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Can robots and migration help address the challenges of ageing? Specification and initial analysis of dynamic model for examining policy resilience*

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Abstract

Labour shortages are common in developing countries, whether through poor job-skill matching or imbalances originating in the existing labour force. Migration has long been perceived as a possible solution to labour market shortages, but it is also known to be a temporary fix. At the same time, advantages in technology have helped to introduce robots to the production processes, but so far, it has not become a large-scale panacea, partially due to the expense, with some countries lagging behind in automating their industries. Yet another labour shortage challenge is coming from ageing of the population and the labour force – for some European countries, the associated labour force decline is already very visible. At the same time, ageing generates additional labour demand, particularly in the very labour-intensive health and social care sectors, which are not prone to automation.

This research presents the specification and some initial analysis of a dynamic stochastic general equilibrium (DSGE) model that looks at whether migration and automation can help address some of the challenges of ageing. We focus on a case study of a two-country system linked through migration: on the one hand, we look at Germany, as Europe's largest migrant receiving country and leader in automation. On the other hand, we examine the effects of the migration and automation on Poland, which until recently was predominantly a migrant sending country, and which is still lagging significantly in terms of automation behind most of the other EU countries. The DSGE model will ultimately serve as a tool to examine the vulnerability of European socio-economic systems to external shocks, and will be extended by substantive analysis in its own right in the next report.

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1 Introduction

Migration and job automation have been two significant topics of the discussion on the future of European labour markets already before the COVID-19 pandemic, and will conceivably remain important in the future, even if with somewhat different focus. During the pandemic, migration fell significantly due to uncertainty in labour markets and temporarily border closures, but the numbers of people moving into and between European countries has since more than recovered. At the same time, the automation of jobs is forecast to continue growing, possibly at an increasing rate, owing to the most recent advances in technology, including artificial intelligence (AI) algorithms.

The reasons for this expansion seem simple. In the situations when robots can be seen as substitutes for workers, they can offer a reliable alternative for maintaining or increasing productivity. Robots can operate up to 24 hours a day whereas a worker is limited to 8-10 hours (see for example, Borjas and Freeman, 2019)[1]. A robot can have a higher initial outlay, but, especially for simpler and more routine tasks, the maintenance costs are often lower than wages. In such a scenario, automation is one of the biggest perceived sources of competition on the low-skill segment of the labour market. In this way, it can lead to reducing low-skill migration flows to countries with high levels of automation, with the situation for high-skill migrants remaining more ambiguous.

The COVID-19 pandemic has led to a decrease in labour force participation rates in some European countries (Doornik et al., 2023), especially concerning people who are of retirement age, or close to retirement age. There were large lay-offs in the first COVID lockdowns and, for a variety of reasons, some people have decided not to return to the labour market. Labour markets in Europe remain tight, with ample supply of jobs, but a short supply of workers, emphasised by unemployment rates that are at record lows. This holds even for economies which are not growing at what would be their expected rates. The cost of living crisis caused by higher inflation has enticed some people back to work, but has not restored the pre-pandemic labour force *per se*. These effects on the participation rate are furthered by demographic change, exacerbated by the challenges of population ageing that many western countries now find themselves facing.

[1] In the context of a pandemic, it might be added that the lack of viral transmission between robots could have given them an additional advantage.

In the midst of the COVID-19 pandemic, some countries have indicated that increasing immigration could stimulate economic growth, both from the demand and supply side (see Howard, 2020), whilst an opposite view would prioritise employing native workers first. Here, some populist and anti-immigration arguments may suggest that migrants take the jobs of native workers, particularly low-skilled ones (for a discussion see, Dustmann et al., 2010, 2013; Fromentin et al., 2017). At the same time, advances in automation and robotics can be seen as yet another large threat to the same worker group.

Nevertheless, from a macroeconomic perspective, the use of robots is not necessarily associated with job loses, mirroring a similar discussion about the wage effects of migration, and in particular the debate between George Borjas and David Card. The work of these two researchers has produced contrasting evidence. Immigration in the US is stereotypically dominated by inflows of mainly low-skill workers from Latin America (whether they are low-skill by training, or just end up in low-skill jobs, is a different matter), so focus has been placed on the effects of migration on low-skill wages and employment. Borjas (2017) found that low-skill immigration reduced the wages, while Card (2005) found the effect to be either insignificant or increasing, depening on the definitions used.

The main case study originated in a unique natural experiment of 'Mariel Boatlift' – the inflow of 125,000 Cubans into Miami, Florida in 1980 over the space of a few months, or an 7% increase in the workforce, and a 20% increase in the number of Cuban workers in Miami. Contrary to Card (2005), Borjas (2017) found a decrease in wages, and argued that the lack of effect was due to using a too broad definition of low-skill. In addition, Peri (2010) hypothesised that productivity was increased for native workers. Card and Peri (2016) also looked at how the methodology of Borjas (2017) could ignore the more recent work seeing how natives and migrants can be complementary on the labour market.

For robots, in turn, surveys carried out in the US have found that only 4% of firms expect automation to result in job losses, with 91% planning to maintain or increase the number of workers.[2] The aggregate number of workers may remain unchanged or increase, but job descriptions may evolve and create new opportunities, as it had happened many times in the past. The type of robots is important to consider as well. Labour-saving technologies in themselves are not new, and indeed on a significant scale have

[2]Manpower (2018) Skills Revolution 2.0 Accessed June 1, 2023.

been seen at least since the industrial revolution. The majority of the existing literature assumes that robots are labour-saving devices, however, in addition, some robots can be *labour enhancing*, enabling work that would not be possible without them. Examples include exoskeletons, which can enhance manual productivity and prevent injury of human workers, or artificial intelligence (AI) algorithms for the high-skilled segment of the labour market[3]. Such inventions can open up new possibilities for previously-impossible or impractical work, ultimately leading to productivity increase.

An additional consideration here is one of inequalities between countries. Given the aforementioned labour market shortages, immigration could in principle benefit the receiving countries by filling labour gaps, while worsening the situation in the sending countries, especially those without their own significant immigration to compensate losses of labour force. On the common labour market within the European Union (EU), there is no legal basis to prioritise recruitment of a national over a person from another EU country. Factors such as these add a political dimension to an economic challenge.

In this report, we present the specification and some initial analysis of a dynamic stochastic general equilibrium (DSGE) model that looks at whether migration and automation can help address some of the challenges of ageing. In particular, we examine the role of endogenous migration in a two-country DSGE model with job automation. As a basis for our model dynamics, we assume that the rate of automation depends on how vacancies are filled, and on the evolution of their investment. Once calibrated, the model would to serve as a tool to develop scenarios to examine the vulnerability of European socio-economic systems to external shocks. We aim to ultimately use the model to carry out substantive analysis, to be presented in the next report from this series.

As the impact of robots on labour market outcomes can vary, particularly for different skill levels, in this report, we consider two skill levels (low and high), with low-skill workers assumed to be perfect substitutes for robots. We ask the following questions: (i) What is the impact of automation on high and low-skill native and migrant labour force? (ii) Can automation or migration shocks help alleviate labour market shortages? (iii) Can retirees be encouraged to re-engage with the labour force? and (iv) What are the possible future trajectories of the future of migration flows assuming increasing automation rates?

[3] See https://www.bbc.co.uk/news/business-56660644

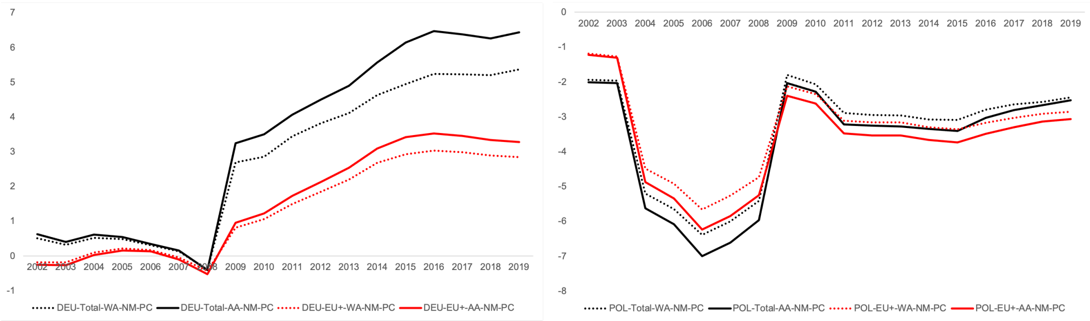
In terms of the country selection, we focus on a case study of a two-country system linked through migration. On the one hand, we look at Germany, as Europe's largest migrant receiving country and leader in automation, both in the number of robots used in production, and in the quantity exported. Migration is important to Germany as it has been the only source of population growth for a number of decades, and is a key source of low-skilled labour. On the other hand, we examine the effects of the migration and automation on Poland, which until recently was predominantly a migrant sending country (including to Germany), largely at the lower end of the skill spectrum. Poland is still lagging significantly in terms of automation behind western EU countries, and remains mid-range compared to other Central and Eastern European (CEE) countries.

Figure 1 shows the net migration 'rates' of working-age and all age people between the chosen countries and either all countries or EU+ and the UK. Our model is estimating by using data from both Germany and Poland[4] As can be seen from Figure 1b, the net migration flows remain significantly negative, even though progress has been made economically there is still a significant emigration incentive, which has somewhat tapered off since the first years of joining the EU. Germany's ins net migration has increased significantly, they placed heavy restrictions on the A8 countries who joined in 2004 which were fully lifted in 2011.

Figure 2 shows the number of robots per 10,000 workers in selected EU countries, additionally including the United Kingdom. The notable variance of robot density especially in the CEE countries can be attributed to differences in the industrial structure and the presence of large firms, and in particular, automotive and electronics.

The remainder of this report is structured as follows. In Section 2 we discuss some of the existing macroeconomic literature on migration and automation and their possible impacts on the labour market. Section 3 details the specification of the two-country DSGE model, the calibration of which is subsequently presented in Section 4. In Section 5, we show preliminary results of the analysis of the DSGE model, and Section 6 concludes the report by offering a discussion of the key findings and their policy implications.

