms are at play behind the dynamics of the education-fertility relationship. In the short run, the simultaneous choice between how many children to have and their 'quality' is conditional on the choice parents make based on expected returns to investing in their children's education. In the long run, the relationship between education and fertility is conditional on the opportunity costs for parents of having children.

2.1. Education-Fertility Nexus

Becker (1960) was the first to introduce the distinction between child quantity and child quality. Becker postulates that an increase in parental income reduces fertility by raising the opportunity cost of having children. In an extension of Becker's seminal work, Becker and Lewis (1973) explain that the elasticity of the quality of children is greater than the elasticity of the number of children. Consequently, an increase in income is expected to induce an increase in children quality and a decrease in fertility.

Unified growth theory (Galor, 2011) suggests that the rise in the demand for human capital is at the origin of the demographic transition observed in Western countries at the end of the nineteenth century. Various models have extended the theory developed by Galor and Weil (1999, 2000) to account for additional mechanisms likely to have contributed to foster the process of human capital accumulation in the transition from stagnation to modern growth (see, for instance, the role of natural section, Galor and Moav, 2002; government policies on education and child labor, Doepke, 2004; life expectancy, Cervellati and Sunde, 2005; bargaining power of women in the family, Diebolt and Perrin, 2013, 2019a; among others).

Common to most unified growth models, the emergence of new technologies during the process of industrialization increased the need for skilled workers (i.e. the demand for human capital) and induced parents to invest more in the education of their offspring. Investing in education increases the opportunity cost of having children and implies for parents to choose between the number and education of children, the so-called child quantity-quality (Q-Q) trade-off. Most unified growth models consider the child Q-Q trade-off as the key mechanism allowing economies to switch from a positive correlation linking income and population size, during the Malthusian stagnation, to a negative one, during the modern growth regime.

In the long run, the relationship between education and fertility is conditional on the opportunity costs for parents of having children. The model developed by Diebolt and Perrin (2013, 2019a) emphasizes the importance of the role played by gender equality in education and labor force participation to explaining the increasing opportunity cost of having children. The model highlights the mechanisms through which gender equality affects decisions taken by members of the household, foster the process of human capital accumulation and trigger the fertility transition. At the dynamical level, the increase in gender equality and the rise in technological progress create higher opportunities for women to invest in skilled human capital. The negative association linking mothers' human capital and child rearing (career or family – Goldin, 2006) encourages families to have fewer children but better educated ones. This process ultimately triggers to the demographic transition and plays a central role for the transition from stagnation to modern growth.

The existence of gender-driven evolution of choice functions over the course of history confirms the need for integrating such a crucial aspect in theoretical and empirical research on the mechanisms governing the quality-quantity trade-off(s). We present next a simple economic model of fertility and education choice with a quantity-quality trade-off in the context of gender where households make rational decisions about the number of children and their education.[10]

2.2. A Simple Formalization

The model we present below is driven by insights from de la Croix and Doepke (2003), de la Croix and Delavallade (2018), and de la Croix and Perrin (2018).[11] We consider a hypothetical economy populated by overlapping generations of individuals who live over two periods: childhood and adulthood. All decisions are made in the adult period of their lives. Males and females are denoted

[10] See Doepke (2015) for a review of the emergence of the concept.

[11] The model is also in the spirit of the literature accounting for gender aspects, e.g. Diebolt and Perrin (2013, 2019), Doepke and Tertilt (2009, 2019).

with upper indices m and f. Each member of the household is endowed with one unit of time. Parents spend their time either at work or at rearing children. Households draw utility from adult consumption c_t, their number of children (boys and girls) n_t^m and n_t^f, and their quality (endowment in human capital in adult age) h_{t+1}^m and h_{t+1}^f. Men and women act cooperatively (unitary model of household).

The household preferences are represented by the following utility function:

$$U = \ln(c_t) + \gamma \ln\left(\omega h_{t+1}^f n_t^f + h_{t+1}^m n_t^m\right) \quad (1)$$

The parameter $\gamma > 0$ measures the value attached to the number of offspring relative to the consumption.

The budget constraint for a couple with human capital (h_t^m, h_t^f) is:

$$c_t = w_t h_t^m (1 - a_t^m) + \omega w_t h_t^f \left(1 - a_t^f\right) - p_t w_t \left(e_t^m + e_t^f\right) \frac{n_t}{2} \quad (2)$$

where w_t is the wage per unit of human capital, and $\omega < 1$ is an exogenous gender wage gap (asymmetry between men and women can be explained by discrimination against women). Due to this asymmetry, it will be optimal to have women spending more time of rearing children. a_t^m and a_t^f are the time spend by parents to rear children. e_t^j is the number of hours of teaching bought by the parents for the children of gender $j = m, f$ at a price p_t

Similar to de la Croix and Delavallade (2018), the technology that allows producing children is given by:

$$\varphi n_t = \sqrt{a_t^m a_t^f} \quad (3)$$

Time is essential to produce children. Therefore, mother's and father's time are mild substitutes ($\varphi \in (0, 1)$ gives an upper bound to the number of children). Hence, if men and women spend their entire time rearing children, they will get $1/\varphi$ of them. Since there exists a minimum time cost required to rear children, having more children is more costly for parents who enjoy high wages. Highly educated parents therefore spend more on the quality of their children and have less children.[12] Given the gender wage gap $\omega < 1$ it is optimal for women to spend more time on child rearing.[13] For simplicity, the ratio of male and female children is assumed to be one: $n_t^m = n_t^f = n_t/2$.

Individuals' quality is conditional to their endowment in human capital that depends positively on their education e_t:

$$h_{t+1}^j = \left(e_t^j\right)^{\eta_t^j + \varepsilon \bar{h}_t^j} \tag{4}$$

Parents influence their children's human capital through education spending. $\eta_t^j + \varepsilon \bar{h}_t^j$ is the elasticity of human capital to education. Similar to de la Croix and Perrin (2018), the elasticity of human capital to education has a gender-specific part η_t^j. Additionally, it contains a part that depends positively on the (average) human capital of the parents $\bar{h}_t^j$. The latter component aims at capturing a cultural capital effect, according to which the return to education is higher when parental human capital is higher. Parameter $\varepsilon > 1$ determines the strength of this effect.

The decision problem of the household can be summarized as follows:

$$\{a_t^m, a_t^f, e_t^m, e_t^f, n_t\} \ = \ \text{argmax} \ \ \ln(c_t) + \gamma \ln\left(n_t^f \omega h_{t+1}^f + n_t^m h_{t+1}^m\right)$$

Subject to:

- $\varphi n_t = \sqrt{a_t^m a_t^f}$
- $c_t = w_t h_t^m (1 - a_t^m) + \omega w_t h_t^f \left(1 - a_t^f\right) - p_t w_t \left(e_t^m + e_t^f\right) \frac{n_t}{2}$
- $h_{t+1}^j = \left(e_t^j\right)^{\eta_t^j + \varepsilon \bar{h}_t^j}$

[12] Similar to de la Croix and Doepke (2003) and Moav (2005)

[13] Similar to de la Croix and Delavallade (2018), we do not incorporating uncertainty from child mortality in child production.

The optimization problem can be decomposed into two steps: (i) parents allocate their time efficiently by minimizing the cost of rearing children; (ii) households choose the optimal number of children and schooling time for their children.

Parents minimize the cost of child rearing:

$$\min_{a_t^m, a_t^f} w_t\left(h_t^m a_t^m + \omega h_t^f a_t^f\right) n_t$$

Subject to:

- $\varphi n_t = \sqrt{a_t^m a_t^f}$

The cost minimization problem leads to the following optimal rule:

$$a_t^m = \varphi n_t \sqrt{\frac{\omega h_t^f}{h_t^m}} \qquad a_t^f = \varphi n_t \sqrt{\frac{h_t^m}{\omega h_t^f}} \tag{5}$$

The share of child rearing supported by the mother is inversely proportional to her human capital, weighted by the gender wage gap:

$$\frac{a_t^f}{a_t^f + a_t^m} = \frac{h_t^m}{h_t^m + \omega h_t^f}$$

Given the optimal a_t^m and a_t^f, the household labor income can be written as follows:

$$y_t = w_t h_t^m \left(1 - a_t^m\right) + \omega w_t h_t^f \left(1 - a_t^f\right) = w_t h_t^m + \omega w_t h_t^f - 2 w_t \varphi n_t \sqrt{h_t^m \omega h_t^f}$$

The second step of the maximization problem allows us to characterize the quantity-quality tradeoff faced by individuals. The problem can be written as follows:

$$\left\{e_t^m, e_t^f, n_t\right\} = \operatorname{argmax} \ \ln(c_t) + \gamma \ln\left(\frac{n_t}{2}\left(\omega\left(e_t^f\right)^{\eta_t^f + \varepsilon \bar{h}_t^j} + \left(e_t^m\right)^{\eta_t^m + \varepsilon \bar{h}_t^j}\right)\right)$$

Subject to

$$c_t = w_t h_t^m + \omega w_t h_t^f - 2w_t \varphi n_t \sqrt{h_t^m \omega h_t^f} - p_t w_t \left(e_t^m + e_t^f\right) \frac{n_t}{2}$$

The first-order necessary condition describing the optimal choice of n_t is:

$$\frac{\gamma}{n_t} = \frac{1}{c_t}\left(2\varphi\sqrt{h_t^m \omega h_t^f} + p_t \frac{\left(e_t^m + e_t^f\right)}{2}\right)$$

The marginal utility gain of children equalizes the income loss due to the time spent on rearing children, which is larger for educated people, and the cost of education.

The first-order necessary condition describing the optimal choice of education e_t^j with $j = m, f$ is:

$$\frac{p_t}{c_t}\frac{n_t}{2} = \gamma \frac{\left(\eta_t^m + \varepsilon \bar{h}_t\right)(e_t^m)^{\eta_t^m + \varepsilon \bar{h}_t - 1}}{\left((e_t^m)^{\eta_t^m + \varepsilon \bar{h}_t} + \omega\left(e_t^f\right)^{\eta_t^f + \varepsilon \bar{h}_t}\right)} = \gamma \frac{\omega\left(\eta_t^f + \varepsilon \bar{h}_t\right)\left(e_t^f\right)^{\eta_t^f + \varepsilon \bar{h}_t - 1}}{\left((e_t^m)^{\eta_t^m + \varepsilon \bar{h}_t} + \omega\left(e_t^f\right)^{\eta_t^f + \varepsilon \bar{h}_t}\right)}$$

The marginal cost of education equalizes the return of education for boys and for girls. A higher parental human capital $\bar{h}_t^j$ implies a higher return to education for boys $\eta_t^m + \varepsilon \bar{h}_t^j$ and for girls $\eta_t^f + \varepsilon \bar{h}_t^j$. This implies a higher share of income spent on educating children, and a lower share spent on the number of children. Hence, the model predicts, ceteris paribus, in counties with higher expected parental human capital, enrollment are higher and fertility lower.

The first order conditions imply:

$$n_t = \frac{\gamma}{(1+\gamma)} \frac{\left(h_t^m + \omega h_t^f\right)}{2\varphi\sqrt{h_t^m \omega h_t^f} + p_t \frac{\left(e_t^m + e_t^f\right)}{2}}$$

The term $\sqrt{h_t^m \omega h_t^f}$ reflects that the income loss of having children is higher for highly educated parents. For poorer households endowed with too little human capital, the optimal choice for children's education e_t^m is and e_t^f is zero.

The optimal fertility and education levels can be written as follows:

$$e_t^j = \frac{2\varphi\left(\eta_t^j + \varepsilon\bar{h}_t^j\right)\sqrt{h_t^m \omega h_t^f}}{\left(1 - \left(\eta_t^j + \varepsilon\bar{h}_t^j\right)\right) p_t}$$

$$n_t = \frac{\gamma\left(1 - \left(\eta_t^j + \varepsilon\bar{h}_t^j\right)\right)}{(1+\gamma)} \frac{\left(h_t^m + \omega h_t^f\right)}{2\varphi\sqrt{h_t^m \omega h_t^f}}$$

The model presented thus far generates the following testable implications. First, the cost of having children increase with the human capital of the parents. Second, parents spend on education up to the point where the marginal gains in the quality of children equals their marginal cost in terms of forgone consumption. Third, the share of child rearing supported by the mother is inversely related to her human capital, weighted by the gender wage gap. And finally, a rise in parental human capital increases education spending and decreases fertility.

3. Data

3.1. Data sources and descriptive statistics

The major part of the dataset is constructed from General Censuses, Statistics of Primary Education, Population Movement and Industrial Statistics conducted in 1851 (1850 for Education, 1861 for Industrial Statistics). The rest of the data stems from diverse sources. A part of fertility data is available from the Princeton European Fertility Project (Coale and Watkins, 1986). Data on life expectancy at birth come from Bonneuil (1997). A combined use of the various Censuses allows us to construct a dataset with detailed information on fertility, mortality, literacy rates, and enrollment rates in primary schools for both boys and girls, employment in industry and agriculture by gender, level of urbanization and stage of industrialization. In addition, we use data from French Censuses for the years 1821, 1835, 1861, 1881 and 1911 to get more demographic and socio-economic information necessary to carry out our analysis. Note that we do not account for internal and/or external migration because it was small. According to Rosenthal (2004) 80% of the population was composed of either sedentary individuals or short-distance migrants (less than 25 km) during the 19th century. Long-distance migrants were mainly seasonal migrations (Châtelain, 1967). Only a few counties

(Seine, Rhône, Bouches-du-Rhône, and Var) intensively attracted individuals from agrarian counties (Bonneuil, 1997).

As stated earlier, gender is likely to affect education and fertility through various channels, thus justifying the inclusion of gender dimension in our empirical analyses. Along the development process, women got greater access to education what could have consequently diminished distortions in the labor markets. As argued by Forsythe et al. (2000), the differences between men and women in employment or wages may primarily be due to differences in human capital endowments, consequence of the evolution and weakening of traditional structures over time. But the relationship could also run the other way round.

Various historical studies have also shown that parents treated their sons and daughters differently, notably by providing unequal allocation of food or care.[14] With regard to education, parents may have greater incentives to invest in their boys than in their girls if returns to education are lower for girls (possibly due to lower opportunities on the labor market) – lower perceived value of girls. Women are also more likely to affect and be affected by fertility decisions than men. Accounting for gender in the regression contributes to better capture the channel through which fertility decisions derive.

In the *short-run* analysis, we use crude birth rate (CBR) in 1851 as a measure of fertility behavior, defined as the number of births per thousand people. The reason for using CBR is that it is well-suited for construction from vital registration and census data. Moreover, it is easy to calculate when using historical data. For robustness analysis, we have used General Fertility Rate (GFR), which is measured as the number of births per women in age of childbearing (15-49). There are, of course, alternative measures of fertility suggested in the literature, for instance, index of marital fertility (used in Murphy, 2015). However, this measure inherits some important limitations; Sanches-Barricarte (2001) argues that this variable is not a good indicator when there are important delays in the female mean age at marriage, which was the case for several counties in France in the middle of the 19th century (see Perrin, 2013, p. 52). This leads us to choose a simple measure, CBR, which is frequently used and suffer less from possible misspecification biases.