[4]The significant change in migration data for 2008–2009 in Figure 1 can partially be explained by the change in methodology the two sets of estimates: IMEM (2002–2008) and QuantMig (2009–2019). For more information, see Aristotelous et al. (2023).



(a) Net Migration 'rates' in Germany

(b) Net Migration 'rates' in Poland

Figure 1: Net Migration 'rates' in Germany and Poland 2002-2019

This figure shows the *estimates* of net migration 'rates' (net migration divided by the total population in 1000s) for the years 2002–2019. The black lines show migration between the country in the caption and *all* other countries, while the red lines show net migration with the country in the caption and other countries in the EU, EFTA and the UK. The solid lines are for migrants of all ages, while the dotted lines are migrants of working-age (15-64). The estimates are obtained from Aristotelous et al. (2023).

2 Literature Review

The research presented in this report focuses on job automation, where robots can do the same tasks as workers. We also explicitly analyse the migration decision in the context of automation. Combining these two topics – migration and automation – in a single model provides a novel way of looking at the effects of the expansion of robots on the labour market on future migration flows, both for sending and receiving countries.

There are two strands in the literature regarding measurement of job automation and – more broadly – its technological progress. The first one focuses predominantly on the information-and-communication-technology (ICT) capital (see, e.g., Eden and Gaggl 2018), while the second focuses on strictly robotics (see, e.g., Graetz and Michaels 2018). At the same time, the role of automation in shaping migration remains largely unexplored topics in business cycle macroeconomics. Recent work by Leduc and Liu (2019) provides the first quantitative general equilibrium evaluation of the interactions between automation and labour market fluctuations over the business cycle.

In the model of Leduc and Liu (2019), robots can perfectly substitute for workers, therefore differing from standard physical capital. The authors estimate a Real Business Cycle model and find that automation can partially explain the Shimer (2005) puzzle[5]

[5]The Shimer puzzle is defined as the inability for traditional search-and-matching models to generate the observed business cycle fluctuations for unemployment and job vacancies and to recreate their responses to the changes in labour productivity.

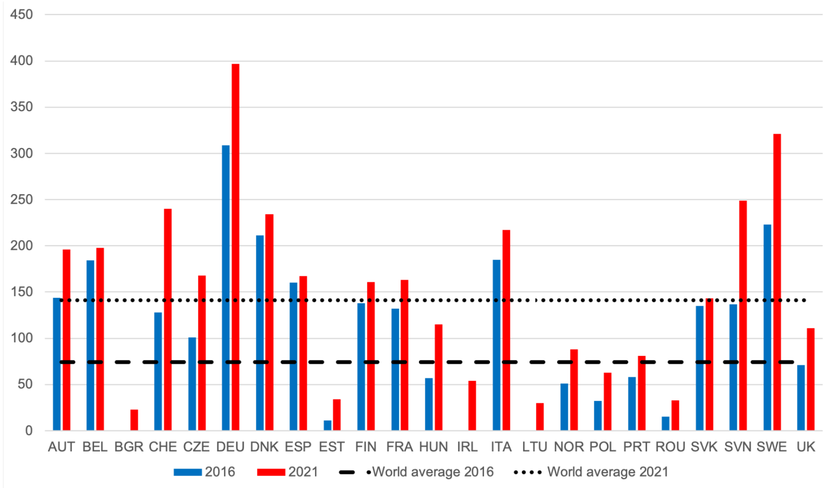


Figure 2: Robots per 10,000 workers in selected EU countries and the UK, 2016 and 2021

The blue bars give the values for 2016 (where available), with the red bars the values for 2021. The dashed and dotted horizontal lines are the global averages for these respective years. Source: International Federation of Robotics (IFR).

with observed differences of volatility between models and data for unemployment and job vacancies.[6] Leduc and Liu (2019) emphasise that automation acts as an endogenous wage rigidity in the labour market by posing a threat to workers in wage negotiations.

The model of Leduc and Liu (2019) was subsequently extended in Leduc and Liu (2020) by including nominal rigidities. This study focuses on one channel of pandemic-induced uncertainty, labelled as *job uncertainty*. The authors assume labour-specific productivity shocks that are subject to second-moment disturbances, capturing variations in uncertainty.[7] After estimating the model, Leduc and Liu (2020) introduced additional uncertainty shocks to worker productivity to examine their macroeconomic effects. In an alternative approach, Bergholt et al. (2022) has also considered the effects of automation in a DSGE model, but this time without the search-and-matching frictions.

Models with automation, skill-heterogeneous households, and matching frictions have also been developed by other authors. One example is the work by Jaimovich et al.

[6]Leduc and Liu (2019) fit the model to four quarterly time series: unemployment rate, job vacancy rate, growth rate of average labour productivity in the non-farm business sector, and growth rate of the real wage rate. Their sample covered the period from 1985:Q1 to 2018:Q4. The four shocks included were: neutral technology shock, discount factor shock, separation shock, automation-specific shock.

[7]Leduc and Liu (2020) estimate the model to fit the US data from 1985:Q1 to 2018:Q4. In addition to unemployment and vacancy rates, they fit the model to the time series of real wages, labour productivity, inflation, and nominal interest rates. Since the rate of automation has implications for productivity and wage growth, including these variables helped demonstrate the importance of automation.

(2020), who considered participation and occupational choice for the low-skilled workers and conducted a welfare analysis across different steady-state conditions. To measure advances in automation technology, they also looked at by how much the relative price of ICT capital fell between 1989 and 2017 (see also Cords and Prettner 2018). In addition, automation with a task-based framework and matching frictions has been analysed for example in the work of Guimarães and Gil (2022*a*) and Guimarães and Gil (2022*b*).

In another relevant piece of work, Berg et al. (2018) focused on inequality effects of automation between high- and low-skill labour in the absence of labour market frictions. Two assumptions are key: (1) "robot" capital is distinct from traditional capital with respect to its degree of substitution with labour; and (2) only capitalists and skilled workers can save money. The authors found that automation was positive for growth but negative for equality; in their benchmark model real wages fell in the short run, and eventually increased, but "eventually" could easily take generations.

Regarding the interactions between automation and migration, Borjas and Freeman (2019) analysed robot and immigrant supply shocks. Basso et al. (2020) showed that unskilled immigration in the United States attenuates the drop in routine employment from technological change, enhances skill upgrading for the native-born labour force, and raises the economy-wide productivity and welfare. Research by Mandelman and Zlate (2020) indicates that offshoring and automation negatively affects the middle-skill but benefits the high-skill occupations in terms of employment and wages, whilst low-skill employment is relatively unaffected. Still, in this model, no wage gains are experienced due to low-skill immigration in the US. In this framework, automation tends to be complementary to both low- and high-skill occupations, but substitute for medium-skill jobs.

The introduction of ageing into DSGE models is relatively recent. Yoshino and Miyamoto (2019) examined the effect of an ageing population on fiscal and monetary policy. Their results show the decreasing effectiveness with an economy that is ageing, with conclusions calling for structural economic reforms. Their empirical analysis for a panel of OECD countries found that countries with more rapid ageing saw insignificant responses to output from government spending shocks, whilst countries with slower ageing experienced an increase in output for the short- and medium-term. On a related topic, Rohenkohl and Clarke (2023) reviewed the well-being of workers in the context of automation with the results as expected – low-skill workers who perceive automation as a threat were negative towards automation whilst (high-)skill workers who see automation as complementary were more positive towards the advances in technology.

With respect to the case study countries, Astrov et al. (2021) looked at labour shortages in the CEE member states of the EU, with a detailed analysis of the current and future demographic change, which is especially concerning for some countries involved. In the last two decades, Poland's working-age population first increased from 26.5 million to 27.2 million in 2009, before declining to 24.4 million in 2022[8]. At the time of writing (as of late 2023), Poland and Germany had some of the lowest unemployment rates in the EU, which can be indicating their labour shortages: in 2022, Poland's unemployment rate of 2.9% was the second lowest in the EU. Similarly, Germany's desire to increase skilled migration is demonstrated by its policies, including the number of EU-Blue Cards that are issued.[9] Interestingly, according to Eurostat data, Poland and France were ranked second and third in the Blue Card issuance for 2021 and 2022.

In summary, a two-country DSGE model that we introduce in this report contributes to the literature, especially *vis à vis* Leduc and Liu (2019), by: (i) including physical capital and therefore considering its complementarity with high-skill labour, (ii) considering heterogeneous households which allows us to study inequality and welfare questions, (iii) including two economies with contrasting macroeconomies and automation trends, (iv) introducing the open economy features, (v) including fiscal policy to evaluate effects of investment, and (vi) considering migration. In comparison with two other papers closest to this study, Berg et al. (2018) differs with respect to the automation type and the migration aspect, whilst Mandelman and Zlate (2020) differs with regard to the type of production, automation capital, number of countries, and levels of heterogenity. In our case, we present the results for a heterogenous pair of large EU countries, with strong

[8] Population ages 15-64, both sexes. Cited after: World Bank World Development Indicators database. In this study, we will use a broader definition of labour force, until 75 years of age, due to data availability, and reflecting that as ageing progresses, retirement age is bound to increase.

[9] EU Member states (except Denmark and Ireland, who opted out) can issue EU-Blue Cards to high-skilled third-country nationals, with national limits on length of contracts and minimum earnings thresholds: as of 2023, this was between 1 to 1.6 times the average gross salary (Directive (EU) 2021/1883). These thresholds can be adapted for industries which experience shortages. In 2021, Germany issued 19,502 Blue Cards, or 65.97% of all Blue Cards issued. Source: Eurostat Table: MIGR_RESBC1. Accessed 20 September 2023. These numbers do not include other visas issued by national governments.

migration links and visible labour force challenges, exacerbated by population ageing. The details of our analytical approach are presented next.

3 DSGE Model

In this report, we present a two-country model where each country is populated by infinitely lived households, perfectly competitive firms, and a fiscal authority. The largest country is modelled to reflect Germany, which has the largest population in Western Europe and one of the highest robot stocks globally. The second country is modelled to reflect Poland, which has a lower GDP and stock of robots per capita. The asymmetries extend to include trade openness, technology levels, and whether the countries are (were) net senders or recipients of migrants. The selection of Germany and Poland is suitable, as it is involves one of the long-standing largest intra-European migration flows.

Within the DSGE model, the households are intertemporal optimisers who provide labour services that are subject to search and matching frictions, participate in international financial markets, and own firms. Low-skill households do not have access to the international financial markets. The agents in Poland are assumed to have a domestic employment opportunities in a final good producing and a second source of employment that requires migration to Germany. The migration decision is endogenous based on current and expected labour market conditions, and there is a cost to migration.

In addition to the households and firms, each country has a fiscal authority that consumes and has the option to provide further investments in automation capital. The model builds on the two-country model presented in Barker (2021) and the automation processes presented by Leduc and Liu (2019).

3.1 Labour Market

There is a total number of native agents in country i, $\overline{\mathcal{N}_t^i}$, where $i \in [G, P]$ denotes Germany and Poland, respectively. There are two-skill levels, identified by k, where $k \in [H, L]$ for high- and low-skill respectively. The relative size of a household is given by φ_t^b, where b identifies a household by: (i) location or migration status ($i \in [G, P, M]$); (ii) skill-level, ($k \in [H, L]$); and (iii) age group, which is assumed to be working-age, with the 65–74 age group having an extra superscript O.[10]

Agents can be economically active, as such take a status of employed, n_t^b, unemployed, u_t^b or inactive, l_t^b; thus, using household-level notation, $n_t^b + u_t^b + l_t^b = 1$. At an aggregate level, the number of employed agents is: $\mathrm{N}_t^b = \varphi_t^{ik} n_t^{ik}$ and unemployed: $\mathrm{U}_t^b = \varphi_t^{ik} u_t^{ik}$. The **native** population, without age distinction, is given in equation (1):

$$\overline{\mathcal{N}_t^i} = \underbrace{\varphi_t^{iH}(\mathrm{n}_t^{iH} + \mathrm{u}_t^{iH} + \mathrm{l}_t^{iH})}_{\text{high-skill workers}} + \underbrace{\varphi_t^{iL}(\mathrm{n}_t^{iL} + \mathrm{u}_t^{iL} + \mathrm{l}_t^{iL})}_{\text{low-skill workers}} \qquad i \in [G, P] \tag{1}$$

There are two skill-specific labour markets in each country, with each labour market having agents from two or more households employed or searching for jobs matching their skills. These four markets, j, are given by: G^H, G^L, P^H, and P^L. There is no transfer between skill level. In Poland, the only households involved in the k-skill labour market are the working-age k-skill household and the older agents who are aged 65-74 – i.e. $b \in [P^k, P^{k^O}]$. These older households have significantly lower participation rates.

For Poland, in the working-age households, unemployed workers are searching for employment in Poland and Germany. In the older households, unemployed agents do not search for work internationally, i.e. are no longer considered as possible migrants. In Germany, the k-skilled labour market includes working-age k-skill natives and migrants, along with the k-skilled older workers, who can be natives or migrants, i.e. $b \in [G^k, G^{k^O}, M^k, M^{k^O}]$. The equations below define, first the total population sizes, $\mathbb{N}_t^i$, in (2) for Germany and in (3) for Poland,

$$\mathbb{N}_t^G = \underbrace{\varpi_t^{G^H} + \varpi_t^{G^{H^O}}}_{\text{high-skill natives}} + \underbrace{\varpi_t^{G^L} + \varpi_t^{G^{L^O}}}_{\text{low-skill natives}} + \underbrace{\varpi_t^{M^H} + \varpi_t^{M^{H^O}}}_{\text{high-skill migrants}} + \underbrace{\varpi_t^{M^L} + \varpi_t^{M^{L^O}}}_{\text{low-skill migrants}} \tag{2}$$

$$\mathbb{N}_t^P = \underbrace{\varpi_t^{P^H} + \varpi_t^{P^{H^O}}}_{\text{high-skill population}} + \underbrace{\varpi_t^{P^L} + \varpi_t^{P^{L^O}}}_{\text{low-skill population}} \tag{3}$$

and secondly, the relative population size where $\varphi_t^b = \varpi_t^b / \mathbb{N}_t^i$.

$$1 = \underbrace{\varphi_t^{G^H} + \varphi_t^{G^{H^O}}}_{\text{high-skill natives}} + \underbrace{\varphi_t^{G^L} + \varphi_t^{G^{L^O}}}_{\text{low-skill natives}} + \underbrace{\varphi_t^{M^H} + \varphi_t^{M^{H^O}}}_{\text{high-skill migrants}} + \underbrace{\varphi_t^{M^L} + \varphi_t^{M^{L^O}}}_{\text{low-skill migrants}} \tag{4}$$

[10] The relative size the respective households are time-varying, due to migration to or from households.

$$1 = \underbrace{\varphi_t^{PH} + \varphi_t^{PH^O}}_{\text{high-skill population}} + \underbrace{\varphi_t^{PL} + \varphi_t^{PL^O}}_{\text{low-skill population}} \tag{5}$$

Of the high- and low-skill Polish working-age household members, a proportion (λ_t^k), are searching for work *in* Poland, while $(1 - \lambda_t^k)$ are searching in Germany. We introduce asymmetric search and matching frictions through the efficiency of the matching process, a^b, and by the exogenous periodic destruction rate of employment, ρ_n^b. These differences reflect the relative difficulties in gaining employment, between high- and low-skill, as well as natives compared to migrants.

The formulation of the labour market follows the standard approaches from the literature, however, the unemployed searchers for employment in the next period, $\widetilde{u_t^b}$, include unemployed workers and $\rho_n^b n_{t-1}^b$ workers who would otherwise be unemployed in the next period, $\widetilde{u_t^b} = u_t^b + \rho_n^b n_{t-1}^b$. Matches are made according to:

$$m_t^b = a^b (\widetilde{u_t^b})^\Gamma (v_t^j)^{1-\Gamma} \tag{6}$$

The probability of finding a job, q_{U_t}, vacancy filling rate, q_{v_t}, and labour market tightness, θ_t, are given by:

$$q_{U_t}^b = \frac{m_t^b}{\widetilde{u_t^b}} \qquad q_{v_t}^j = \frac{m_t^b}{v_t^j} \qquad \theta_t^i = \frac{v_t^j}{\widetilde{u_t^b}} \tag{7}$$

Low-skill vacancies are posted following the model of Leduc and Liu (2019). The number of vacancies available includes all the vacancies posted in the previous period, those that remain unfilled $\left(1 - q_{v_{t-1}}^{i^L}\right) v_{t-1}^{i^L}$, or not automated $1 - q_{A_t}^i$, plus the matches broken, $\rho_n^b N_t^b$, and the newly created vacancies, η_t^i.

$$v_t^{i^L} = (1 - q_{v_{t-1}}^{i^L})(1 - q_{A_t}^i) v_{t-1}^{i^L} + \rho_n^b N_{t-1}^b + \eta_t^i \qquad j \in i^L \tag{8}$$

For the high-skill sectors, the probability of automation is assumed to be zero. The number of high-skill vacancies available are optimised by traditional methods.

3.2 Households

There are high- and low-skill households in both countries. High-skill households own the domestic firms and invest in the financial markets. The households in Poland also have the option to migrate. Due to the wage premium, migration of German workers to Poland is set to zero, or, in an alternative interpretation, we only consider the *net* effect of migration from Poland to Germany. Hours worked are determined by collective bargaining by the unions and firms, dependent on the marginal product of hours. The number of hours worked in the model is important because as an alternative to increasing the employment, at times when employing labour is more challenging, hours can be increased to compensate for that. Both of the case study countries experience low unemployment rates and tight labour markets, as discussed before.

To introduce ageing into the model, we identify a subset of households that are of retirement age. As participation rates in this age category are significantly lower than for the working-age households, this adds to the economy a dynamics that was largely not explored before. To follow the standard domestic policies, the retirees that are actively searching for employment are not entitled to unemployment insurance, but rather a pension. Those who are unemployed receive a partial pension. We set the retiree category for ages 65–74, to align with the availability of data on labour force participation. High-skill retirees receive a higher pension to account for higher savings and assets, but this is less than the corresponding skill wage. The retirees in Poland do not migrate, and the retirees resident in Germany do not search for employment in Poland.

3.2.1 Households in Germany

The households in Germany gain utility from consumption, $c_t^{G^k}$ and leisure hours, $l_t^{G^k}$, while experiencing disutility from labour hours. They provide labour to the firms, $n_t^{G^k}$. Income is pooled to allow the same consumption amongst all members irrespective of their employment status. The discount factor β^G and the utility function parameters are specific to skill level, as given in (9) below.

$$U_t^{G^k} = E_t \beta^{G^t} \sum_{t=0}^{\infty} \frac{\left(c_t^{G^k}\right)^{1-\sigma_{G^k}}}{1-\sigma_{G^k}} - \frac{\phi_0^{G^k}\left(h_t^{G^k}\right)^{1+\phi^{G^k}}}{1+\phi^{G^k}} + \frac{\Phi_0^{G^k}\left(l_t^{G^k}\right)^{1-\Phi^{G^k}}}{1-\Phi^{G^k}} \tag{9}$$

Households face household-specific budget constraints, where common features include expenditures on consumption, $c_t^{G^k}$, and paying lump-sum taxes, Tax_{G_t}, which are financed by labour earnings, $w_t^{G^k}$, as well as unemployment insurance, ub^{G^k}.