To measure education, we use *enrollment rates* in public primary school in 1850, constructed as the number of girls (boys) attending school divided by the total number of girls (boys) aged 6-14. The main specifications applied in our analysis are expected to capture: *(i)* the variations in fertility with educational level and in education with fertility level; and *(ii)* the supply and demand factors

[14] See, for example, Baten and Murray (2000), Alter and Oris (2000), McNay et al. (2005), Sandström and Vikström (2015), Horrell and Oxley (2016), or Manfredini et al. (2016) for recent studies.

represented by a set of control variables. The supply and demand factors aim at capturing both economic and cultural factors likely to have impacted educational and fertility behaviors. The demand for children, for instance, depends on the opportunity cost of having children. Based on the prediction of theoretical models, we expect income to affect fertility. As a proxy for the income level, we use population density, as well as the employment opportunities, measured by the share of women (men) employed in manufacturing and in agriculture. As a control for the supply of children, we use the life expectancy at birth. The life expectancy at birth allows controlling for the decline in infant mortality and may be a proxy for the lengthening of both the individual longevity and the reproductive period. We also control for religion to account for cultural differences that may have affected individuals' behaviors in regards with fertility (birth control) and education (Lutheran ideas). As a measure of religious practices, we use the share of Protestants within the population.

For our *long-run* analysis, we use literacy rates (or enrolment rate in education) to capture the amount of human capital accumulated. One limitation (already raised by Becker et al., 2010, 2012) of using enrolment rate concerns mismatching of attendance at the census date to that of the year-round attendance, and thus can prevent us from capturing the right amount of accumulated human capital. We use similar control variables to the one used in the short-run analysis. Hence, we control for the level of employment opportunities and religious practices. As additional controls, we use the crude birth rate in 1881 to address potential issues raised by intergenerational correlation of fertility. Furthermore, to account for differential fertility development that might have occurred before the fertility transition, investigated over the period 1881-1911, we control for the initial level of fertility in 1881, measured by the crude birth rate.

Table 1 reports descriptive statistics of the main variables. We find heterogeneity across counties and over time. In 1850, 54.5% of boys aged 6-14 were enrolled in public primary school, while the enrollment rate in public primary school for girls was 36%. Some counties dedicated effort on educational investments for boys but also for girls, i.e. counties located in the northeastern diagonal part of France. Enrollment rates spread from 19% to 106% for boys and from 0.3% to 99% for girls in 1850.[15] The period 1850-1867 recorded fast changes. The number of counties with girls' enrollment rates higher than 50% expanded significantly. This fast increase was followed by a consolidation period, between 1867 and 1876 during which national enrollment rates increased from 66% to 72.3%. The increase in schooling between 1867 and later periods occurred mainly through

[15] Enrollment rates above 100% is because children below 6 years old and above 14 years old were enrolled in public primary schools. Three counties display (small – less than 1%) negative growth rates of male literacy over the 1856-70 periods, one county for the female literacy growth rates (Table 1). These counties are characterized by very high literacy rates over the studied period. More than 90% of the population in these counties was literate. These may explain negative values in a few counties.

the catch up of counties which were originally lagging behind. In 1881, 70.84% of boys and 57.16% of girls (aged 5-15) were enrolled in public primary schools.[16] These variations can be explained by several factors: the diffusion of the official French language, the difference in attitudes toward education between Catholics and Protestants (Becker and Woessmann, 2008), the wave of spreading ideas coming from Prussia and the insufficiency of educational resources deployed in rural areas in terms of teachers and financial spending.

Figure *1a* and *1b* display the geographical distributions of boys' and girls' enrollment rates in 1850. The maps highlight a development gap between Northeastern-France and Southwestern-France separated by the famous line Saint-Malo/Genève. Similar to Prussia (see Becker et al., 2010), the most industrialized area (the Northeast part in France) shows higher enrollment rates. These variations may also find explanations in the different attitudes toward education between Catholics and Protestants as advanced earlier and by the insufficiency of educational resources in terms of teachers and financial spending deployed in rural areas. The rural and more agricultural remainder of France displays higher fertility rates in 1851, as evidenced by Figure *1c*.

Akin to education, data on fertility show an important heterogeneity across counties. These differences support the evidence that some counties have adapted their fertility behavior and therefore experienced a demographic transition before others. A crude birth rate close to 40 is considered as a natural level of fertility, i.e. the level of fertility that would prevail in a population making no conscious effort to limit, regulate or control fertility (Henry, 1961). According to Chesnais (1992), a crude birth rate below 30 per one thousand individuals marks the entry into a regime of controlled fertility; a crude birth rate below 20 children per one thousand individuals suggests that a large share of the population practice birth control. In 1851, the average crude birth rate was 27‰, ranging from 18.72‰ to 34.27‰. In 1851, 19 counties over 86 exhibited a crude birth rate above 30 children per thousand individuals. Thirty years later, in 1881, the average fertility rate decreased to 24‰, with minimum and maximum crude birth rates equal to 17.28‰ and 34.57‰, respectively.

[16] This does not appear in the summary statistics but is available in the data.

Table 1: Summary statistics

	Mean	Std. Dev.	Min	Max
Education				
School enrollment rate (1850)	0.454	0.229	0.13 3	1.029
Boys enrollment rate (1850)	0.544	0.211	0.188	1.059
Girls enrollment rate (1850)	0.356	0.259	0.003	0.997
Boys enrollment (1850-67)	0.600	0.342	-0.076	1.624
Girls enrollment (1850-67)	1.067	1.962	0.017	17.485
Male literacy (1856-70)	0.113	0.092	-0.093	0.358
Female literacy (1856-70)	0.271	0.213	-0.085	0.956
Boys schools (1850)	1.217	0.588	0.143	2.616
Girls schools (1850)	0.152	0.170	0.005	0.907
Distance to Mainz (in km)	699	248	181	1222
Fertility				
Crude birth rate (1851)	26.95	3.597	18.717	34.275
Index of marital fertility rate (1851)	0.497	0.109	0.298	0.747
Crude birth rate (1881)	24.22	3.798	17.28	34.57
Crude birth rate (1881-1911)	-0.245	0.092	-0.405	-0.002
Marital fertility rate (1851)	3.218	0.579	2.07	4.77
Marital fertility rate (1881-1911)	-0.290	0.091	-0.476	0
Economic				
Share in industry (1851)	0.029	0.047	0	0.370
Share in agriculture (1851)	0.426	0.106	0.031	0.655
Male in industry (1851)	0.057	0.081	0	0.636
Male in agriculture (1851)	0.737	0.171	0.046	1.135
Female in industry (1851)	0.036	0.070	0	0.552
Female in agriculture (1851)	0.615	0.179	0.037	1.054
Urbanization (1851)	0.029	0.074	0.003	0.694
Population density (km²) (1851)	1.011	3.166	0.219	29.907
Male wages in agriculture (1852)	1.414	0.287	0.77	2.52
Female wages in agriculture (1852)	0.892	0.186	0.55	1.62
Demographic				
Male life expectancy at age 0 (1856)	38.080	4.424	26.454	48.960
Female life expectancy at age 0 (1856)	40.556	4.834	27.506	49.846
Share married women (1851)	0.534	0.057	0.430	0.641
Male workers (1861)	11 918	19 106	735	141 905
Female workers (1861)	5 271	8 167	215	54 062
Adult sex ratio (1851)	0.993	0.063	0.810	1.194
Infant mortality (1851)	0.301	0.078	0.162	0.483
Child mortality (1851)	0.040	0.012	0.019	0.068
Socio-economic				
Share Protestants (1861)	2.258	5.332	0.003	31.298

Note: Detailed description of variables and their expected signs of impacts in quality-quantity equations are provided in Appendix A

Two contrasting profiles emerge from the analyses of socio-economic and demographic characteristics of the French counties. Whilst we find that agrarian counties have greater number of poorly educated population and higher fertility rates, industrialized counties (but still rural areas) have put measurable effort on education for both genders, although women tend to be more integrated in the labor market, and fertility rates appears to be smaller in comparison.

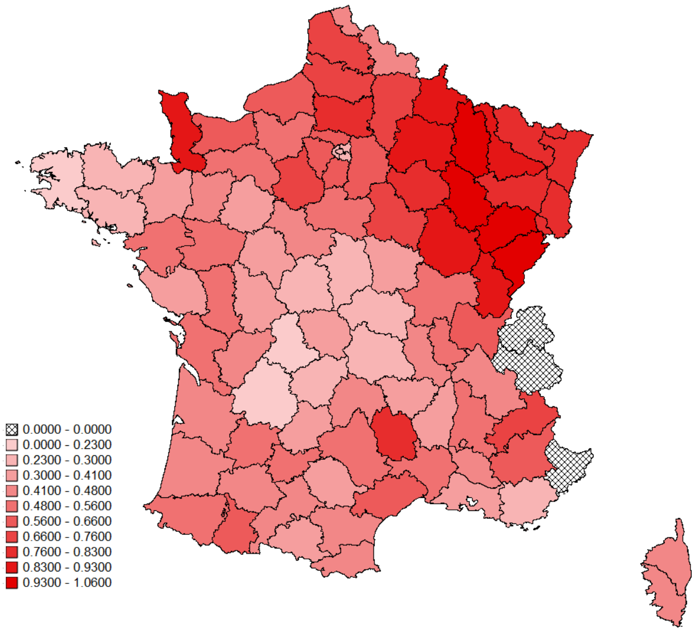
3.2. Distributional characteristics

Are fertility and educational attainment distributions are normal or do they reveal any feature of multimodality? The multimodal structure of a distribution often helps us detect possible cluster dynamics in the data. This section presents any evidence of multimodality of fertility and education from our data. Our underlying idea is to detect equilibrium clusters of counties with different educational attainment and fertility behavior. This is important for several reasons; one of them being that such evidence often guides researchers in choosing the correct estimation method – for instance, whether to focus on the 'mean-based' conventional OLS method or to adopt 'quantile-based' full distributional method. Another reason is that any evidence against unimodality of distribution of these variables would indicate possible presence of multiple equilibria/clusters, leading to variable inferences at various points of the distribution the dependent variable.

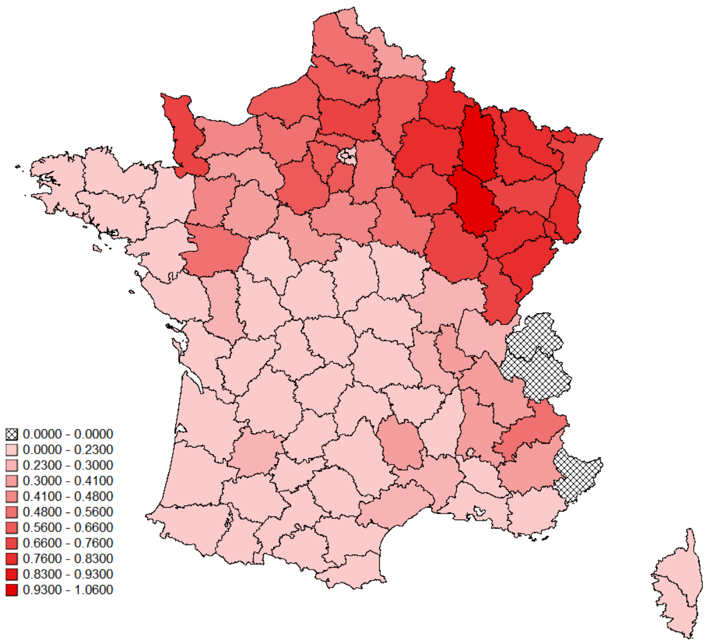
Alternately speaking, it might be possible, for instance, that the response of fertility to low educational attainment level is different (both quantitatively and direction of causality-wise) from the one at high educational attainment levels. In Section 1, we have motivated this by providing economic and sociological arguments. It may not be always be a sufficient reason to employ a certain flexible estimation technique (such as quantile regression approach) to estimate heterogeneous effects, because the underlying assumption of, for instance, heterogenous response of fertility to the variation of educational attainment between male and female, needs to be theoretically verified. In our work, the quantile regression method is employed for the purpose of demonstrating sensitivity of the effects of education on fertility or vice versa across the distribution of the dependent variable. The changes in the signs in addition to the size differential of effects across the distribution may be interesting for policy making.

Figure 1: Geographical Distribution of Education and Fertility

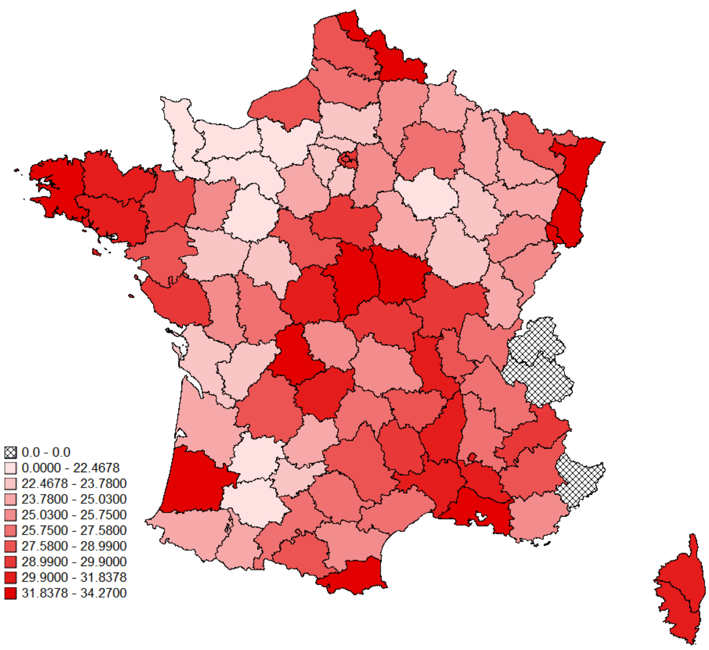
(1a) Boys Enrollment Rate, 1850



(1b) Girls Enrollment Rate, 1850



(1c) Crude Birth Rate, 1851



Sources: Using data from Statistique Générale de la France – Enseignement Primaire 1850; Census 1851

Following this idea, we have presented Adaptive Kernel density plots of crude birth rate (Figure 2a.1) and enrollment (Figure 2a.2). It needs mentioning at this point that adaptive Kernel density extends the possibilities offered by Kernel density estimation in two ways: first, it allows the use of varying, rather fixed bandwidth. Second, it provides estimation of pointwise variability bands. Following this density estimation, these two figures present evidence of significant bimodality – which is further confirmed by Hartigan and Hartigan's (1985) Dip test. In case of fertility, the crude birth rate mean is 26.976 with a standard deviation of 3.610. However, Figure 2a.1 presents two significant modes (one around 30 and another at 25). These modes, as confirmed by Dip test are significant at 5% level. Likewise, education (enrollment rates) for both men and women also depict significant bimodality (weaker for men – Dip test accepted at 10% level) whereas it is stronger for women (accepted at 5% level).