High-skilled households are able to purchase one-period bonds, d_t^G, from the international financial markets, at the international price level of $p^P_{G_t}$, and receive return on the previous period's bond purchases. Carried over stocks of bonds are deflated by the gross growth rate of working-age population $\frac{\mathbb{N}^G_t}{\mathbb{N}^G_{t-1}} = g^G_t$ in Germany. The high-skill households own the firms and receive the profits from the final-good production, Π^G_t.

Each household maximises utility with respect to consumption, hours worked, employment status, labour market participation, and the high-skill household maximise bond holdings. Marginal utility of consumption is denoted by $\mu^{G^k}_t$, and $\eta^{G^k}_t$ is the Lagrange multiplier on the law of motion of employment. The maximisation and constraints are given below.

High-skilled households:

$$\max_{c^{G^H}_t, h^{G^H}_t, n^{G^H}_t, l^{G^H}_t, d^G_t} \sum_{t=0}^{\infty} E_t \beta^{G^t} \frac{\left(c^{G^H}_t\right)^{1-\sigma_{G^H}}}{1-\sigma_{G^H}} - \frac{\phi^{G^H}_0 \left(h^{G^H}_t\right)^{1+\phi^{G^H}}}{1+\phi^{G^H}} + \frac{\Phi^{G^H}_0 \left(l^{G^H}_t\right)^{1-\Phi^{G^H}}}{1-\Phi^{G^H}}$$

$$n^{G^H}_t w^{G^H}_t h^{G^H}_t + u^{G^H}_t ub^{G^H} + \Pi^G_t + p^G_{G_t} \frac{d^G_{t-1}}{g^G_t}(1+r^G_{t-1}) = c^{G^H}_t + p^G_{G_t} d^G_t + Tax^H_{G_t}$$

Low-skilled households:

$$\max_{c^{G^L}_t, h^{G^L}_t, n^{G^L}_t, l^{G^L}_t} \sum_{t=0}^{\infty} E_t \beta^{G^t} \frac{\left(c^{G^L}_t\right)^{1-\sigma_{G^L}}}{1-\sigma_{G^L}} - \frac{\phi^{G^L}_0 \left(h^{G^L}_t\right)^{1+\phi^{G^L}}}{1+\phi^{G^L}} + \frac{\Phi^{G^L}_0 \left(l^{G^L}_t\right)^{1-\Phi^{G^L}}}{1-\Phi^{G^L}}$$

$$n^{G^L}_t w^{G^L}_t h^{G^L}_t + u^{G^L}_t ub^{G^L} = c^{G^L}_t + Tax^L_{G_t}$$

With the employment law of motion given as:

$$n^{G^k}_t = (1-\rho^{G^k}_n) n^{G^k}_{t-1} + \zeta^{G^k}_t u^{G^k}_t$$

First-order conditions:

$$\mu^{G^k}_t = \left(c^{G^k}_t\right)^{-\sigma_{G^k}}$$

$$H^{G^k}_t = w^{G^k}_t - ub^{G^k} - \frac{\phi^{G^k}_0 \left(h^{G^k}_t\right)^{1+\phi^{G^k}}}{1+\phi^{G^k}} + \beta^G (1-\rho^{G^k}_n) \frac{\mu^{G^k}_{t+1}}{\mu^{G^k}_t} H^{G^k}_{t+1} (1 - q^{G^k}_{U_{t+1}})$$

$$\frac{1}{1+r^G_t} = \beta^G \frac{\mu^{G^H}_{t+1}}{\mu^{G^H}_t} \frac{p^P_{G_{t+1}}}{p^P_{G_t}} \frac{1}{g^G_{t+1}}$$

The labour hours provided to the firms are negotiated and based on the optimisation and marginal productivity.

$$\phi_0^{G^k}\left(h_t^{G^k}\right)^{\phi^{G^k}} = \frac{\partial p_{G_t}^G Y_t}{\partial h_t^{G^k} N_t^{G^k}} \tag{10}$$

The decision on labour market participation is solved with the first order conditions between leisure optimisation and unemployment:

$$\mu_t^{G^k} = \frac{\Phi_0^{G^L}\left(l_t^{G^k}\right)^{-\Phi^{G^k}} - ub^{G^k}\mu_t^{G^k}}{\zeta_t^{G^k}}$$

3.2.2 Households in Poland

The households in Poland gain utility from consumption, $c_t^{P^k}$ and leisure hours, l_t^b, while experiencing dis-utility from labour hours, h_t^b. They provide labour to the firms, n_t^b, domestically and in Germany. Income is pooled to allow the same consumption amongst all members irrespective of their employment status. The discount factor β^P and the utility function parameters are specific to Poland.

$$U_t^{P^k} = E_t \beta^{P^t} \frac{\left(c_t^{P^k}\right)^{1-\sigma_{P^k}}}{1-\sigma_{P^k}} - \frac{\phi_0^b \left(h_t^b\right)^{1+\phi^b}}{1+\phi^b} + \frac{\Phi_0^b \left(l_t^b\right)^{1-\Phi^b}}{1-\Phi^b} \qquad j \in P^k, M^k \tag{11}$$

Similarly to their German counterparts, households face household-specific budget constraints, with expenditures on consumption, $c_t^{P^k}$, lump-sum household and country specific taxes, $Tax_{i_t}^b$, financed by labour earnings, $w_t^{P^k}$, and unemployment insurance ub^{P^k}. As in Germany, high-skilled households are also able to purchase one-period bonds d_t^P at the price of $p_{P_t}^G$, and receive return on their past bonds. Carried over stocks of bonds are deflated by the gross growth rate of working-age population $\frac{\mathbb{N}_t^P}{\mathbb{N}_{t-1}^P} = g_t^P$. The high-skilled households own the firms and receive profits from the final-good producing firms, Π_t^P. Polish households also receive remittances, Ξ_t^k.

Each household maximises utility with respect to consumption, hours worked, employment status, labour market participation, and the high-skill household additionally maximise bond holdings. For Polish households, their marginal utility of consumption is denoted by $\mu_t^{P^k}$, and η_t^b is the Lagrange multiplier on the law of motion of employment. The maximisation and constraints are as follows:

High-skilled households:

$$\max_{c_t^{PH},n_t^b,h_t^b,d_t^P} \sum_{t=0}^{\infty} E_t \beta^{P^t} \frac{\left(c_t^{PH}\right)^{1-\sigma_{PH}}}{1-\sigma_{PH}} - \frac{\phi_0^b \left(h_t^b\right)^{1+\phi^b}}{1+\phi^b} + \frac{\Phi_0^b \left(l_t^b\right)^{1-\Phi^b}}{1-\Phi^b} \qquad b \in P^H, M^H$$

$$n_t^{PH} w_t^{PH} h_t^{PH} + u_t^{PH} ub^{PH} + \Pi_t^P + \Xi_t^H + p_{P_t}^G \frac{d_{t-1}^P}{g_t^P}(1+r_{t-1}^G) = c_t^{PH} + p_{G_t}^G d_t^G + Tax_{P_t}^H$$

$$n_t^{MH} w_t^{MH} h_t^{MH} + u_t^{MH} ub^{MH} = c_t^{MH} + \Xi_t^H + Tax_{G_t}^{MH}$$

Low-skilled households:

$$\max_{c_t^{PL},n_t^{PL}} \sum_{t=0}^{\infty} E_t \beta^{P^t} \frac{\left(c_t^{PL}\right)^{1-\sigma_{PL}}}{1-\sigma_{PL}} - \frac{\phi_0^b \left(h_t^b\right)^{1+\phi^b}}{1+\phi^b} + \frac{\Phi_0^b \left(l_t^b\right)^{1-\Phi^b}}{1-\Phi^b} \qquad j \in P^L, M^L$$

$$n_t^{MH} w_t^{MH} h_t^{MH} + u_t^{MH} ub^{MH} = c_t^{MH} + \Xi_t^H + Tax_{G_t}^{MH}$$

$$n_t^{PL} w_t^{PL} h_t^{PL} + u_t^{PL} ub^{PL} + \Xi_t^L = c_t^{PL} + Tax_{P_t}^L$$

$$n_t^{ML} w_t^{ML} h_t^{ML} + u_t^{ML} ub^{ML} = c_t^{ML} + \Xi_t^L + Tax_{G_t}^{ML}$$

Both households then face the law of motion of employment for optimisation.

$$n_t^{Pk} = (1-\rho_n^{Pk}) n_{t-1}^{Pk} + \zeta_t^{Pk} u_t^{Pk}$$

First order conditions:

$$\mu_t^{Pk} = \left(c_t^{Pk}\right)^{-\sigma_{Pk}}$$

$$H_t^{ik} = w_t^{ik} - ub^{ik} - \frac{\phi_0^{ik}\left(h_t^{ik}\right)^{1+\phi^{ik}}}{1+\phi^{ik}} + \beta^G(1-\rho_n^{Gk}) \frac{\mu_{t+1}^{ik}}{\mu_t^{ik}} H_{t+1}^{ik}(1-q_{U_{t+1}}^{ik})$$

$$\frac{1}{1+r_t^G} = \beta^P \frac{\mu_{t+1}^{PH}}{\mu_t^{PH}} \frac{p_{P_{t+1}}^G}{p_{P_t}^G} \frac{1}{g_{t+1}^P}$$

The labour hours provided to the firms are negotiated and based on the optimisation and marginal productivity.

$$\phi_0^{ik}\left(h_t^{ik}\right)^{\phi^{ik}} = \frac{\partial p_{i_t}^i Y_t}{\partial h_t^{ik} N_t^{ik}} \tag{12}$$

The decision on labour market participation is solved with the first order conditions between leisure optimisation and unemployment:

$$\mu_t^{ik} = \frac{\Phi_0^{iL}\left(l_t^{ik}\right)^{-\Phi^{ik}} - ub^{ik}\mu_t^{ik}}{\zeta_t^{ik}}$$

Agents residing in Poland have the option to migrate to Germany in search for work. They make an inter-temporal decision using their knowledge of current and discounted future labour market conditions, as demonstrated in Figure 3. In each market, they face the probability of finding employment $q_{U_t}^b$ in labour market $j \in [P^k, M^k]$ for Poland and migration markets respectively, which would give them income w_t^b. Then, they take into account the expectations for the next period of remaining employed or becoming unemployed once more. Alternatively, being unemployed with a probability of $1 - q_{U_t}^b$, and receiving unemployment benefits ub^b, they account for the next period of finding employment or remaining unemployed. The migrants who become unemployed in period t, join the pool of job searchers with their respective household, with the search intensity deciding where they search for employment.