Question may arise on whether the observed bimodality can be explained by differences between urban and rural departments or differences across geographical locations, viz., North and South of France?[17] To answer these questions, we re-examine any changes in the distributional patterns over rural and urban share as well as the counties' geographical dispersion. To present adaptive Kernel density plots (see Appendix B for details) with regard to urban and rural residents share, we have ordered CBR and enrolment ratio by above and below median shares for each category (rural and urban). In the appendix we have presented the corresponding adaptive Kernel density plots. The results are quite mixed: for CBR, there is some evidence of bimodality for rural residential share (below median) and for urban residential share (above median). For enrolment category, data for boys display bimodality above median rural residential share, and data for girls display bimodality below urban population share. For the enrollment rates, one would also expect to find an effect of the location as possible source of bimodality as the counties displaying higher enrollment rates are located on the Northeastern part of France. Indeed, from our estimated geography-differentiated Kernel densities, we concur with our observations of bimodality.

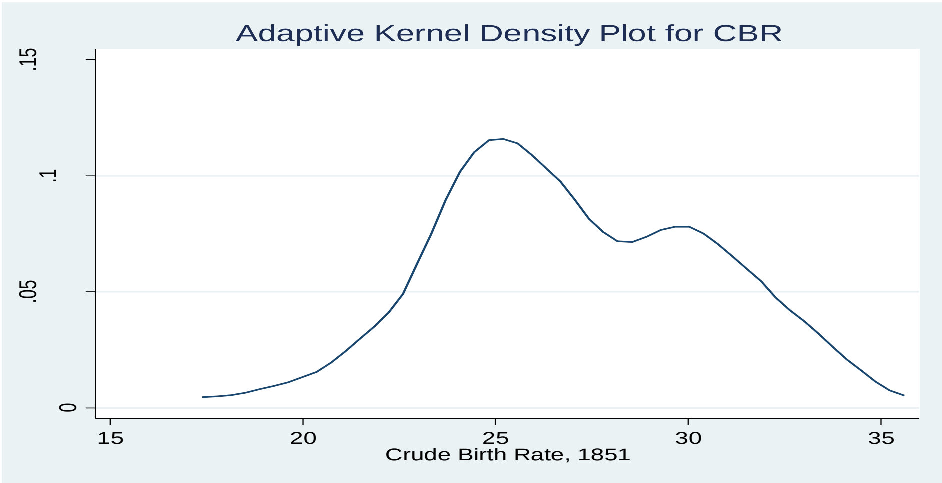
The source of bimodality can also be explained by differences in cultures and norms and effects of social status as much as the different stages of development reached by counties. For some underdeveloped regions (with less education), the social norms and entrusted familial responsibilities on women may prohibit them to bargain more for education, in contrast to the regions with a developed education system. Such differences influence choice of parents to go for more education or more children. When one considers a mix of regions/counties with these innate differences in parental attitudes towards quantity and quality of children and education, respectively, it may

[17] Many thanks to an anonymous referee who raised this insightful question.

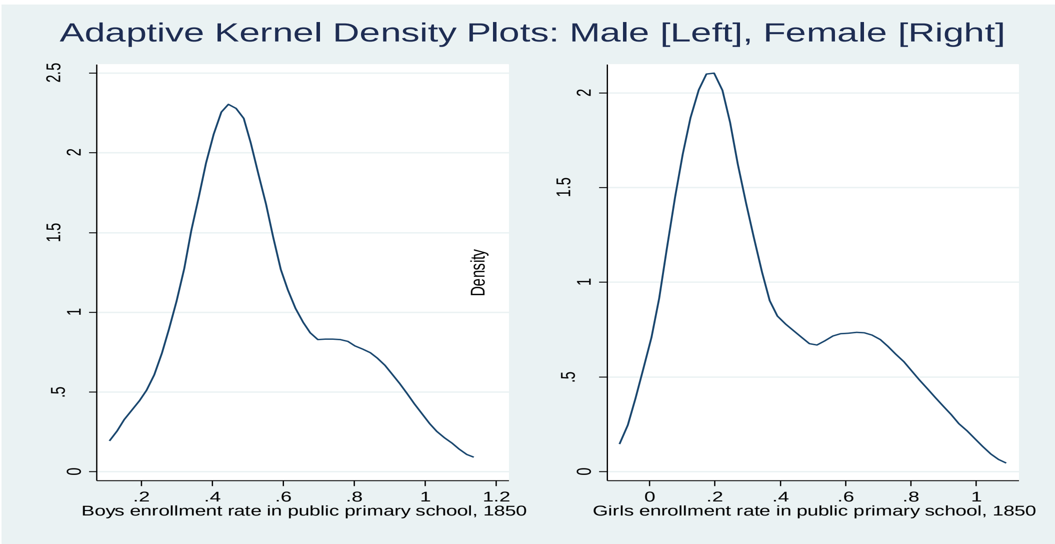
invariably create a distributional pattern with varying modes or clusters. To study sensitivity of our estimates obtained using conventional mean-based estimation, therefore, we have also performed quantile estimation so that the impact of education (fertility) on fertility (education) can be gauged at each part of the distribution.

Figure 2a: Distributional Characteristics of Fertility and Education

(2a.1) Distribution for crude birth rate (CBR)



(2a.2) Distribution for enrollment rate



Figures 2b.1 and 2b.2 present the bivariate Kernel density plots for CBR and enrollment rate (boys and girls). The contours reflect the fact that low educational attainment for girls evinces higher fertility rate, which is far greater than that of the male with similar enrollment scale. Moreover, we have also performed a skewness test of CBR as well as the enrollment rate for boys and girls. Figure 2c (2c.1

for male enrollment, 2c.2 for female enrollment, and 2c.3 for CBR) present the skewness plots. A rising graph implies that there is significant bias to the right of the distribution and the distribution is not normal. Indeed, all three graphs depict the expected pattern: they are right-skewed distributions and therefore the mean and the mode of these distributions are markedly different. These results and the reasons cited above motivate us to go beyond conventional OLS based estimation method, as the estimated coefficients may be either under- or over-estimated and may not present the complete picture of the response of education to changes in fertility (and the converse). Alternative estimation method, such as quantile regression technique, has been found to be very useful in this regard. We present them in the next section.

Figure 2b: Bivariate Density Plots for Fertility and Education: Boys and Girls

(2b.1) Boys (2b.2) Girls

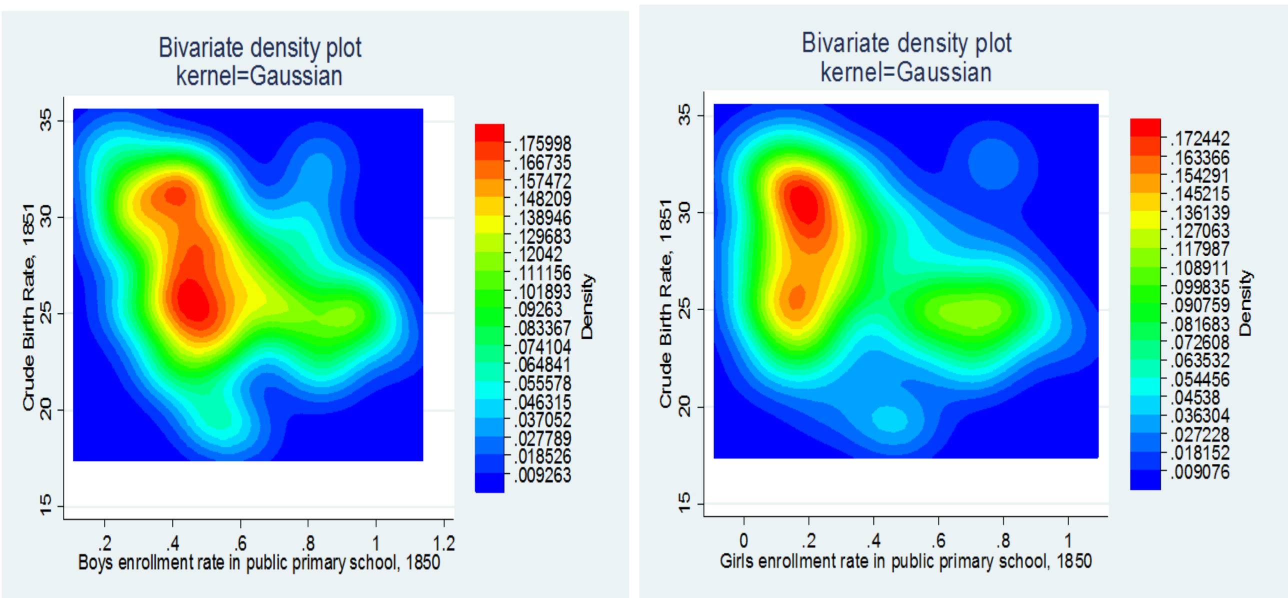
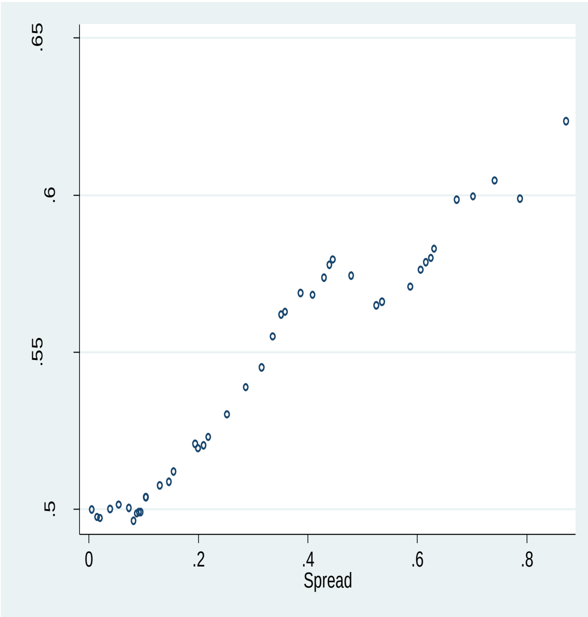
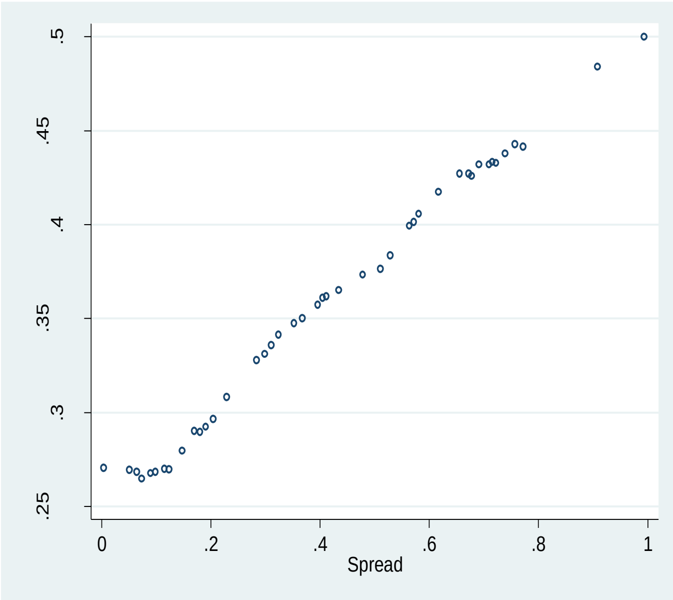


Figure 2c: Skewness Test

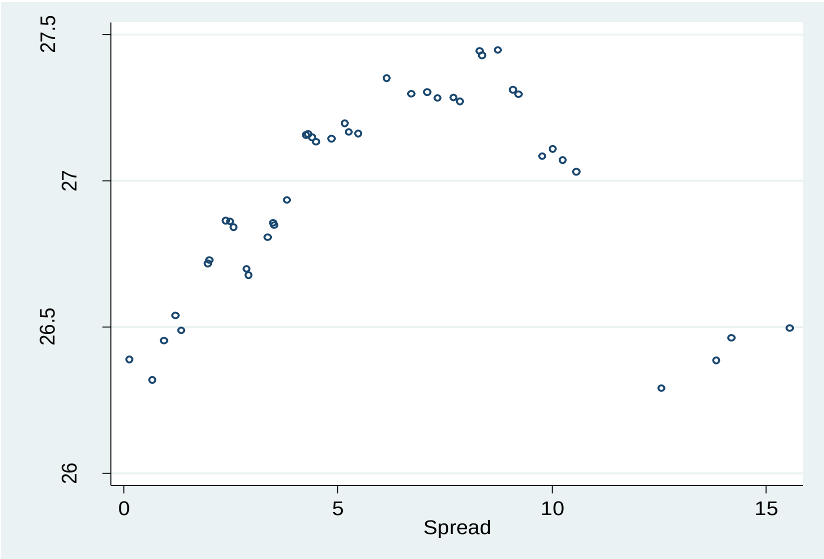
(2c.1) Boys Enrollment



(2c.2) Girls Enrollment



(2c.3) Crude Birth Rate



4. Methodological setting

In this section we develop and present the methodological construct that would adequately account for sensitivity of the education-fertility relationship to distributional heterogeneity. Towards this end, we first describe the empirical framework and use the same to develop necessary methodological tool.

4.1. Empirical construct

We follow our theoretical construct in Section 2 and estimate both short-run and long-run relationship between investment in human capital and fertility. For the short-run analysis, our interest is on the returns to education, whereas for the long-run, we aim to focus on relationship based on opportunity cost and/or bargaining power of women in the family. The following empirical construct are designed to study the existence of any significant causal relationship between education and fertility driven by gender differences.

***Short-run**:*

We follow Becker et al. (2010) and differentiate between the two directions of causality*: from education to fertility* and *from fertility to education*. We estimate the following empirical models separately (Wooldridge, 2002):

$$fertility_i^j = \alpha_1 + \beta_1 education_i + \boldsymbol{X}_{i1}\,\delta_1 + e_{i1} \tag{6}$$

$$education_i^k = \alpha_2 + \beta_2\, fertility_i + \boldsymbol{X}_{i2}\delta_2 + e_{i2} \tag{7}$$

where $fertility_i$ and $education_i$ refer to the crude birth rate and the enrollment rate in public primary schools for each county i. The coefficients β_1 and β_2 are our parameters of interest. $\boldsymbol{X}_1$ and $\boldsymbol{X}_2$ are the vectors of control variables.

Long-run*:*

We use equation (8) to test the hypothesis that increasing investment in education might have played a significant role in the fertility transition:

$$\Delta fertility_{i,1881-1911} = \alpha_i + \beta \, \Delta \, education_{i,1856-70} + \boldsymbol{X}_i \; \delta + e_i \qquad (8)$$

where $\Delta fertility_{i,1881-1911}$ is the percentage change in the crude birth rate between 1881 and 1911 is the dependent variable and $\Delta \; education_{i,1856-70}$ is the percentage change in literacy rates between 1856 and 1870. $\boldsymbol{X}$ is the vector of control variables (see Appendix A for a detailed description). The time lag of twenty-five years between the dependent and the explanatory variable prevents from having a direct simultaneity between the variables.

We keep in mind that there might be a bidirectional causal relationship between fertility and education. Indeed, unobserved characteristics affecting schooling choices are potentially correlated with unobservable factors influencing the decision to have children (and inversely). To mitigate potential endogeneity issues, we estimate equations (6) - (8) by both the conventional Two Stage Least Square (2SLS) Instrumental Variable method as well as an Instrumental Variable Quantile regression method. While the conventional approach will enable inference of the average effects of education (fertility) on fertility (education) keeping other things constant, the quantile approach will enable us to study the sensitivity of the estimates at various parts of the distribution. Alternatively speaking, based on quantile approach (with and without instrumentation), our investigate: *(a)* to what extent the level of male education at time t is influenced by the level of parental fertility at time t; and *(b)* to what extent the level of girls education at time t is determined by the level of parental fertility at time t.