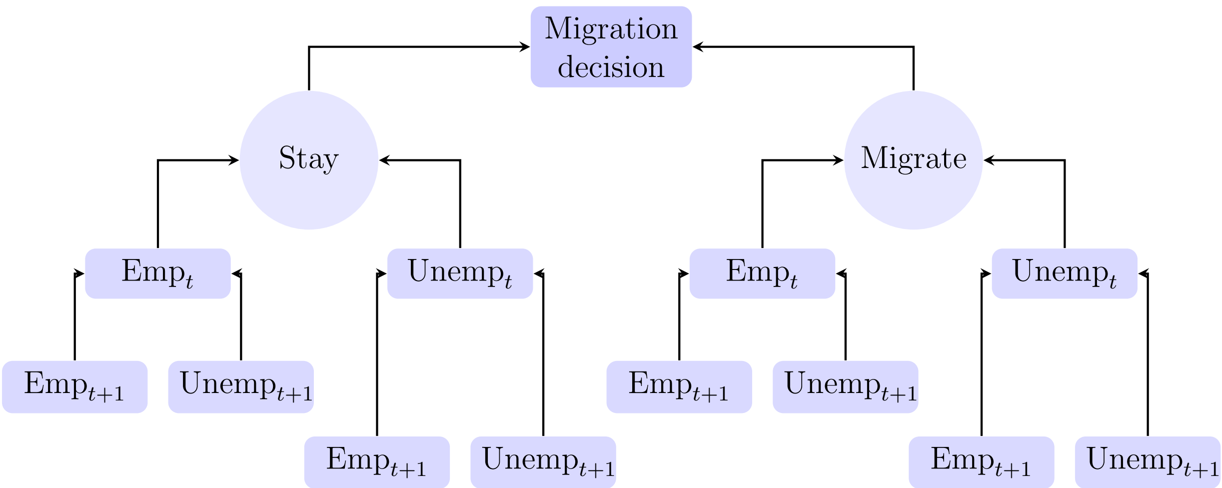


Figure 3: Framework for Modelling Endogenous Migration Decisions

The migration decision optimises the employment status in the current period and the expected employment status in the next one. Individuals can be employed (Emp$_t$) or unemployed (Unemp$_t$). The labour market in which an individual is searching for employment in defines their country of unemployment.

The migration decision is made dependent upon current and expected labour market conditions, where the expected surplus from being employed in sector $j \in [P^k, G^k]$ is given by E_t^b and from being unemployed by U_t^b. The optimisation conditions are :

$$E_t^b = w_t^b + \beta^P((1-\rho_n^b)w_{t+1}^b + \rho_n^b ub^b) \qquad b \in [P^k, M^k] \tag{13}$$

$$U_t^b = ub^b + \beta^P(q_{u_{t+1}}^b w_{t+1}^b + (1-q_{u_{t+1}}^b)ub^b) \qquad b \in [P^k, M^k] \tag{14}$$

$$\underbrace{q_{u_t}^b E_t^b + (1-q_{u_t}^b)U_t^b}_{\text{Search in Poland - } b=P^k} = \underbrace{q_{u_t}^b E_t^b + (1-q_{u_t}^b)U_t^b}_{\text{Search in Germany - } b=M^k} + \underbrace{EC}_{\text{Emigration cost}} \tag{15}$$

The migration decision is changeable and reversible in any period, and depends on the search intensity. An increase to search intensity results in an increase of unemployed agents searching for employment in Poland, whilst a negative response to search intensity is an increase in the number of agents searching for employment in Germany. The decision is subject to a migration shock which is reflected by a *decrease* in the migration cost.

3.3 Older Households

The older households, or retirees, that are aged 65–74, face the same utility function, with household-specific parameters as younger ones, although with a different budget constraint. Unemployed members of the older households are not entitled to receive unemployment insurance, as the working-age household are. They are entitled, as with the members who are retired, or those who have exited the labour market, to a pension, $\mathbb{P}^{i^{k^O}}$. If an unemployed retiree forgoes part of their pension, they receive $\mathcal{P}^{i^{k^O}} = \chi\mathbb{P}^{i^{k^O}}$ High-skill workers receive a higher amount. The unemployed workers do not take the full pension they are allowed to. Those who have retired, are able to re-enter the labour market at any point. Once a person reaches aged 75, they will have left the labour market (and household) completely. The wages are taxed at a lower rate than for the working-age population, to correspond to a lower contribution rate as put forth by governments which encourage higher labour market participation in this age group.

The budget constraint for the older (retiree) households is given by:

$$(1-\tau_{i_t}^{w^O})n_t^{i^{k^O}} w_t^{i^{k^O}} h_t^{i^{k^O}} + \mathbb{P}^{i^{k^O}}(\chi u_t^{i^{k^O}} + l_t^{i^{k^O}}) = c_t^{i^{k^O}}(1+\tau_{i_t}^c) \tag{16}$$

3.4 Firms

In both countries, there are perfectly competitive firms which share common features. Firms employ a high-skill 'bundle' comprised of the physical capital, K_t^i, which is complementary to high-skilled labour. The low-skilled 'bundle' combines robots, A_t^i, and low-skilled labour. The firms are subject to a country-specific: total productivity shocks, $\psi_t^{a^i}$, labour productivity shocks, $\psi_t^{L^i}$, automative productivity shocks, $\psi_t^{A^i}$, and investment shocks, $\psi_t^{x^i}$. This model uses the automation dynamics put forth by Leduc and Liu (2019). The inputs of production are shown in Figure 4.

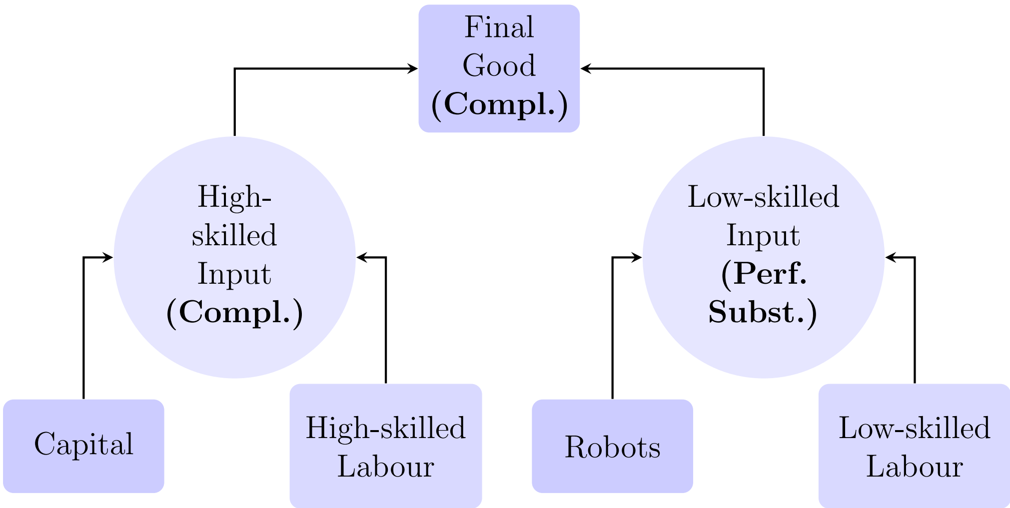


Figure 4: Overview of the Production Setup

The inputs to the final good production for the firms. In Germany, labour includes immigrants from Poland but in Poland, there the labour market is local. Natives and migrants are imperfect substitutes.

The high-skill input is denoted by H_t^i and the low-skilled input by L_t^i. The complementarity of the high-skill and low-skill inputs is given by Φ^i, which is a function of the elasticity of substitution $\sigma_{H,L} = \alpha^i/(\alpha^i - 1)$. The final output production follows a capital-skill complementarity form, and is given by:

$$y_t^i = \psi_t^{a^i} p_{i_t}^i \left(e \left(H_t^i \right)^{\alpha^i} + (1-e) \left(L_t^i \right)^{\alpha^i} \right)^{\frac{1}{\alpha^i}} . \tag{17}$$

with $p_{i_t}^i$ denoting the relative price, and α^i identifies the complementarity between the high and low-skill inputs. The complementarity of capital and high-skill labour is given by Φ^i, which is a function of the elasticity of substitution $\sigma_{K,N^{iH}} = \Phi^i/(\Phi^i - 1)$. The respective high-skill services and low-skill services are defined as follows:

$$H_t^i = \left[\nu^i (K_{t-1}^i)^{\Phi^i} + (1-\nu^i)(N_t^{i^H} h_t^{i^H} \psi_{N_t}^{i^H})^{\Phi^i}\right]^{\frac{1}{\Phi^i}} \tag{18}$$

$$L_t^i = \left[N_t^{i^L} h_t^{i^L} \psi_{N_t}^{i^L} + A_t^i \psi_t^{A^i}\right] \tag{19}$$

Labour and automation capital are subject to specific factor productivity shocks, $\psi_{N_t}^{i^K}$ for labour and $\psi_t^{A^i}$ for automation. In Germany, the migrants from Poland are assumed to be perfect substitutes with natives as per Iftikhar and Zaharieva (2019). The low-skill labour and automation are modelled in the same perfect substitute form as in Leduc and Liu (2019).physical capital is accumulated following standard methods, subject to investment adjustment costs, $\iota(x_t^i, x_{t-1}^i)$, as shown in the accumulation equation (20):

$$K_t^i = (1-\delta^i)K_{t-1} + \iota(x_t^i, x_{t-1}^i) \tag{20}$$

3.4.1 Automation

In this setup, robots are assumed to be a labour-saving technology which are perfect substitutes to low-skill labour. Firms have the option to either automate a vacancy, or a job, which would result in a further job destruction. Since the economies in our study have close to full employment levels, in this model the vacancies are automated. The firm can choose a robot to complete the task or post a vacancy to employ a worker. The process of employing a worker or a robot have a number of similarities. We use the automation evolution of workers vs robots as in Leduc and Liu (2019), where unfilled vacancies can be automated. The introduction of robots as an alternative to labour changes the evolution of vacancies posted. The number of vacancies available is shown in equation (8).