To control for the main determinants of fertility and education The covariates used in the regression analysis are: *(i)* proxies for the level of industrialization specified as the population density; *(ii)* employment opportunities measured by the share of people making their living of agriculture and the share of people employed in manufacturing; *(iii)* the share of Protestants; and *(iv)* the life expectancy at age 0.

4.2. *Estimation and identification strategy*

(i) Estimation

Since the conventional two-stage least square (2SLS) instrumental variable strategy is standard, in this section, we will focus more on the identification problem in a quantile setting. The 2SLS requires us to estimate the first stage regression of an endogeneous variable on a potential instrument. Depending on the significance and magnitude of the coefficient, one can infer on the suitability of that instrument for the purpose endogeneity mitigatio. Of course, once the first stage regression is performed, the predicted value of endogenous regressor is generated (after making it relatively noise-free, ones that may be correlated with the instrument). This predicted value is used in the second stage regression. The baseline estimation from this 2SLS approach for both short-run and long-run models are compared with the estimated values from quantile regression so that we can informatively conclude whether the average effects obtained from 2SLS are robust across quantiles.

Quantile regression approach has been proved very useful in this regard (Koenker and Bassett, 1978, for instance). In quantile regression, by specifying different covariate effects at different quantile levels we allow covariates to affect not only the center of the distribution (that is mean-based OLS estimation), but also its spread and the magnitude of extreme events. Indeed, by using quantile model we allow for unobserved heterogeneity and heterogeneous covariate effects. In addition, quantile regression allows for some conditional heteroskedasticity in the model (Koenker and Portnoy, 1996), and is a method that is more robust to outliers.

Recalling the quantity-quality trade-off problem in equation (1) and denoting, fertility as (F), education as (E), and other variables as (X), we can re-write the vectorial notation as follows:

$$\begin{aligned} F &= \beta E + \gamma X' + \varepsilon \\ X &= f(z, u) \\ \varepsilon &= \mu + u \end{aligned} \tag{9}$$

We assume that education (E) not only affects fertility (F) but also life expectancy, population density, and many other variables (denoted in our equation as X). z is a vector of instruments which drive education but are uncorrelated with u and ε. Moreover, μ are country specific factors affecting the evolution of F and E. As evident, we are interested in estimating β, the causal effect of education on fertility, at different quantiles of the conditional distribution of fertility. The following possibilities arise:

(i) Mean based regression

In a typical least squares approach, one may focus on estimating:

$$E(F_i|E_i, X_i) = \beta E_i + \gamma X_i \tag{10}$$

In equation (10), β captures the 'average' response of fertility due to a small change in educational attainment and other variables. What is missing in this estimate is the possibility of *heterogeneous* response of fertility to changes in the explanatory variables. It is now well-known that average response of the dependent variable is less informative of the actual dynamics that occurs between the regressors and the full range of distribution of the dependent variable. Indeed, this is the case in the present context. As demonstrated before, the unconditional distribution of fertility is strongly bimodal. Thus, it seems that the analysis that focuses on the (conditional) mean of the distribution might miss important distributional effects of education and other variables on fertility. To capture this effect, quantile regression will offer a wholesome view of the effect of education on the entire distribution of fertility (or vice versa as in equation 8). Given the cross-sectional nature of our data, we adopt the following *cross-sectional quantile regression* framework.

(ii) Median regression: (Quantile) regression

$$Q_{F_i}(\tau|E_i, X_i) = \beta(\tau) + \gamma(\tau)X_i \tag{11}$$

The parameter $\gamma(\tau)$ captures the effect of education at the τ-th quantile of the conditional distribution of fertility. This model can be estimated by solving the following minimization problem:

$$\min_{\beta,\gamma} \sum_{i=1}^{N} \rho_\tau(F_i - E_i - \gamma X_i) \tag{12}$$

where $\rho_\tau(u)$ is the standard quantile regression check function (see, e.g., Koenker and Bassett, 1978; Koenker, 2005). The partial effects for education on fertilty can be obtained by $\frac{\partial Q_t(F_i|E_i)}{\partial E_i}$.

(ii) Identification strategy – Endogeneity issue

(a) *Choice of instruments and first stage results*

Two types of endogeneity problems can plague regressions of education on fertility. One type is the simultaneity bias introduced by the reverse causality of education and fertility (equation 3). A second type of endogeneity problem arises from omitted variable bias. While including policy variables helps reduce the problem of the endogeneity of education, it is still quite plausible that a third variable jointly causes both fertility and education – perhaps religious, cultural, or geographic factors. In order to mitigate the problems of endogeneity, we innovate upon the previous literature by employing an instrumental variables approach in our cross-sectional quantile regression (see for instance, Chernozhukov and Hansen (2005) and Harding and Lamarche (2009) for detailed estimation procedures and motivation).

What leads to the choice of our instruments? Because we have two different channels (fertility to education and the reverse) for quantifying quantity-quality trade-off, several possible instruments can be considered. In case of fertility-education channel (equation 6), A good instrument for education needs to be highly correlated to our education variable but not to fertility. There are a number of possibilities for instrumenting education. For instance, one can use distance to Wittenberg or distance to Mainz, share of male (female) spouse signing the contract 1816-20, landownership inequality in 1835, agricultural inequality, public primary schools for 100 boys and girls. Consistent with the existing literature (such as Becker et al. 2010) we use Distance to Wittenberg as a potential instrument to identify exogenous variations in enrollment rates. Diebolt et al. (2017) also use distance to Mainz as another potential instrument for education.[18] Distance to Wittenberg is calculated as the straight line distance of each county to Wittenberg. This instrument is highly correlated with enrollment rates but has no obvious link with the crude birth rate. We find that the correlation between educational attainment (for male) and distance to Wittenberg is -0.635 while the same with the Distance to Mainz is -0.625 (all significant at 5% level). Similarly, for female the correlation is -0.803 for the distance to Wittenberg and -0.79 for the distance to Mainz. Technically, we know that the bias of 2SLS becomes small only if the endogenous variable and the IVs are highly correlated. This is what we obtain from our data. As an additional instrument (in the robustness exercise), we also use share of spouse signing the marriage contract and landownership inequality.

[18] Mainz is the city where the printing technic was invented in the mid-fifteenth century and from where the technological innovation spread. The printing press fundamentally changed the way knowledge was disseminated. It allowed a larger share of the population to access knowledge and at a faster pace than ever before.

When considering the reverse channel, i.e., education-fertility relationship, a good instrument for fertility should be highly correlated to our fertility measure but not to education. The possible instruments for fertility are crude birth rate of the previous generation (in 1821), adult sex ratio 15-45 , and children and non-married sex ratio in 1821, 1831, and 1836. As we know, all instruments may not identify the dependent variable and may suffer from weak-identification problem. Moreover, many of them may not be strictly exogenous. The possibility of weak correlation of the instruments with other regressors in the two different channels we are interested in estimating can make estimated coefficients unreliable. We are guided by the literature in the instrument choice. Similar to Becker et al. (2010), we use the adult sex ratio as instrument for fertility in 1851, defined as the number of men aged 15-45 over the number of women aged 15-45. This variable measures the tightness of the marriage market that could affect the rates of marriage and fertility (see for instance Angrist 2002 and Abramitzky et al. 2011). As explained by Becker et al. (2010), the sex ratio is exogenously determined by differential birth and death rates that 'affects fertility behavior only through its influence on the probability of finding a mate, but is otherwise unrelated to education'. From our data, we observe that the correlation between fertility and the sex-ratio is 0.707 which is statistically significant at 5% level.

First stage results: We have undertaken first stage regression to study whether the instruments are appropriate. The underlying modelling assumption is that *Covariance(Instrument, Endogenous Variable)* is non-zero. To obtain this, we simply estimate:

Endogenous Variable = p_0 + p_1 *IV+ random error,* and test H0: $p1$ = 0. We refer to this regression as the 'first-stage regression'. In our case, this translates to:

Education (male and female) = p_0 + p_1 *IV for Education (Distance to Wittenberg)* + + p_2 *Controls* + *random error*

Fertility = p_0 + p_1 *IV for Fertility (Adult Sex-ratio)* + p_2 *Controls* + *random error*

For education regression (in case of male), we obtain the estimated p_1= -0.632 with a standard error of 0.077 and female, p_1= -0.900 with a standard error of 0.067. Both indicate significance at 1% level. The R^2 values for male education regression is 0.51 whereas for female education regression 0.70, indicating good explanatory power of the instrument. Likewise, for fertility regression, the estimated p_1 = 1.728 with a standard error of 0.136 indicating significance at 1% level. The R^2 value of 0.53 also indicates good model fit (detailed results are available with the authors).

(b) Testing for exogeneity of instruments across quantiles

Although one may expect a test of exogeneity of instruments (for instance, whether the instruments are weakly or strongly exogenous) in the quantile estimation setting following conventional mean-based regression methods, to the best of our knowledge, no such unique method exists.[19] What is available until recently, only a test of exogeneity at one quantile (see for instance, Jun, 2008). There are many challenges one has to tackle before proposing a uniform test of exogeneity across quantiles. Firsly, as one expects heterogeneity in effects of the dependent variable to a change in the explanatory variable, the ranking of the data (ordered from low to higher quantiles) essentially represent different characteristics of the data. For instance, in our case, if we look at the fertility distribution, a lower fertility quantile represents a different state of the demographic and economic system than it is at the higher fertility level at higher quantiles. A chosen instrument or set of instruments (in our case, the instrument of education) may or may not remain exogenous across quantiles, simply because a ranking of educational distribution also means that the system has evolved significantly over time and thus the determinants of low and higher educational levels are different at different points of the distribution.

This is the primary reason to assume that our instrument for education, viz., the distance from Wittenberg (used in Becker et al. 2010) or Distance to Mainz, will be consistently exogenous across quantiles of education. For a cross-sectional data, such as ours, finding a unique testing strategy may be less complex than for a panel data, when one has to deal with the additional dimension of time, whereas unobserved heterogeneity may bias the estimates.[20] For our purpose, we have employed an F-test to decide at each quantile, if the instrument is exogenous at a specific quantile. We present the results of equation (8) and F-test, in various tables.

(c) Exlusion restrictions and first stage regression

In the standard linear instrumental variable (IV) regression case, the instruments need to meet some important conditions: *(i)* the IV should be strongly correlated with the endogenous treatment (in our

[19] The authors are currently developing a general theory of testing for overidentification and exogeneity across quantiles.

[20] In this circumstance, it is required to prove consistency of exogeneity inference across quantiles. In the absence of a ready unique test of exogeneity, an alternative but less scientific approach is to test for exogeneity of instruments with the error term from the regression from a specific quantile. In other words, we test whether Correlation(instruments, Estimated errors) = 0 at quantile q = 0.1 and sequentially through q = 0.9. A general test can be proposed: $\lim_{i,t \to \{N,T\}} \sum_{q=1}^{Q} f(Instrument, Error) \to 0$. It is preserved for future research.

case, fertility or education, depending on the regression context), (ii) it should be uncorrelated with unmeasured confounders (the error term), and (iii) should influence the outcome (here, fertility or education) only through the treatment variable. This last condition, known as exclusion restriction, would require a test, following convention, where a regression of outcome variable (fertility, for instance) on treatment variable (for instance, education) and the candidate IV (for instance, distance to Mainz) should be able to estimate the coefficient of IV is zero. However, Deng (2019) show that this does not have to be the case and that this approach is misguided. Rather, it is possible that the coefficient on IV can still be non-zero even while satisfying exclusion restrictions.

The conventional approach of zero coefficient of the IV in a regression of outcome on the treatment variable do not really stand in a quantile framework. Each part of the distribution in a quantile framework, while follow the same data generating process, are designed to display heterogeneous behaviour. Therefore, as Deng (2019) proposes is essentially true in a quantile regression framework. Moreover, Kiviet (2020) also notes that 'if one wants to verify whether just-identifying instruments are valid, the only route provided by the standard approach is: first adopt another non-testable set of valid identifying instruments'. Hence, providing full-fledged statistical evidence on the validity of all instruments is simply impossible by these tools. [21] In the context of our work, given the complexity of testing across quantiles, we have performed a test where the IV and the error terms are uncorrelated at each level of quantile and that the coefficient of the IV is close to zero at each quantile. Our IV implementation strategy involves addition of a control function to the specifications of the conditional quantile equations. The control function consists of residuals from the regression of education (or fertility) on the instruments. This comprises of our first stage regression for each quantile and the saved residuals from this quantile run will be used in the second stage regression for the same quantile. Kim and Muller (2004) argues that this is easy to use, intuitive, and is a robust estimation procedure.

[21] Kiviet presents an approach by which, without exploiting any external instruments, general linear coefficient restrictions can be tested in a multiple regression model with an arbitrary number of endogenous regressors. Instead, it requires a flexible assumption on the degree of endogeneity of all regressors. This approach – which is of substantial practical relevance by itself – can be implemented such that it also allows to generate statistical evidence on the tenability of exclusion restrictions.

5. Results and discussion

In this section, we present two sets of results. First, we analyze the conventional instrumental variable Two Stage Least Square (2SLS) results for short-run effects of gender-specific educational attainment on fertility. We also discuss long-run effects of education on fertility within the same estimation domain. To check the sensitivity of our estimates across various parts of the distribution, our second set of results focus on instrumental variable quantile regression. We begin with the 2SLS results first.

5.1 Instrumental variable 2SLS Results

(a) Short-run Effects

Tables 2a and 2b present results of short-run effects (equations 6 and 7) for both men and women with regard to the impact of education on fertility and fertility on education, respectively. As noted earlier, instrument for education (viz., distance to Wittenberg) appears to be a good predictor of both boys and girls enrolment rates. Using this instrument, the 2SLS regression results in Table 2a depict measurable difference between boys' and girl's education on fertility. The coefficients are -3.371 and -3.600 respectively for boys and girls. The negative sign is compliant to theory of quality-quantity tradeoff. We find that a unit rise in educational attainment rate, will trigger a fall of fertility by 3.371 and 3.600, on average. Although we expect negative and significant effect of employment of women in industry on fertility, the estimated effects appear to be positive but statistically insignificant. Life expectancy appears to exert a significant negative effect as it captures partly infant mortality. In fact, counties where infant mortality is lower are the ones which might reach the desired number of offspring in a more effective way. This is expected to lower fertility. Our result is consistent with the established literature, such as Becker et al. (2010). Although Becker et al. (2010) find a negative effect of Protestant population share, they do not explain the reasons behind such an observation. In our estimation, we obtain positive effects of protestant (significant only for male population). A possible explanation is that at the early stage of the French demographic transition, individuals who were more engaged in religion were likely to have a greater number of children.

In Table 2b, we have presented results for the effect of fertility on education. For both men and women, we find statistically significant negative impact of fertility on education (-0.021 and -0.020, respectively for men and women). Employment is agriculture appears to exert negative impact on education, because one would expect low return from educational investment when working in agriculture, contrary to employment in industry (with a positive effect). Moreover, we find share of protestant to be significantly positive implying a higher propensity to invest in education as observed by Becker et al. (2010) and Becker and Woessmann (2009).