The alternative to posting a vacancy is automating the task. Robots become defunct following an exogenous rate ρ_A^i. The robots are task-specific, with migrants and low-skill native German workers assumed to be their imperfect substitutes. There are two types of task-specific robots, which are also imperfect substitutes between themselves.

$$A_t^i = (1-\rho_A^i)A_{t-1}^i + (1-q_{v_{t-1}}^j)q_{A_{t-1}}^i v_{t-1}^j \tag{21}$$

The firm chooses a robot only when the value of automation exceeds the value of a vacancy. The probability that a robot is adopted is given by the excess of the automation value over the vacancy value $x_t^* = J^i_{A_t} - J^{i^L}_{v_t}$ relative to robot adoption cost:

$$q^i_{A_t} = \left(\frac{x_t^{*^i}}{\overline{x^i}}\right)^{\eta_a} \tag{22}$$

Additional vacancies are created in an equivalent form:

$$\nu^j_t = \left(\frac{J^{i^L}_{v_t}}{\overline{e^{i^L}}}\right)^{\eta_v} \tag{23}$$

After a robot ceases to be used by the firm, with $\rho^i_A A^i_t$ defunct robots each period, the robots are recycled or resold, including the knowledge and usefulness, on the international market. The pass-on value has no impact on the value, or choice, of automation.

3.4.2 Wage Bargaining

The wages are determined through Nash bargaining. There are skill-specific household bargaining powers, ϑ^b. For the forms of employment which are substitutes to automation, the value of placing a vacancy is not possible to be eliminated using the envelope theorem[11], since the value of posting a vacancy is directly affected by the value of automation. A firm has a value from employment of a worker in labour market j, $J^b_{e_t}$, posting a low-skill vacancy, $J^{i^L}_{v_t}$, and automation, $J^i_{A_t}$.

$$J^b_{e_t} = p^i_{i_t}\frac{\partial y^i_t}{\partial(N^b_t h^b_t)} - w^b_t + \beta^i \frac{\mu^{i^H}_{t+1}}{\mu^{i^H}_t}\left[\rho^b_n J^j_{v_{t+1}} + (1-\rho^b_n) J^b_{e_{t+1}}\right] \tag{24}$$

Where automation exists, the values of the relevant J parameters, for a low-skill vacancy and for automation, are given by:

$$J^{i^L}_{v_t} = -\kappa^{i^L} + q^{i^L}_{v_t} J^{i^L}_{e_t} + (1-q^{i^L}_{v_t})\beta^i \frac{\mu^{i^H}_{t+1}}{\mu^{i^H}_t}\left[(1-q^i_{A_{t+1}})J^{i^L}_{v_t} + q^i_{A_{t+1}} J^i_{A_{t+1}}\right] \tag{25}$$

$$J^i_{A_t} = p^i_{i_t}\frac{\partial y^i_t}{\partial A^i_t} - \kappa^i_A + (1-\rho^i_A)\beta^i \frac{\mu^{i^H}_{t+1}}{\mu^{i^H}_t} J^i_{A_{t+1}} \tag{26}$$

As such, the weight of the bargaining powers is defined by:

$$\vartheta^b = \frac{H^b_t}{J^b_{e_t} - J^{i^L}_{v_t} + H^b_t} \text{ where } k = L \qquad \text{and} \qquad \vartheta^b = \frac{H^b_t}{J^b_{e_t} + H^b_t} \text{ where } k = H \tag{27}$$

[11] According to the Oxford Economic Dictionary, the envelope theorem is "determining the effect of a differential change in a parameter on the outcome of a maximization problem", in that "the derivative of the value function is the partial derivative of the objective evaluated at the solution to the optimization" (cited after: Oxford Reference, as of 1 February 2024).

3.5 Fiscal Authority

In both Poland and Germany there exists a fiscal authority that consumes, collects taxes, and borrows (lends) from (to) the financial markets in the case of a primary deficit (surplus). The fiscal authority collects taxes from households via time variant lump sum taxes, $Tax^b_{i_t}$. The government spending, G^i_t, has expenditures from automation investment, gx^i_t and the government consumption, gc^i_t.

$$G^i_t = gc^i_t + gx^i_t \tag{28}$$

$$gc^i_t = \left(\frac{y^i_t}{\overline{y^i}}\right)^{\theta^i} \overline{gc^i} + \psi^{gc^i}_t \qquad gx^i_t = \rho^{gx^i} gx^i_{t-1} + \psi^{gx^i}_t \tag{29}$$

Changes in government expenditure occur through deviations of GDP relative to steady state and subject to a shock. The elasticity of government spending with respect to the business cycle is given by θ. Where fiscal policy is countercyclical, $\theta < 0$.

As the focus of this report is on automation, we assume that government investment is restricted to automation only. The investment is provided through subsidies, rather than direct supply of robots. This results with a smaller value for the threshold level of automation, $\overline{x^i}$, which increases the probability of the automation, *ceterius paribus*. Ultimately, the fiscal authorities' budget constraints are given as:

$$G^i_t = Tax_{i_t} \tag{30}$$

3.6 Driving Processes

The model has listed independent shocks to the economy: total factor productivity (TFP), automation productivity, labour productivity, discount factor, migration, and government consumption. Each of these shocks follow a generalised form:

$$\Psi^x_t = \rho_x \Psi^x_{t-1} + (1-\rho_x)\overline{\Psi^x} + \varepsilon^x_t \qquad \varepsilon^x_t \sim \mathcal{N}(0, \sigma^2_x), \tag{31}$$

where $\rho_x \in (0,1)$ is the autoregressive parameter, $\overline{\Psi^x}$ is the steady state value, and ε^x_t is an i.i.d. shock with zero mean and a constant variance σ^2_x.

4 Model Calibration and Estimation

4.1 Model Calibration

The model described in Section 3 has been built and calibrated, and had its parameter estimated, in `Dynare` for `MATLAB`. The demographic aspects of the model are calibrated based on the calculations from Eurostat data on population structures by age, educational attainment and country of birth or migration status. In particular, the corresponding values have been calculated from Table `EDAT_LFS_9912` for population; Table `LFSA_EGAISEDM` for employment (1000s), and Table `LFSA_URGANEDM` for unemployment rates.

Poland's foreign-born demographics are in stark contrast to Germany's. In 2020, 97.8% of all age groups were native-born, while for the working-age population, 98.6% were born in Poland which was at the time the highest in the EU+.[12] In the same period, the corresponding values for Germany were 81.9% and 79.7%. For the 'low-skill' level, we combine the medium and low-skill levels of education. The parameter values related to the demography and labour market, used for model calibration, are listed in Table 1.

In terms of macroeconomic variables, the endogenously determined value for search intensity for Polish households is set to 0.7602 and 0.8337 for high- and low-skill respectively. High-skill households have a higher emigration cost than low-skill household members. To calculate the skill premium between high- and low-skill households domestically and internationally, we used the median hourly earnings from Eurostat (Table `EARN_SES_PUB2I`) in euros. For combining the low-skill and medium-skill categories, we used the percentages of the population by the same education measure. The skill premium targets for Germany is 1.71, compared to 1.78 for Poland. The international high-skill wage premium (in euros) is 3.64 and low-skill 3.79. However, the international wage premium is not as simple due to purchasing power parity (PPP). Living costs are lower in Poland, as observed by the purchasing power parity. Using data from the OECD[13], there has been significant closing of the wage premium, from 2.16 in 2000 to 1.60 in 2022 in 2022 constant prices at 2022 USD PPPs term. This is due to an average growth rate

[12] The values for 2023 are unpublished as of July 2023, however, this will be considerably lower due to the war in Ukraine. Note that the EU+ includes the EU-27 and EFTA countries, and the UK.

[13] OECD estimates based on OECD (2023), OECD Economic Outlook, Volume 2023 Issue 1, OECD Publishing, Paris, https://doi.org/10.1787/16097408 and OECD Annual National Accounts Prices and Purchasing Parities Database, https://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE4.

of 0.634% for Germany, and 2.05% in Poland. If we exclude 2020-2022, the averages are 0.89% and 2.34% respectively. Targeting these wage premiums is not realistic as migration flows would be lower if based on a 60% wage premium. Further research is required for a more precise calibration of the native wage premium in Germany. Research from existing studies find wage gaps between 7 to 20%, greater for high-skilled workers.

Table 1: Demographics and labour market

Country	**Skill level**		**Natives**		**Migrants**	
Germany			*WA*	*65–74*	*WA*	*65–74*
	High-skill					
		Population share	0.194	0.035	0.047	0.005
		Participation rate	0.950	0.204	0.906	0.196
		Unemployment rate	0.018	0.084	0.058	0.268
	Low-skill					
		Population share	0.477	0.088	0.136	0.018
		Participation rate	0.693	0.126	0.686	0.118
		Unemployment rate	0.036	0.197	0.058	0.268
Poland						
	High-skill					
		Population share	0.243	0.025		
		Participation rate	0.839	0.204		
		Unemployment rate	0.018	0.074		
	Low-skill					
		Population share	0.593	0.139		
		Participation rate	0.593	0.092		
		Unemployment rate	0.043	0.281		

Source: Authors' own calculation based on Eurostat data. WA denotes the main working age (15–64). The values are calculated from Table `EDAT_LFS_9912` for population; Table `LFSA_EGAISEDM` for employment, and Table `LFSA_URGANEDM` for unemployment rates. High-skill is defined as ISCED 5+, with low-skill values corresponding to ISCED 0-2 and 3-4.

The net replacement rate for pensions is taken from the OECD. The retirees that are in employment do not take a pension, and the unemployed only take a partial pension. In Germany, the net replacement rate is an average of 0.53, whilst in Poland, it is 0.325 (there is a gender imbalance in Poland with 0.37 for men, vs 0.28 for women). The values for automation stock are taken from the International Federation of Robotics (IFR) World Robotics Industrial Robots 2022 report. The discount factor for Poland is calculated from the risk-free rate of Germany, plus the interest rate premium faced by Poland. Capital depreciation rates are standard to the literature. The elasticity of vacancy creation and automation cost follow that of Leduc and Liu (2019). The replacement rates are standard to the literature. A full set of calibrated parameters is given in Table 2.

Table 2: Calibrated Economic Parameters

Parameter Description		Germany	Poland
Discount factor	β^i	0.9900	0.9502
Elasticity of matching function	Γ	0.5000	0.5000
Automation stock	A^i	3.9700	0.6300
Job separation rate	ρ_n^H	0.0500	0.0500
	ρ_n^L	0.1000	0.1000
	ρ_n^M	0.1000	
Automation obsolescence rate	ρ_A^i	0.0017	0.0037
Capital depreciation rate	δ^i	0.0250	0.0250
Elasticity of vacancy creation cost	η_v	1.0000	1.0000
Elasticity of automation cost	η_a	1.0000	1.0000
Elasticity of substitution K vs H	$\sigma_{K,H}$	0.5556	0.9091
Elasticity of substitution K,H vs A,L	$\sigma_{K,A}$	2.5000	2.3500
Share of K vs H	ν^i	0.4000	0.3000
Share of K,H vs A,L	e	0.3440	0.4900
Probability of filling a vacancy	$q_v^{i^H}$	0.8000	0.8000
	$q_v^{i^L}$	0.6000	0.6000
Steady state debt to GDP	$\overline{b^i}$	0.0000	0.0000
Replacement rate		0.2000	0.2000
Pension replacement rate		0.5300	0.3250

The values are standard to the literature or set as values are central to the model. The table shows only selected parameters used in the calibration of the DSGE model: the majority of parameters are endogenously determined.

4.2 Bayesian Estimation

Using the model's driving processes as described in Section 3.6, we estimated the standard deviation and persistence parameters of the shocks plus model parameters using mixed frequency data (annual and quarterly) with the default MCMC algorithm provided within `Dynare`. The data for migration has been obtained from the annual net emigration flows Poland as presented in Figure 1. The remaining data have been obtained from the national accounts at a quarterly frequency. Table 3 shows the mean values for priors and posteriors, 5^{th} ad 95^{th} percentiles, prior shape, and deviation of the posterior (obtained after 300,000 MCMC iterations). We choose default priors for the persistence parameters. The TFP shocks are estimated from the GDP that is converted to real terms with the deflator, transformed to per capita terms and logged. The government consumption and private investment follow the same methodology. This data is sourced from the OECD economic outlook, covering the period 2002Q1:2019Q4.

Table 3: Bayesian Estimation: Prior and Posterior summaries

Parameter Description		**PDF**	**Prior mean & SD**		**90% HPD Interval & mean**		
Autoregressive Parameters							
TFP - G	ρ_Z^G	β	0.7000	0.1000	(0.5213,	0.8525)	0.6955
TFP - P	ρ_Z^P	β	0.7000	0.0500	(0.6252,	0.7827)	0.7045
Pref - G	ρ_β^G	β	0.7000	0.1000	(0.5566,	0.8679)	0.7089
Pref - P	ρ_β^P	β	0.7000	0.1000	(0.5360,	0.8662)	0.6974
Invest - G	ρ_X^G	β	0.7000	0.1000	(0.5680,	0.8745)	0.7125
Invest - P	ρ_X^P	β	0.7000	0.1000	(0.5339,	0.8700)	0.6931
AFP - G	ρ_ζ^G	β	0.7000	0.1000	(0.5585,	0.8742)	0.7056
GC - G	ρ_{GC}^G	β	0.7000	0.1000	(0.5376,	0.8454)	0.6936
GC - P	ρ_{GC}^P	β	0.7000	0.1000	(0.5411,	0.8585)	0.6922
Net Emig	ρ_{NE}	β	0.7000	0.0500	(0.6122,	0.7737)	0.6904
Model Parameters							
International EofS	Θ	Γ	1.5000	0.0500	(1.4285,	1.5901)	1.5027
Bond Holding Cost	ϕ_{d^P}	β	0.0100	0.0001	(0.0098,	0.0102)	0.0100
Standard deviation of shocks							
TFP - G	σ_Z^G	Γ^{-1}	0.1000	0.0500	(0.0994,	0.1452)	0.1210
TFP - P	σ_Z^P	Γ^{-1}	0.1000	0.0500	(0.0314,	0.0507)	0.0410
Pref - G	σ_β^G	Γ^{-1}	0.1000	0.0500	(0.0602,	0.0942)	0.0771
Pref - P	σ_β^P	Γ^{-1}	0.1000	0.0500	(0.4598,	0.7344)	0.5948
Invest - G	σ_X^G	Γ^{-1}	0.1000	0.0500	(0.0795,	0.1119)	0.0954
Invest - P	σ_X^P	Γ^{-1}	0.1000	0.0500	(0.2954,	0.4019)	0.3438
AFP - G	σ_ζ^G	Γ^{-1}	0.1000	0.0500	(0.1234,	0.1851)	0.1553
GC - G	σ_{GC}^G	Γ^{-1}	0.1000	0.0500	(0.0458,	0.0602)	0.0528
GC - P	σ_{GC}^P	Γ^{-1}	0.1000	0.0500	(0.0558,	0.0736)	0.0650
Net Emig	σ_{NE}	Γ^{-1}	0.1000	0.0500	(0.6620,	0.9449)	0.8018

Results from the Bayesian estimation after 300,000 MCMC iterations. The first two columns list the estimated parameters and their corresponding symbols. The third column shows the assumed distributions (β: Beta, Γ: Gamma, and Γ^{-1}: Inverse Gamma). Columns four and five give the prior means and standard deviations. Columns six and seven show the 5^{th} and 95^{th} percentiles of the posterior densities (90% Highest Posterior Density intervals, HPD). The last, eighth column shows the posterior mean.

5 Results

The primary research question of this paper is whether robots and migration can mitigate the challenges of ageing? From the discussion so far, these are the two potential means to address especially the economic and labour market-related challenges of the changes in the age structures of the European populations and labour force.

The economic and labour force challenges of ageing are caused primarily by the increased proportion of the non-working-age population, indicated by increasing dependency ratios. As the DSGE model is covering a short time-horizon, during which the population shares of the native households are unlikely to change significantly, we keep the household shares at their calibrated level, except for the households featuring migrants.[14] There is a limit to a number of policies that can be modelled in this type of economic model, however, the results can nevertheless point to policy implications that would aid the search for resilience in the face of ageing. Still, in our model we cannot, for example, model a policy including re-activating the labour market or child friendly policies, which would require much more complex models and adopting longer-run perspectives, overlapping generations, and so on. Some of these questions are addressed in other reports from the FutuRes project, such as Sánchez-Romero et al. (2023).

The answers to our main questions differ for the migrant sending and receiving countries, in this case Poland and Germany. A country which is highly attractive to migrants (such as Germany) can adopt short-term labour market 'fixes' easier than countries that are not such popular migrant destinations. In this case, the question can be rephrased as: 'Can robots and migration address Germany's ageing challenges'. Here, it is also important to consider the response of migration to a range of shocks. It might seem obvious for an increase in migration when there is a wage increase in Germany relative to Poland, or vice versa for return migration, but there are also several other factors at play. If the current international or migration wage premium is insufficient to attract migrants, a relative decrease or increase will not lead to a significant change in flows.

To check whether the main challenges are being adequately addressed, we suggest setting out four policy objectives that would need to be reached: (i) increasing participation and employment; (ii) balanced investments in labour and capital/robots; (iii) a decrease in the job vacancy rate and (iv) increase in output. We can then assess the robustness of the labour markets and economies by testing their responses to a range of 'shocks', a selection of which – related ot automation, total factor productivity (TFP), and migration – we discuss in the subsequent parts of this section. Please note that all these 'shocks' and their impacts need to be treated as model-based scenarios of possible futures, rather than predictions of any particular economic reality.

5.1 Automation shocks

The responses (impulse-response functions, IRF) to an increase to robot productivity by one standard deviation are shown in Figure 5, with productivity shocks of German robots

[14] Future work will explore longer-horizons which will see these household shares change.

shown in Figure 5a and Polish robots in Figure 5b. Germany has clearly greater spillover effects, and robot productivity change in Germany has a contrasting effect on high-skill and low-skill migrants. The search intensity of unemployed high-skill working-age Polish workers is sensitive to the wage premium. At the wage premium in the model, there is a switch to searching in Germany, though by a fraction of the change in search intensity of low-skill workers. With changing value of the steady-state wage premium, and the steady-state value of the high-skill wage in Germany and for high-skill migrants, relative to the high-skill wage in Poland, the response of search intensity can also change. The higher the value of the wage premium, the more likely the shift to search in Germany occurs, however, for lower values, the shock in Germany can actually shift search towards Poland as the increase in the high-skill wage there can be larger.

For low-skill migrant workers, even for lower values of a steady-state wage premium, the attraction of the Germal labour market is still strong. This is an important factor to consider, as the wage premium has been closing in recent years, with a strong wage growth in Poland and relatively slower in Germany. In the future, as the wage premium closes further, the incentive to migrate will be reduced. Nevertheless, the increase in wage for the low-skill migrants, due to the large increase in value put on the employment in Germany, which increases their bargaining power, acts as an important migration driver.