Table 2a: 2SLS-Instrumental Variable Estimation: Education to Fertility (Short-run Effects)

$$fertility_i^j = \alpha_1 + \beta_1 education_i + \boldsymbol{X}_{i1}\,\delta_1 + e_{i1}$$

Dependent variable	Crude Birth Rate	
Enrollment (Boys)	-3.371***	--
	(1.153)	
Enrollment (Girls)	--	-3.600*
		(1.966)
Employment in agriculture	-0.922	-0.857
	(1.765)	(1.666)
Employment in industry	0.528	0.682
	(3.734)	(2.638)
Population density	-0.150***	-0.132***
	(0.056)	(0.059)
Share Protestants	0.143***	0.085
	(0.058)	(0.060)
Life expectancy	-0.499***	-0.496***
	(0.064)	(0.071)
Constant	48.844***	48.194***
	(3.026)	(3.482)
N	85	85
R^2	0.540	0.512
Wald Chi-square	218.50***	147.93***

Note: Dependent variable: Crude Birth Rate (CBR 1851). Robust standard errors in parentheses. ***: significant at 1% level; **: significant at 5% level; *: significant at 10% level Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys/Girls enrollment rate is the share of boys/girls aged 5-15 enrolled in public primary schools.

Source: County-level data from the *Statistique Générale de la France*.

Table 2b: 2SLS-Instrumental Variable Estimation: Fertility to Education

(Short-run Effects)

$$education_i^k = \alpha_2 + \beta_2\, fertility_i + \boldsymbol{X}_{i2}\delta_2 + e_{i2}$$

Dependent Variable	Enrolment (Boys)	Enrolment (Girls)
Crude Birth Rate	-0.021***	--
	(0.006)	
	--	-0.020***
		(0.006)
Employment in agriculture	-0.281**	-0.141
	(0.140)	(0.126)
Employment in industry	0.291*	0.330**
	(0180)	(0.171)
Population density	-0.013***	-0.007***
	(0.004)	(0.003)
Share Protestants	0.011***	0.011***
	(0.003)	(0.003)
Life expectancy	0.002	0.004
	(0.003)	(0.003)
Constant	1.220***	0.966***
	(0.396)	(0.385)
N	85	85
R^2	0.292	0.255
Wald Chi-square	109.39***	127.04***

Note: Dependent variable: Enrolment rate for Boys and Girls is the share of boys/girls aged 5-15 enrolled in public primary schools. Robust standard errors in parentheses. ***: significant at 1% level; **: significant at 5% level; *: significant at 10% level Crude birth rate is defined as the number of birth (in 1000 s) over the total population. *Source:* County-level data from the *Statistique Générale de la France*.

(a) Long-run Effects

From the study of the short-run relationship between education and fertility, our results show that the correlation goes in both directions of causation. This suggests the existence of a child quantity-quality trade-off in France during the French demographic transition. However, these results may hide a more complex underlying relationship (Diebolt and Perrin, 2013, 2019a). To shed deeper insights into the relationship, it is useful to test the hypothesis that women endowments in human capital affect their own choices of fertility, and subsequently that of future generations. Therefore, in this section we determine whether the endowments in human capital in time t affect the level of fertility in period $t + 1$. This motivates us to model the long-run effect of investment in human capital on fertility. We empirically test the effect of the percentage change in human capital investments between 1856 and 1870 on the variations in fertility between 1881 and 1911 across French counties. We choose such data to account for the effect of education on several generations of individuals (parents and grand-parents).

Table 2c reports results for long-run effects of education on fertility. We find that % change in female literacy exerts significant negative effect on the % change in crude birth rate (second column). For male population, the coefficient is negative but statistically insignificant even at 10% level. Importantly, in the long-run, % change in educational attainment has larger effect on fertility change for female population than it is for the male population. Among other covariates, crude birth rate in 1881 has significant positive effect on fertility change for both male and female. Further, employment in agriculture has a negative effect on fertility change mainly because marginal gain from agricultural employment would be smaller than the industrial employment in the long-run. Following Becker et al. (2010) we find negative effect of protestant share on fertility change.

Table 2c: 2SLS-Instrumental Variable Estimation: Change in education to Change in fertility

(Long-run Effects)

$$(\Delta fertility_{i,1881-1911} = \alpha_i + \beta\, \Delta\, education_{i,1856-70} + \boldsymbol{X}_i\ \delta + e_i)$$

Dependent Variable	Crude Birth Rate (% change 1881-1911)	Crude Birth Rate (% change 1881-1911)
Literacy (male)	-0.085	--
(% change 1856-70)	(0.076)	
Literacy (female)	--	-0.131***
(% change 1856-70)		(0.030)
Crude birth rate 1851	-0.017***	-0.015***
	(0.003)	(0.030)
Employment in agriculture	-0.140***	-0.114***
	(0.048)	(0.038)
Employment in industry	0.069	0.014
	(0.094)	(0.119)
Population density	-0.004***	-0.003***
	(0.001)	(0.001)
Share Protestants	-0.003***	-0.003***
	(0.001)	(0.001)
Life expectancy	0.002	0.003
	(0.002)	(0.002)
Crude birth rate 1881	0.006**	0.005*
	(0.003)	(0.003)
Constant	0.098	0.019
	(0.167)	(0.141)
N	82	82
R^2	0.560	0.641
Wald Chi-square	243.01***	341.17***

Note: Dependent variable: Rate (% change 1881-1911). Robust standard errors in parentheses. ***: significant at 1% level; **: significant at 5% level; *: significant at 10% level.

Source: County-level data from the *Statistique Générale de la France*.

5.2 Robustness of estimates across quantiles: IV Quantile regression results

(a) Short-run effects: *Education to fertility*

To gauge if the results obtained for quality-quantity trade-off using 2SLS method (in Tables 2a-2c) are quantitatively similar across quantiles of the dependent variable (fertility or education). Our intention is to identify if there is a notable difference in impact magnitude and signs of the coefficients of fertility and education for both short- and long-run analysis. Due to the potential endogeneity issues as discussed in the methodology section, we report here the instrumental variable quantile regression results. Estimations have been performed for both men and women at 10th, 25th, 50th, 75th, and 90th quantiles. To minimize space, we have reported in all Tables lower quantile ($\tau = 25^{th}$), median quantile ($\tau = 50^{th}$ – generally regarded as an approximate to OLS estimates), and an upper quantile ($\tau = 75^{th}$), although the graphical plots of the effects include estimates at all quantiles (see for instance, Figures 4 and 5). We begin with the case where the dependent variable is fertility (crude birth rate). Table 3 reports results for the effect of education on fertility for both men and women. Overall, we find evidence of quality-quantity tradeoff as we find negative effects of education (enrolment ratio – for both boys and girls) on birth rate (CBR). In comparison to the 2SLS estimates (in Tables 2a and 2b), the quantile estimates are significantly larger. However, the size differential between male and female are not big across models (for male and female) but there is impact heterogeneity within the same distribution. An Interquantile test reveals that the estimates are significantly different.

The results quantitatively confirm the OLS estimates. Note that the fertility transition in France started in rural areas. Before 1851, the fertility transition was a rural phenomenon, Paris being an exception (van de Walle, 1986). It is from 1876 onwards only that all the departments – including urbanized ones – experienced their transition.

(b) Short-run effects: Fertility to education (reverse channel)

Similar to the results above, we present in Table 4, the IV quantile estimates for the effect of fertility on education.[22] To mitigate a possibility of endogeneity of fertility with other regressors, as in 2SLS regression, we have instrumented crude birth rate with adult sex ratio. Table 4 reports the estimates where boys and girls enrollment rates are each in turn function of the crude birth rate. Although a sequential introduction of control variables can provide a detailed picture, to minimize space and repetition, we only present the generalized model with all covariates. We note that across all quantiles, the coefficient of fertility is significant and negative at least at the 1% level which confirms

[22] Test of causality in cross-sectional regression of the type we have presented in this article can be performed either by matching or by spatial causality test. We reserved this for future research.

the significant and robust association from fertility to education. Overall, our results indicate stronger effects of fertility decline on the likelihood of female empowerment with respect to education. By controlling for the role of men and women in agriculture and industry, as well as the effect of population density, the results point at the larger role of women, than men. Our interquartile difference test for men-women differences in results in each quantile also rejects the null hypothesis of no significant effect in favor of greater effects of women (at 5% levels: results not reported here). In addition, higher life-expectancy for women had larger positive and significant effects on the enrollment rates than the life expectancy of men for all quantiles. Conversely, higher share of Protestants had positive and significant effects on the propensity to invest in boys' enrollment rates (at 25th and 75th quantiles in Table 6); but not to invest in girls' education.

(c) Long-run effects: education to fertility

Prior to discussing the quantitative estimates (from Table 5), we would like to draw some insights from Figure 3; Figures 3a and 3b describe the geographical distribution of changes in male and female literacy rates between 1856 and 1870, while Figure 3c provides an insight of the subsequent changes in crude birth rates, in particular between 1881 and 1911. Contrary to the agricultural and rural areas, the most industrialized area of France (Northeast) display lower variations in female literacy rates over the period studied. Comparatively, we see that counties experiencing stronger improvement in female literacy rates over the period 1856-1870 tend also to experience a steeper fertility decline (measured by the percentage change in crude birth rate over the period 1881-1911).

Table 5 reports IV quantile results concerning the hypothesis that educational investments have played a significant role in the fertility transition. We control for socio-economic factors such as employment opportunities and population density, religion, life expectancy, and crude birth rate in 1881.[23] The Quantile estimates show that the percentage change in literacy rates is negatively associated with the fertility transition. This result is strongly significant for women only. This result is in line with Diebolt and Perrin (2013; 2019a,b) and supports the hypothesis that women behavior is at the chore of the demographic transition. It suggests that the more women are educated today, the fewer children they have tomorrow. Contrary also to the results found on the short-run, the coefficients indicate that the fertility transition is stronger in areas where individuals are more oriented toward agriculture.[24] Similarly, the transition is also stronger in areas with a higher share of Protestants.

[23] In order to test the robustness of our results, we add the initial level of birth rate in 1881.

[24] Note that agricultural areas are also those where education levels were historically the lowest and where fertility was the most important (in comparison with industrialized areas).

Table 3: IV Quantile regression results (Short-run effects) - education to fertility

	Men			Women		
Dependent Variable (Crude Birth Rate)	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Enrollment	-6.025***	-6.503***	-7.609***	-5.736**	-7.621***	-8.336***
	(1.801)	(1.605)	(2.102)	(2.110)	(2.120)	(2.021)
Employment in agriculture	7.309***	7.339***	1.797	2.001	-2.117	-0.398
	(3.012)	(2.331)	(1.353)	(2.208)	(2.010)	(1.808)
Employment in industry	-1.838	-8.705	11.203***	13.118**	1.220	1.200
	(5.860)	(6.001)	(4.016)	(6.121)	(4.401)	(2.100)
Population density	-1.280	-1.226*	-1.907	-2.901**	-1.054*	0.566
	(2.009)	(0.700)	(1.881)	(1.540)	(0.601)	(0.404)
Share Protestants	0.070	0.004	0.070*	0.135**	0.040	-0.039
	(0.055)	(0.028)	(0.040)	(0.090)	(0.077)	(0.033)
Life expectancy	-0.532***	-0.649***	-0.508***	-0.428***	-0.628***	-0.429***
	(0.095)	(0.101)	(0.093)	(0.107)	(0.089)	(0.099)
Constant	32.101***	40.708***	42.331***	42.196***	52.850***	47.471***
	(5.225)	(4.618)	(5.305)	(4.508)	(4.281)	(4.577)
N	85	85	85	85	85	85
R^2	0.307	0.411	0.395	0.321	0.421	0.400
F	12.35***	16.87***	10.66***	10.02***	31.61***	11.80***

Note: Instrumental variable quantile regressions. Dependent variable: Crude Birth Rate (CBR). Robust standard errors in parentheses***: significant at 1% level; **: significant at 5% level; *: significant at 10% level. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys enrollment rate is the share of boys aged 6-14 enrolled in public primary schools. Instrument for enrollment rate is Distance to Wittenberg.
Source: County-level data from the *Statistique Générale de la France*.

Table 4: IV Quantile regression results - fertility to education

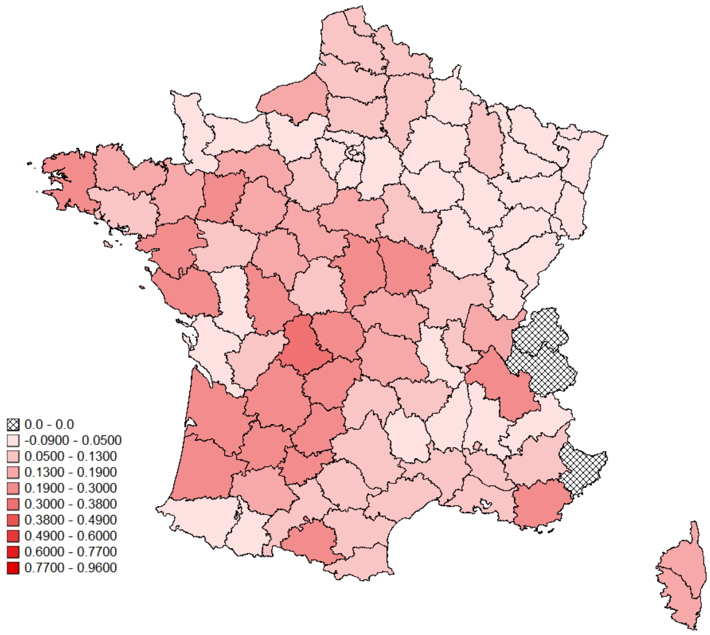
Dependent Variable	Boys' enrollment rate			Girls' enrollment rate		
	(1)			(2)		
(Enrollment rate)	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Crude Birth Rate	-0.017***	-0.024***	-0.046***	-0.018**	-0.022**	-0.055***
	(0.005)	(0.009)	(0.017)	(0.009)	(0.011)	(0.006)
Employment in agriculture	-0.066	-0.140	-0.405	-0.239**	-0.262**	-0.324*
	(0.149)	(0.111)	(0.301)	(0.120)	(0.136)	(0.165)
Employment in industry	0.309	0.322	-0.396	0.550***	0.420***	0.314*
	(0.313)	(0.289)	(0.411)	(0.196)	(0.168)	(0.176)
Population density	-0.022	-0.067	-0.085	-0.028	-0.046	-0.065
	(0.072)	(0.120)	(0.104)	(0.042)	(0.063)	(0.0354)
Share Protestants	0.011***	0.019**	0.013**	0.004	0.009*	0.014*
	(0.004)	(0.005)	(0.007)	(0.004)	(0.005)	(0.008)
Life expectancy	0.002	0.0008	-0.024	0.015***	0.013**	0.022**
	(0.003)	(0.008)	(0.014)	(0.005)	(0.007)	(0.010)
Constant	0.801**	1.223**	3.509***	0.888**	0.282**	0.989**
	(0.320)	(0.501)	(0.864)	(0.302)	(0.111)	(0.500)
N	85	85	85	85	85	85
R^2	0.226	0.202	0.233	0.265	0.270	0.209
F	11.50***	10.22***	12.66***	10.25***	13.61***	9.98***

Note: Instrumental variable quantile regressions. Dependent variable: crude birth rate. Robust standard errors in parentheses. ***: significant at 1% level; **: significant at 5% level; *: significant at 10% level. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Boys enrollment rate is the share of boys aged 6-14 enrolled in public primary schools. Instrument for CBR is Adult sex ratio.

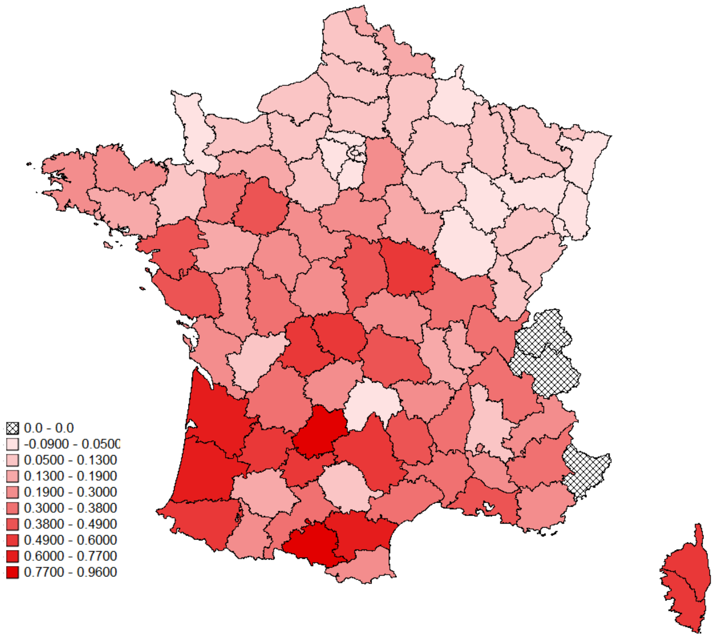
Source: County-level data from the *Statistique Générale de la France*.

Figure 3: Geographical Distribution of the Percentage Change in Education and Fertility

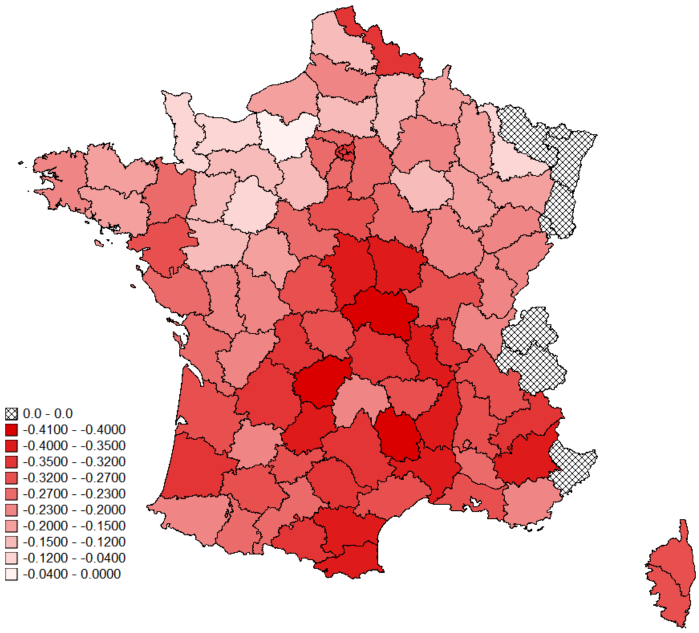
(3a) Male Human Capital, 1856-70



(3b) Female Human Capital, 1856-70



(3c) Crude Birth Rate, 1881-1911



Sources: Using data from Statistique Générale de la France – Enseignement Primaire; Census

Table 5: Long-run effects: Impact of education on fertility

Dependent Variable	Crude Birth Rate (% change 1881-1911)			Crude Birth Rate (% change 1881-1911)		
	Men			Women		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Literacy	-0.068*	-0.111	-0.008	-0.230***	-0.233***	-0.122*
(% change 1856-70)	(0.039)	(0.166)	(0.162)	(0.071)	(0.056)	(0.070)
Crude birth rate 1851	-0.017***	-0.023***	-0.022***	-0.014**	-0.021***	-0.015***
	(0.008)	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)
Employment in	-0.214*	-0.272***	-0.250**	-0.135	-0.172**	-0.284***
agriculture	(0.129)	(0.114)	(0.120)	(0.101)	(0.085)	(0.09)
Employment in	-0.079	0.135	0.651***	-0.096	0.027	0.646***
industry	(0.224)	(0.133)	(0.128)	(0.315)	(0.213)	(0.156)
Population density	-0.008	0.003	-0.070*	-0.030	-0.034	-0.111*
	(0.122)	(0.092)	(0.037)	(0.111)	(0.074)	(0.063)
Share Protestants	-0.002	-0.003	-0.003	-0.002	-0.002	-0.004**
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Life expectancy	0.001	0.006	0.010**	0.007	0.007*	0.009**
	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)
Crude birth rate 1881	-0.001	0.016**	0.012**	-0.006	0.015**	0.015***
	(0.005)	(0.007)	(0.006)	(0.006)	(0.006)	(0.005)
Constant	0.445**	0.529***	0.232**	0.245**	0.198***	0.176***
	(0.130)	(0.125)	(0.074)	(0.101)	(0.005)	(0.005)
N	82	82	82	82	82	82
R^2	0.356	0.478	0.475	0.430	0.541	0.472
F	8.80***	16.05***	11.29***	10.07***	17.80***	10.11***

Note: Quantile regressions. Dependent variable: Percentage change in crude birth rate 1881-1911 Robust standard errors in parentheses. ***: significant at 1% level; **: significant at 5% level; *: significant at 10% level. Crude birth rate is defined as the number of birth (in 1000 s) over the total population. Male literacy rate is the percentage change in the share of who signed their wedding contract between 1856 and 1870.
Source: County-level data from the *Statistique Générale de la France*.

In Figures 4 and 5, we have graphically presented full distributional effects of education on fertility. In these figures the solid lines are the quantile estimates, the thick dotted straight line is the OLS estimate and the thin broken lines are 95% confidence band for the OLS estimate.

Partial effects

We have also estimated the partial effect of education on fertility transition for both men and women. The partial effect at each quantile is given by the formula $\frac{\partial Q_t(F|E_i)}{\partial E_i}$, where *i*= {Male, Female}. Table 6 presents the estimates of these effects based on both short-run and long-run estimates across quantiles. It is clear from the estimates in Table 10 that the magnitude of a decline in fertility in female population is larger than men for all quantiles in the long-run and all quantiles (except 25th) for short-run. Our inter-quantile difference test (F-test values) also point at the significance of difference in results across quantiles.

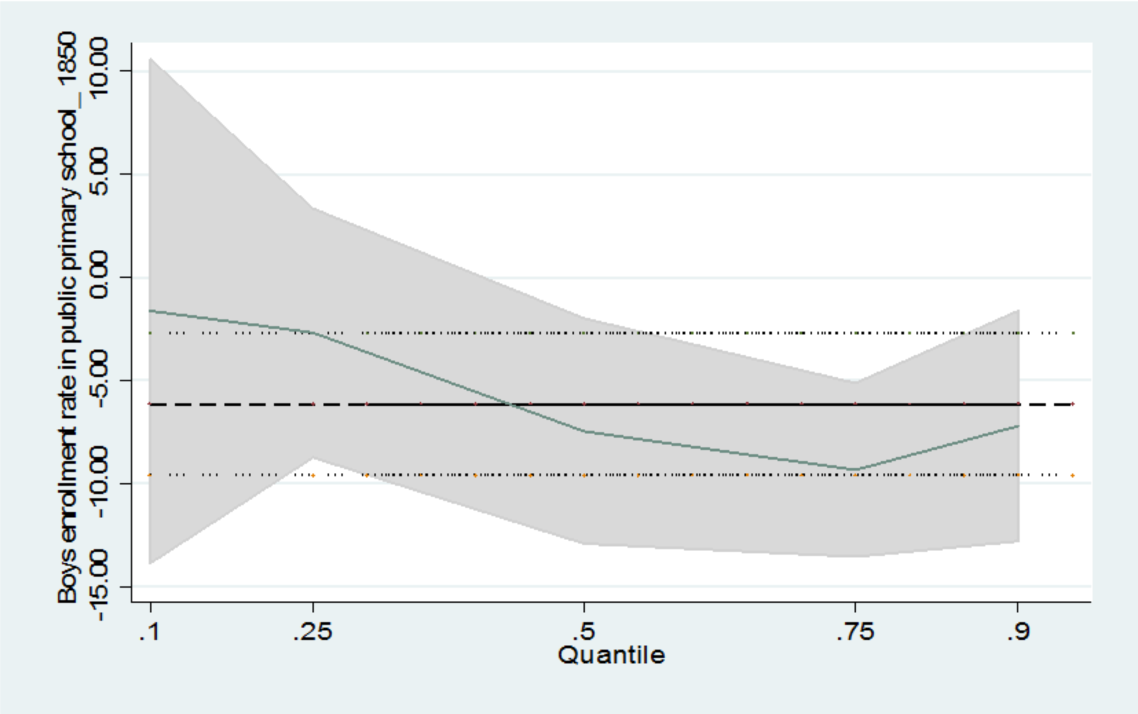
Table 6: Comparison of Partial Effects

	Short-run		**Long-run**	
	Male	Female	Male	Female
25th Quantile	-6.601	-5.435	-0.069	-0.209
50th Quantile	-6.511	-8.609	-0.198	-0.215
75th Quantile	-7.666	-9.116	-0.002	-0.106
Inter-quantile difference test	F(2, 81) = 7.208 (p = 0.006)	F(2,81) = 9.500 (p = 0.004)	F(2, 80) = 5.908 (p = 0.004)	F(2,80) = 7.207 (p = 0.005)

Overall, our results indicate that the variations in female endowment in human capital have a robust and significant impact on the fertility transition contrary to male endowment in human capital. This result is consistent with the intuition of the unified growth model of Diebolt and Perrin (2019a) briefly presented in Section 2, according to which female endowed with a higher amount of human capital tend to limit their fertility due to a larger opportunity cost of having children than female endowed with lower amount of human capital.

Figure 4: Effect of education on fertility (short-run)

(a) Male



(b) Female

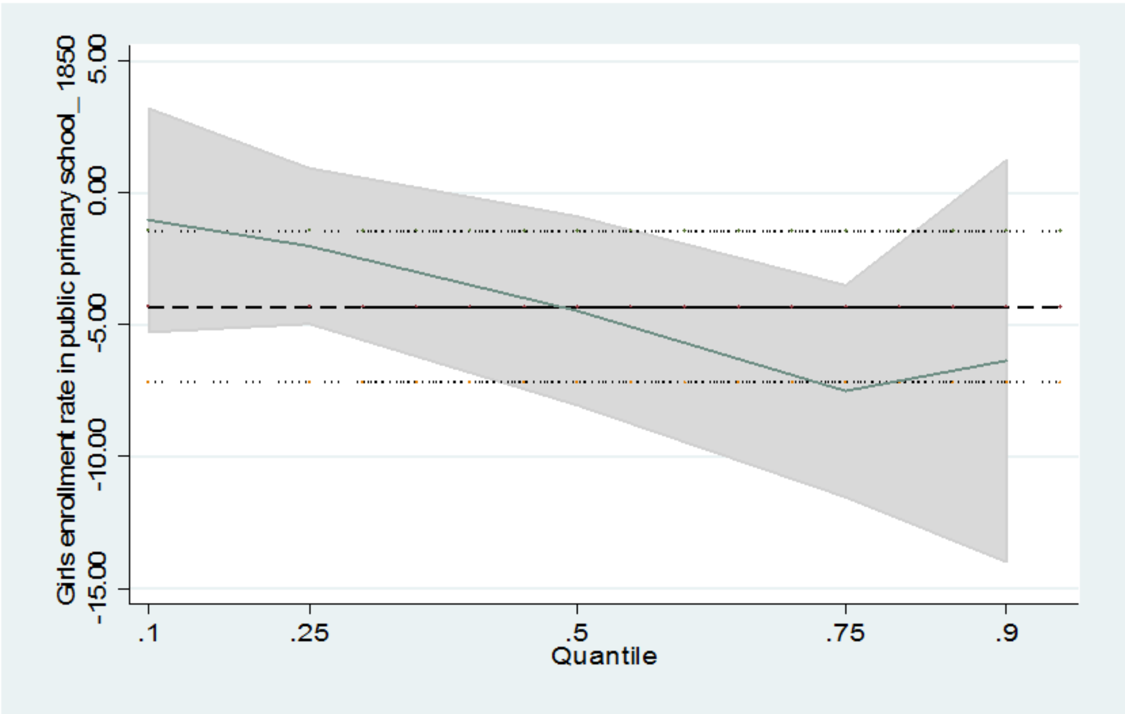
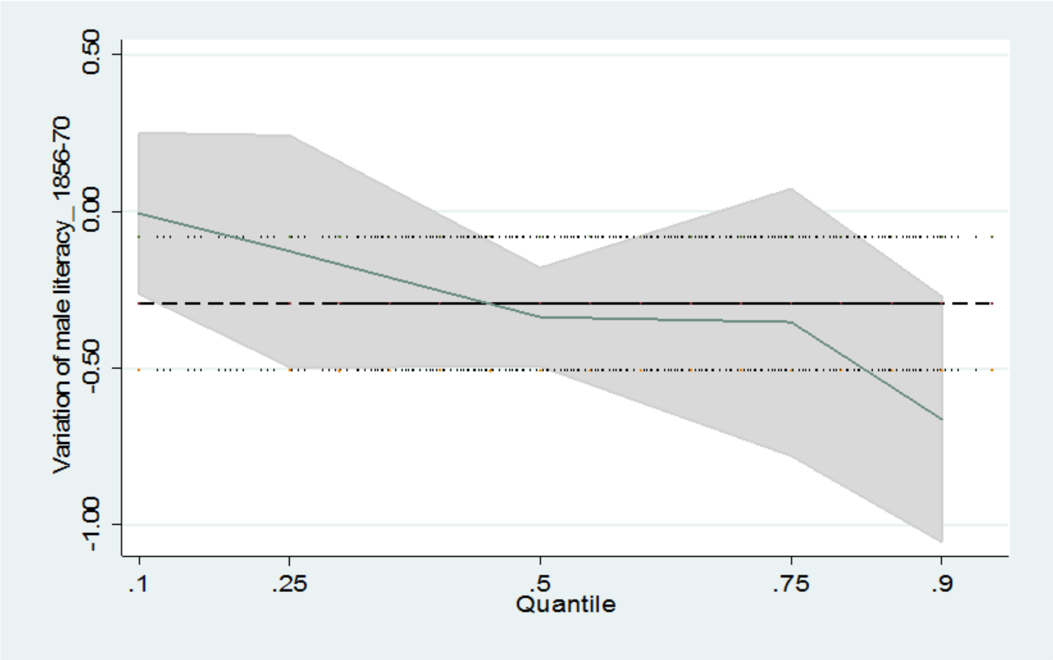
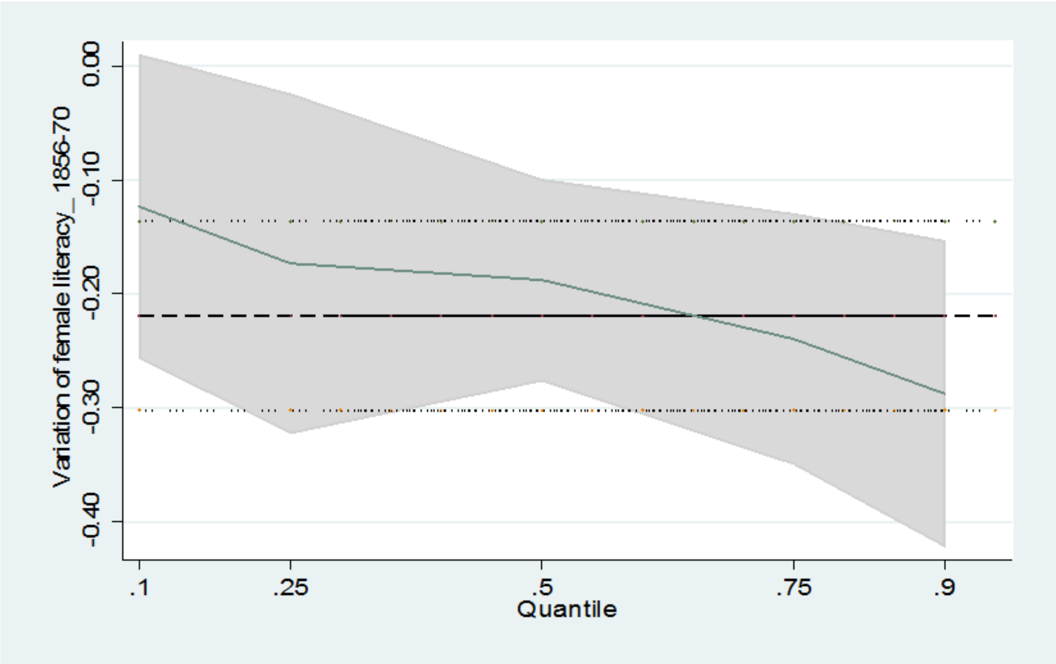


Figure 5: Effect of male human capital on fertility transition: IV Quantile Regression

(a) Male



(b) Female



Additional robustness exercise

An additional exercise is to check if our findings of a quantity-quality trade-off, especially the instrumental role of female empowerment are sensitive to the addition of control variables and/or the introduction of alternative dependent variables. As a first step towards achieving this aim, we have re-estimated the education-fertility channel by replacing first the dependent variable. Accordingly, we have replaced crude birth rate with marital fertility rate. Our second strategy is to retain the original dependent variable, crude birth rate but add extra control variables, such as infant mortality, child mortality, male and female wages in agriculture in 1852. Table 7 reports these results. Instead of estimating each set of equations, we have only presented the estimation results for the full model for both men and women. Model 1 reports the results with respect to a change of the dependent variable in the female and male estimations. Model 2 reports the results with additional control variables.

As such, changing dependent variable does not alter our main finding of a negative relationship between fertility and education, although the results appear weaker in magnitudes at low and high quantiles than the one we observed when using the crude birth rate as dependent variable. Moreover, other control variables in this regression setting also present weak results despite the fact that population density, for instance, indicate negative effect (although insignificant). Life-expectancy, as earlier, is significantly negative and indicates that in the face of fertility, reducing effect of life-expectancy, enhancing education reduced fertility. This result is more acute at the lower quantile for women. When we add more control variables, while maintaining crude birth rate as the main dependent variable, the strategy does not improve the results much. The insignificance and weaker results for the effect of education on fertility seem to have been overweighed by likely correlation between these additional variables with education. Instrumentation did not help much. Therefore, this robustness exercise, while pointing at the capital importance of crude birth rate and marital fertility rate as relevant variables for quantity-quality trade-off, need to be pursued with caution concerning the choice of other variables.

In Table 8 we have presented results for full model (education to fertility channel) with share of spouse signing contracts as an instrument for education, whereas in Table 8 (fertility to education channel), we have used share of dependent children as an instrument for CBR. The results are similar to the baseline and main instruments.

Table 7: Robustness test– education and fertility channel: Men and Women

	Men						Women					
Dependent Variable	(1) MFR			(2) CBR			(1) MFR			(2) CBR		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Enrollment	-0.099***	-0.450**	-0.402***	-0.008	-0.114**	-0.084	-0.166***	-0.430***	-0.565***	-0.018**	-0.139*	-0.091***
	(0.003)	(0.230)	(0.003)	(0.008)	(0.042)	(0.007)	(0.002)	(0.002)	(0.003)	(0.007)	(0.075)	(0.007)
Employ. in agriculture	0.500	-0.138	0.547	0.511	-0.134	0.567	0.269	0.221	0.066	0.538	-0.158	0.525
	(0.306)	(0.201)	(0.534)	(0.465)	(0.206)	(0.522)	(0.418)	(0.390)	(0.440)	(0.465)	(0.206)	(0.522)
Employ. in industry	-1.296***	0.319	0.330	-0.971	-0.878	0.371	-1.535*	-1.069	-1.307	-0.971	-0.699	0.371
	(0.349)	(0.602)	(0.893)	(1.104)	(0.734)	(0.798)	(0.933)	(0.874)	(0.984)	(1.104)	(0.505)	(0.798)
Population density	-0.126	-0.080	-0.145	-0.219	-1.176***	-0.630***	-0.265**	-0.190**	-0.162	-0.220	-0.985***	-0.620***
	(0.130)	(0.131)	(0.111)	(0.230)	(0.220)	(0.215)	(0.108)	(0.101)	(0.114)	(0.235)	(0.301)	(0.210)
Share Protestants	0.012*	0.007	0.037***	0.010*	0.005	0.023	0.020	0.034**	0.037***	0.009*	0.004	0.023
	(0.005)	(0.005)	(0.012)	(0.015)	(0.005)	(0.012)	(0.023)	(0.011)	(0.012)	(0.015)	(0.005)	(0.012)
Life expectancy	-0.065***	0.0009	-0.099***	-0.075***	-0.021	-0.086*	-0.072***	-0.057***	-0.053***	-0.078***	-0.088*	-0.086*
	(0.011)	(0.008)	(0.015)	(0.013)	(0.045)	(0.049)	(0.014)	(0.013)	(0.015)	(0.013)	(0.038)	(0.049)
Child mortality				15.658	25.145	28.517				17.398	29.233	28.517
				(13.218)	(17.167)	(18.888)				(13.666)	(18.260)	(18.888)
Wage in agriculture				-0.702***	-0.686	-0.056				-0.679***	-0.534*	-0.056
				(0.285)	(0.779)	(0.606)				(0.211)	(0.278)	(0.606)
School				-0.280	-0.504	-1.409***				-0.325	-0.652	-1.489***
				(0.240)	(0.408)	(0.411)				(0.242)	(0.415)	(0.407)
Constant	5.612**	5.613***	7.114***	5.796***	5.777***	11.349***	5.555***	5.664***	5.399***	4.6971***	5.668**	11.640***
	(0.701)	(0.700)	(0.731)	(1.114)	(0.745)	(2.615)	(0.724)	(0.804)	(0.802)	(1.111)	(2.314)	(2.658)
N	85	85	85	85	85	85	85	85	85	85	85	85
R^2	0.411	0.436	0.446	0.287	0.474	0.498	0.401	0.406	0.406	0.445	0.487	0.520
F	64.63 ***	36.96***	36.90***	5.55**	14.95**	13.33***	13.65***	11.29***	11.34***	7.30**	16.22**	18.40***

Note: Instrumental variable quantile regressions. Dependent variable: crude birth rate and MFR. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools. Column 1 for both boys and girls use marital fertility rate (mfr1851) as a measure of fertility. Whereas column 2 uses CBR as the measure but we include additional controls for robustness check. The sequential Wald-test for IVs and the estimated error term = 1.64(p= 0.45) for 25th quantile, =1.78 (0.19) for 50th quantile, and = 2,21 (p=0.23) for 75th quantile (for Men). The sequential Wald-test for IVs and the estimated error term = 2.60(p= 0.51) for 25th quantile, =2.39 (0.38) for 50th quantile, and = 2.66 (p=0.11) for 75th quantile (for Women). P-value > 0.05 imply non-rejection of null hypothesis of zero linear restrictions. *Source:* County-level data from the *Statistique Générale de la France*.

Table 8: Robustness test (alternative IV for education: share of spouse signing the marriage contract) – education and fertility channel: Men and Women

	Men			Women		
Dependent Variable	CBR			CBR		
	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$	$\tau = 0.25$	$\tau = 0.50$	$\tau = 0.75$
Enrollment	-0.004	-0.010**	-0.064***	-0.003	-0.099*	-0.112**
	(0.003)	(0.0052)	(0.008)	(0.002)	(0.058)	(0.055)
Employ. in agriculture	0.202	-0.116	0.398	0.430	-0.060	0.112
	(0.407)	(0.219)	(0.414)	(0.338)	(0.197)	(0.404)
Employ. in industry	-0.333	-0.647	0.297	-0.696	-0504	0.201
	(1.000)	(0.512)	(0.224)	(0.508)	(0.494)	(0.187)
Population density	-0.323	-0.674**	-0.881**	-0.181**	-0.660**	-0.575**
	(0.204)	(0.201)	(0.441)	(0.091)	(0.362)	(0.315)
Share Protestants	0.021*	0.0021	0.033	0.007*	0.008	0.048
	(0.011)	(0.002)	(0.022)	(0.036)	(0.005)	(0.032)
Life expectancy	-0.049***	-0.022	-0.069*	-0.065***	-0.074**	-0.070
	(0.015)	(0.032)	(0.041)	(0.011)	(0.041)	(0.061)
Child mortality	10.329	18.222	25.102*	13.301	21.202	24.111*
	(10.214)	(16.160)	(15.221)	(12.331)	(19.266)	(14.340)
Wage in agriculture	-0.558***	-0.619	-0.0664	-0.514***	-0.444*	-0.064
	(0.15)	(0.609)	(0.557)	(0.101)	(0.157)	(0.214)
School	-0.202	-0.297	-0.668***	-0.302	-0.407	-0.504***
	(0.332)	(0.504)	(0.217)	(0.244)	(0.309)	(0.194)
Constant	6.201**	5.402***	9.5511***	4.684***	4.201**	8.523***
	(1.001)	(0.762)	(1.330)	(1.282)	(1.001)	(1.611)
N	85	85	85	85	85	85
R^2	0.284	0.440	0.467	0.409	0.462	0.5485
F	6.12**	15.11**	15.24***	8.22**	16.5**	18.22***

Note: Instrumental variable quantile regressions. Dependent variable: crude birth rate and MFR. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Crude birth rate is defined as the number of birth (in 1000s) over the total population. Girls enrollment rate is the share of girls aged 6-14 enrolled in public primary schools. Column 1 for both boys and girls use marital fertility rate (mfr1851) as a measure of fertility. Whereas column 2 uses CBR as the measure but we include additional controls for robustness check. Alternate IV for education: Share of spouse signing the marriage contract.

6. Conclusions

Using an original county-level dataset of 86 county observations for the year 1851 built up from the *Statistique Générale de la France*, we provide an empirical test of quantity-quality trade-off by modelling gender-specific individual's choice. Our theoretical framework provided setting under which male and female choice functions are different and their educational optimality conditions are also varied. Due to social and familial obligations as well as geography-led development differences, different parameters identify quality and quantity choice of children for men and women. A key finding of the paper is that, the short-run differences between male and female is small whilst the long-run effects are large with regard to the impact of education on fertility. Our results imply that it matters not just that parents educate their children, but specifically that they choose to educate girls.

Investigating the short-run relationship between education and fertility, we find evidence of a child quantity-quality trade-off during the French demographic transition. This result corroborates the predictions and interpretations of the unified growth literature in line with the seminal work of Galor and Weil (2000). We observe that, whilst education is found to exert a negative effect on fertility, on average, we gain significant insights into the heterogeneous nature of the effects, which otherwise would have been overlooked in mean-based estimates. The relationship between education and fertility is likely to be more complex than simply having effect on each other in the short-run. As predicted by Diebolt and Perrin (2013, 2019a), education and fertility are also connected to each other in the long-run, notably through the effect of female endowment in human capital on their decision to have kids or not. Using 19th century French data, we have tested in Section 5.3 the hypothesis that the rise in female endowment in human capital has played a key role in the fertility transition. Our results suggest that women with a higher level of human capital have stronger preferences for a lower number of children. In particular, we find the existence of a negative and significant effect of the variations in female literacy rates (1856-70) on the fertility transition between 1881 and 1911. Counties with higher improvements in female literacy display stronger fertility decline in France at the turn of the 19th century.

From our empirical investigation, we find that the quantity-quality trade-off was possibility driven by women endowment in human capital of the previous generation. By extension, as demographic transition is considered necessary condition to allow economies to move from stagnation to sustained growth, female human capital is likely to be a key ingredient for economic transition. Indeed, female empowerment increases returns to education for girls because of complementarities between technological changes and human capital. Girls invest more in their own education and limit their fertility because of a greater opportunity cost of having children. As a consequence, girls with higher endowments in human capital have fewer children what ultimately leads to the process of fertility transition. To enhance our understanding of the mechanisms at the origin of the development process and the transition to sustained growth, it is necessary to recognize that despite living within the parameters of a similar environment, individuals might not behave in the same way. Certain factors, such as culture, values, or norms, could affect the way individuals' choices above fertility and education are governed.

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Appendix A – County-level Data for France in the 19th Century

The data used in this article are mainly extracted from books published by the *Statistique Générale de la France* (SGF) on population, demographic and public education censuses, between 1800 and 1925. Almost all data are available for 86 counties.

Table A: Data Sources and Construction of the Variables

Variable	Year	Definition	Source
Education			
School enrollment rate	1850	Number of children enrolled in public primary schools divided by children aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys enrollment rate	1850	Number of boys enrolled in public primary schools divided by boys aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Girls enrollment rate	1850	Number of girls enrolled in public primary schools divided by girls aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys schools	1850	Number of public primary schools for boys per number of boys aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Girls schools	1850	Number of public primary schools for girls per number of girls aged 6-14	*Statistique enseignement primaire and Recensement 1851*
Boys enrollment (% change)	1861-67	Variation of boys enrollment rate public primary schools for boys aged 5-15 between 1850 and 1867	*Statistique enseignement primaire and Recensement 1851, 1866*
Girls enrollment (% change)	1851-67	Variation of boys enrollment rate public primary schools for boys aged 5-15 between 1850 and 1867	*Statistique enseignement primaire and Recensement 1851, 1866*
Male literacy (% change)	1856-70	Variation of the share of men who signed their marriage contract between 1856 and 1870	*Statistique enseignement primaire*
Female literacy (% change)	1856-70	Variation of the share of female who signed their marriage contract between 1856 and 1870	*Statistique enseignement primaire*
Distance to Mainz	---	Distance (walk) in km between the main city of the county and Mainz	*http://calculerlesdistances.com/*
Fertility			
Crude birth rate	1851	Number of birth over total population (in thousands)	*Recensement 1851*
Marital fertility rate	1851	Number of new born per married women in age of childbearing (15-45)	*Recensement 1851*
Index of marital fertility rate	1851	Princeton European Fertility Project	*Coale and Watkins (1986)*
Crude birth rate	1881	Number of birth over total population (in thousands)	*Recensement 1881*
Change in Crude birth rate	1881-1911	Variation in the crude birth rate between 1881 and 1911	*Recensement 1881, 1911*
Change in Marital fertility rate	1881-1911	Variation in the marital fertility rate between 1881 and 1911	*Recensement 1881, 1911*
Economic			
Share in industry	1851	Number of people employed in manufacturing per total population	*Recensement 1851*
Share in agriculture	1851	Number of people working in agriculture per total population	*Recensement 1851*

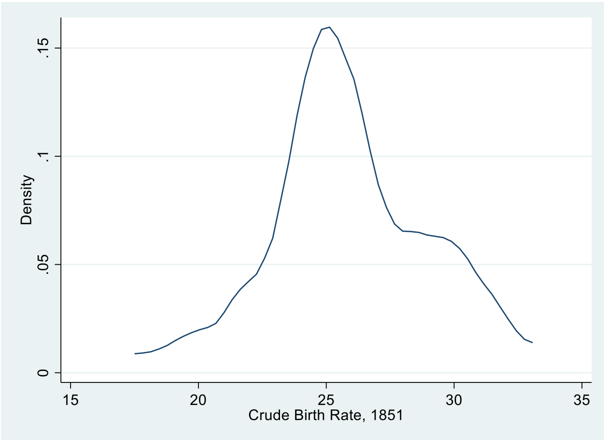
Male in industry	1851	Number of men employed in manufacturing per total population	*Recensement 1851*
Male in agriculture	1851	Number of men working in agriculture per total population	*Recensement 1851*
Female in industry	1851	Number of women employed in manufacturing per total population	*Recensement 1851*
Female in agriculture	1851	Number of women working in agriculture per total population	*Recensement 1851*
Population density	1851	Number of people per km²	*Recensement 1851*
Male wages in agriculture	1852	Average hourly male wages in agriculture	*Enquête agricole1852*
Female wages in agriculture	1852	Average hourly female wages in agriculture	*Enquête agricol 1852*
Demographic			
Male life expectancy at age 0	1856	Creation of male life tables using population data	*Recensement 1856*
Female life expectancy at age 0	1856	Creation of female life tables using population data	*Recensement 1856*
Share married women	1851	Number of married women per women in age of being married	*Recensement 1851*
Adult sex ratio	1851	Number of female aged 15-45 divided by number of male aged 15-45	*Recensement 1851*
Infant mortality	1851	Mortality quotient at age 0 – Probability to die before celebrating age 5	*Bonneuil (1997)*
Child mortality	1851	Mortality quotient at age 5 – Probability to die before celebrating age 10	*Bonneuil (1997)*
Socio-economic			
Share Protestants	1861	Number of Protestants per 100 people	*Recensement 1861*

Appendix B: Additional Results (Following referee 2's comments)

Figure B1: Adaptive Kernel Density by Rural and Urban Residential Share

Adaptive kernel density for CBR (below and above median rural residential share)

(a) Above Median (0.697555)



(a) Below Median (0.697555)

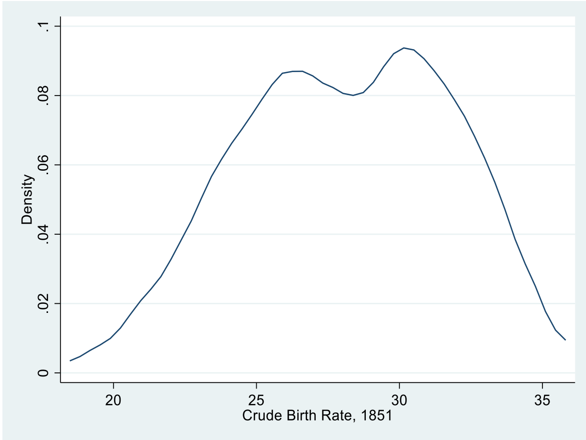
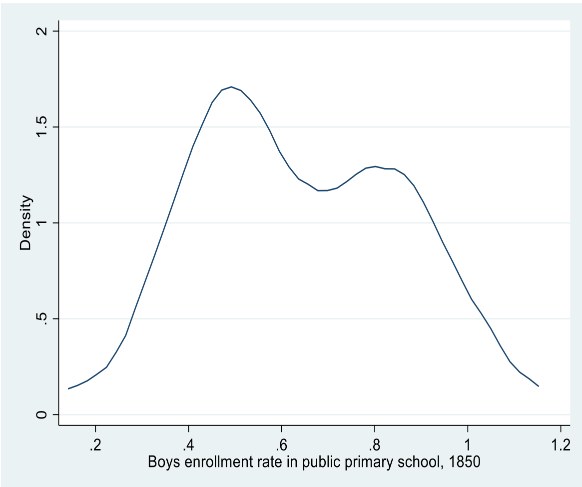
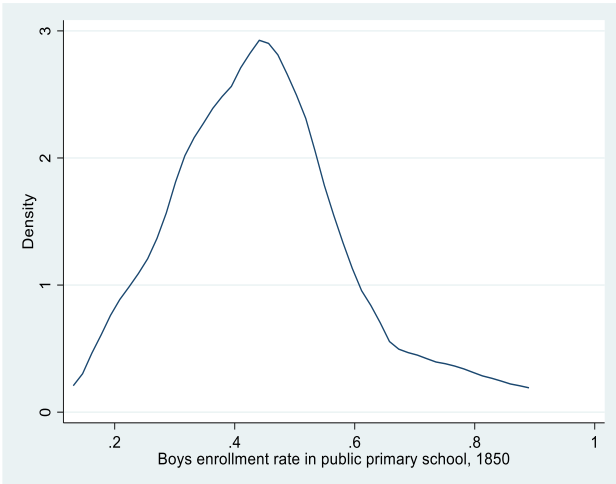


Figure B2: Adaptive kernel density for Enrolment (below and above median rural residential share)

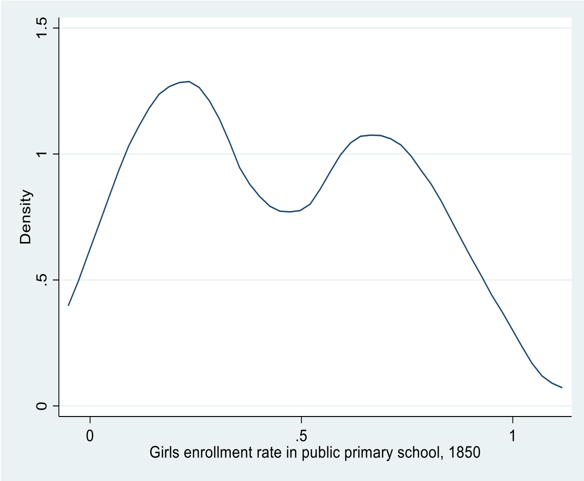
(a) Above Median (0.697555): Male



(a) Below Median (0.697555): Male



(c) Above Median (0.697555): Female



(d) Below Median (0.697555): Female

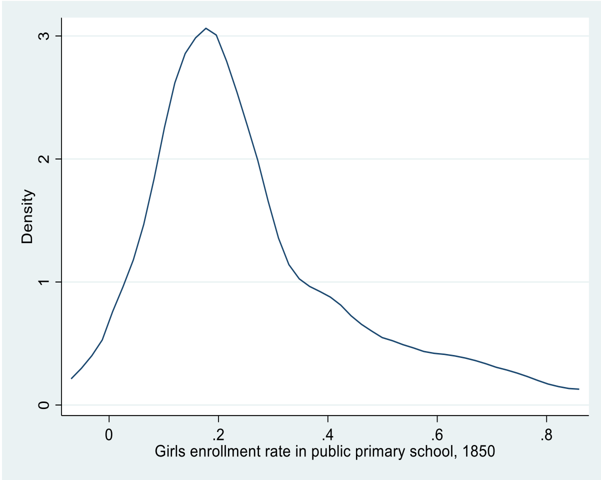
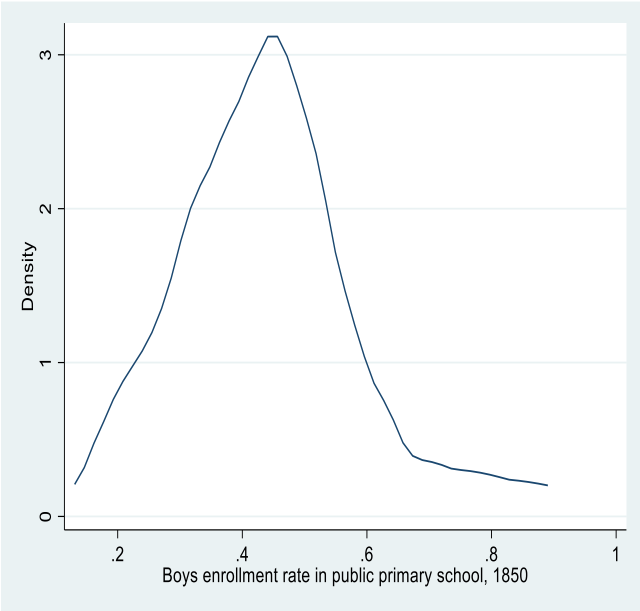
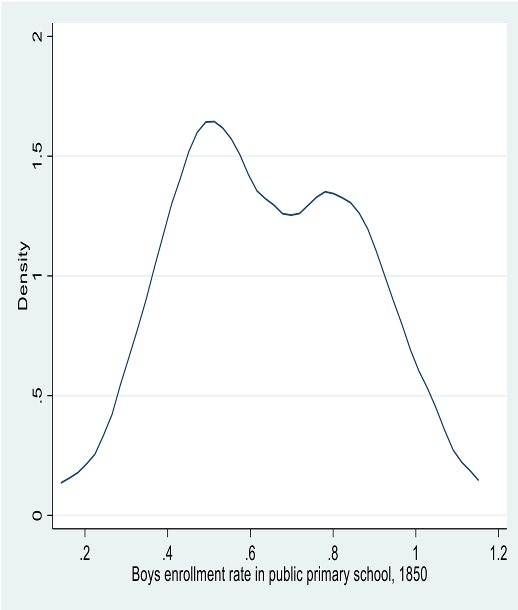


Figure B3: Adaptive kernel density for Enrolment (below and above median urban residential share)

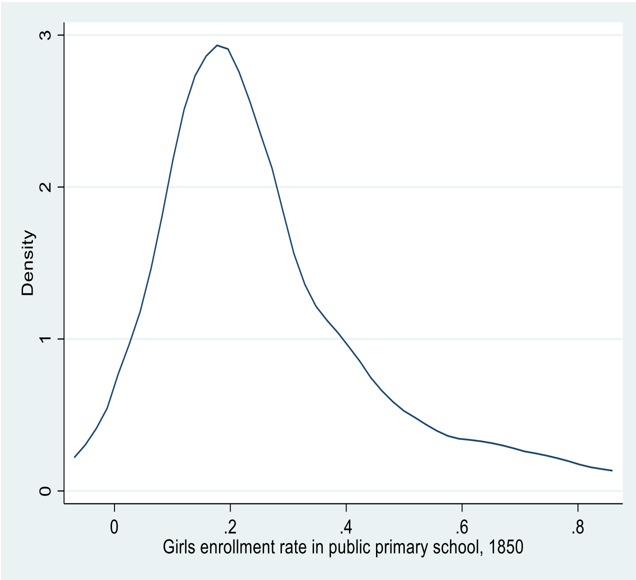
(a) Above Median (0.697555): Male



(a) Below Median (0.697555): Male



(c) Above Median (0.697555): Female



(d) Below Median (0.697555): Female

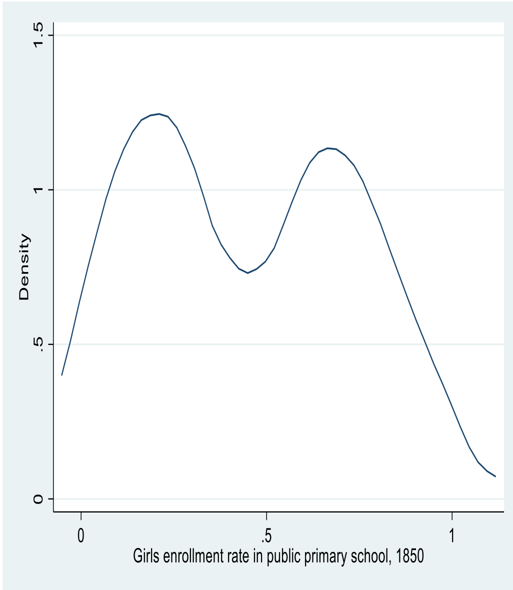
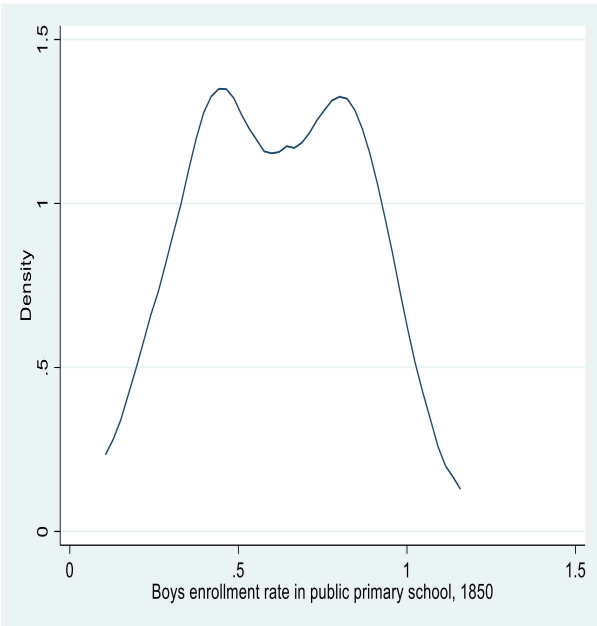
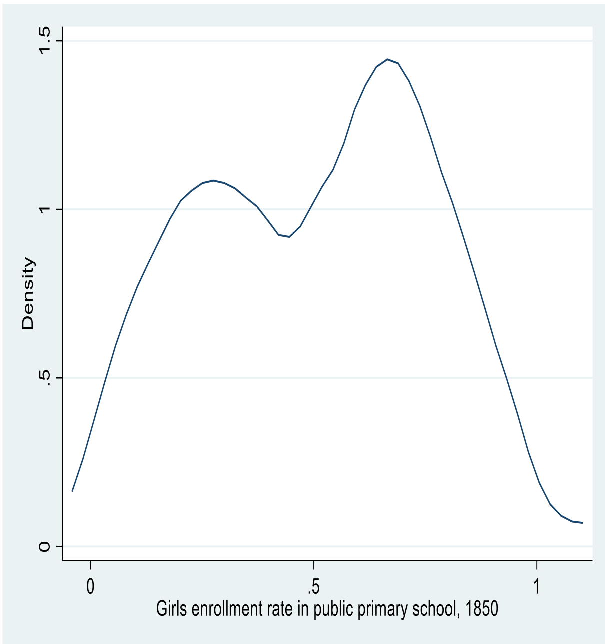


Figure B4: Locational Effects (North-east concentration): characteristics of bimodality

(a) Boys' Enrolment ratio



(b) Girls' Enrolment ratio



(a) CBR in 1851