As expected, significant rises in automation – and thus productivity – lead to an increase in output and GDP. The increase in productivity has expansionary effects on employment in both the high- and low-skill sectors, but due to the surge in vacancies posted, there is also an increase in labour market tightness. This increase causes upward wage pressure, but due to the increases in employment and labour hours provided in the low-skill sector, it is countered by the increase in the value of vacancies $J_{v_t}^{PL}$ and – indirectly – by the increase in automation. This results in an overall decrease in wages, aside from the low-skill migrant wage. The impact on high-skill wages is mostly leading to their increase, but with German retirees only experiencing a small change.

In the context of ageing, a positive result from the point of view of engaging older workers is the surge in participation for each of the high-skill older households. This finding is not reflected in the low-skill sector, with retirees of German natives and migrants decreasing. The change is small but the downward pressure on the low-skill wages is a contributing factor. The gap of low-skill workers is being filled by working-age migrants, as the working-age participation remains relatively unchanged. Given the increasing labour market tightness, particularly in the German low-skill sector, neither migration nor automation are able to fully close the labour gap. As the employment levels are increasing, without a significant change in participation, the rises in employment stem from the employment of the existing unemployed population.

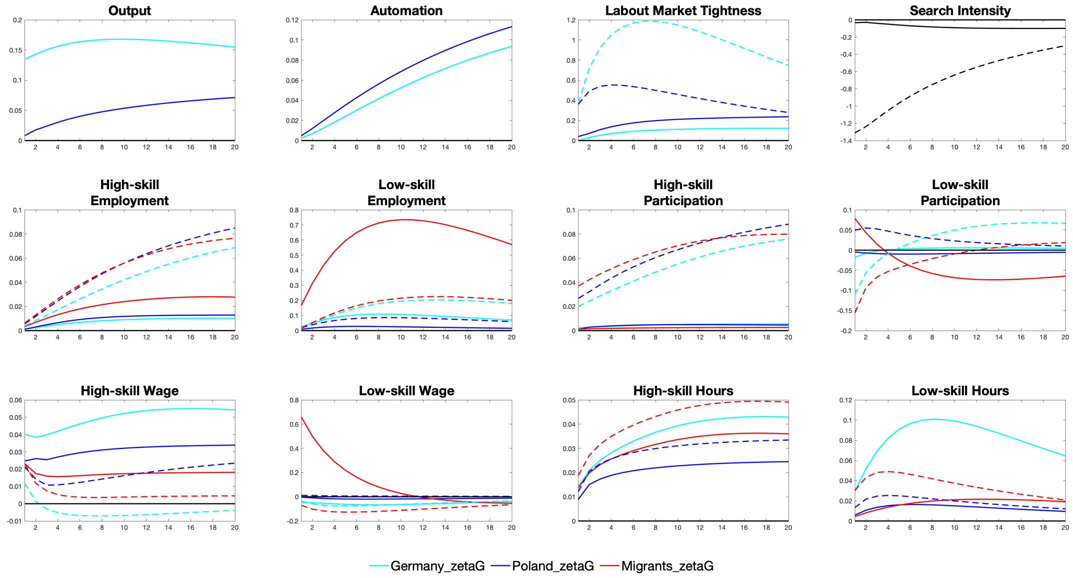
Figure 5b shows the effects of an increase in automation productivity in Poland. Due to the relative size and dominance of the German economy, there are minimal spillover effects. The reduction in working-age migrants is highly sensitive to the steady state wage premium, for the same reasons as above, but there is only a small change and for the high-skill, it is short lasting but there is a negative effect on employment of working-age migrants. For the high-skill retirees in Poland, improvements in labour market participation can be seem. It is possible that, due to emigration, a large increase in automation to replace the emigrated workers risks shifting investment in physical capital towards robots, so that the level of physical capital investment is insufficient to maintain at the current level. The policy issue that arises for Poland, and by extension countries that are senders of migrants to countries with significant wage premiums, is that the effects of any policy to increase automation levels, might inadvertently act as a driver of migration ('push factor'), which should ideally be countered with other measures.

5.2 A Total Factor Productivity (TFP) shock

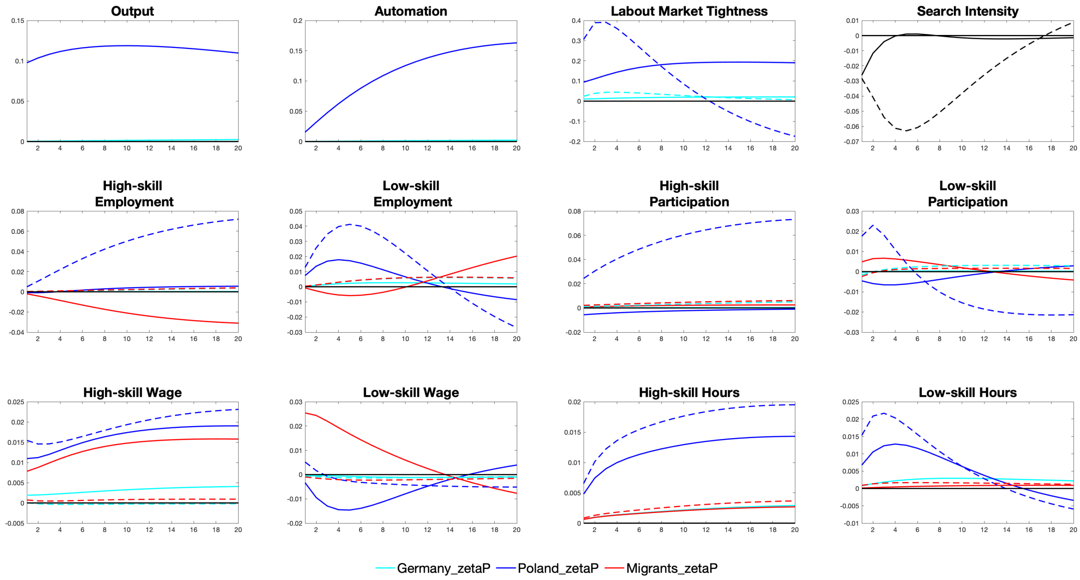
The previous section examined an increase in *robot* productivity, while a Total Factor Productivity (TFP)[15] shock examines an increase in productivity across all input factors. Following a domestic shock, there is an initial increase in the domestic absorption, which causes the trade balance to deteriorate, and consequently a decrease in financial assets held. Due to the dominant size of the German economy, relative to Poland, the spillover effects from a TFP shock in Germany to Poland are greater than in the opposite direction.

Figure 6 shows the responses to a TFP shock for Germany in Figure 6a and for Poland in Figure 6b. An increase in TFP in Germany results in an increase across all factors of

[15] In macroeconomic theory, TFP is one of the main drivers of economic (GDP) growth, net of the increases in the productivity of factors of production, such as capital or labour.



(a) A 1SD increase to Automative Productivity in Germany



(b) A 1SD increase to Automative Productivity in Poland

Figure 5: Country-Specific Automation Productivity Shocks

The figures show impulse-response functions (IRF) for a one standard deviation shock to Automative Productivity in (a) Germany and (b) Poland. The cyan line identifies Germany, the blue line is specific to Poland, and the red line identifies the migrants. For labour market tightness and search intensity, a dashed line corresponds to the low-skill sector, as opposed to the solid line for high-skill sectors. For all other household specific variables, the dashed lines identify the corresponding retiree households.

production. Rises in employment, capital, and automation see an increase in migration due to the favourability of the German labour market opportunities. There is a greater change in search intensity for low-skill migrants. This result is largely due to the effect on the wage premium, and there is no comparable effect for the high-skill workers.

Under a TFP shock scenario, migration alone proves insufficient to fill the resulting labour market shortages. With respect to the steady-state vacancy level, there is some decrease in the job vacancy rates, which is more than compensated by the additional vacancies posted as a result of the TFP shock. The effect on the labour market participation of older workers increases, with not much difference between the skill levels. There is an eventual decrease in the low-skill migrant participation rate, due to the wealth effect and increased employment levels.

Due to the increase in hours of work supplied by households to firms, there is still an overall gain in private consumption of the households that see their wages decrease. The spillover effects into Poland result in increased output, albeit at a smaller scale than in Germany. To make up for the lost low-skill workers, another response of the German economy is an increase in automation. However, the difference in productivity of the robots between the two countries is significant. The lost workers through migration are partially offset by the increased labour force participation. There are wage rises in the high-skill sector which dampen the shift in search intensity for the high-skill households. If the existing wage premium is insufficient to entice workers to move to Germany, then without a significant rise, there will not be the large response.

The results for the TFP shock in Poland are shown in Figure 6b. The dynamics on the factor inputs for Poland are very similar to those for Germany, however, due to the Poland's position of a migrant sender in this duopoly, the opportunities for migrant workers to take up the extra employment resulting from the shocks is not the same. Instead, Poland exhibits dependency on returning workers, which is a challenge, given the significance of the wage premium. In this example, there is an increase in the wage premium for the low-skilled migrants which stimulates the search intensity being strongly focused towards Germany. Most notably, the search intensity for high-skill households is positive – a switch *towards* Poland. Interestingly, there is a rise in the low-skill wage of retirees in Poland which increases their employment and participation. Their households do not have the outside option of migrating, and also due to their existing status, they hold greater bargaining power. The effects on Germany are minimal, with overall employment levels remaining steady, as the German natives take up gaps vacated by the workers. This shows that increases in wages can entice retirees back to the labour market but these cannot be so distorted to negatively impact the working-age employed population.

Even after a TFP shock, both countries are still unable to address the challenges of ageing. Although there are expansionary effects across employment (across skill and age), capital and robots, there is still significant tightness in the labour market which fails to overcome the restrictions induced by population and labour force ageing.

5.3 Migration without automation threats

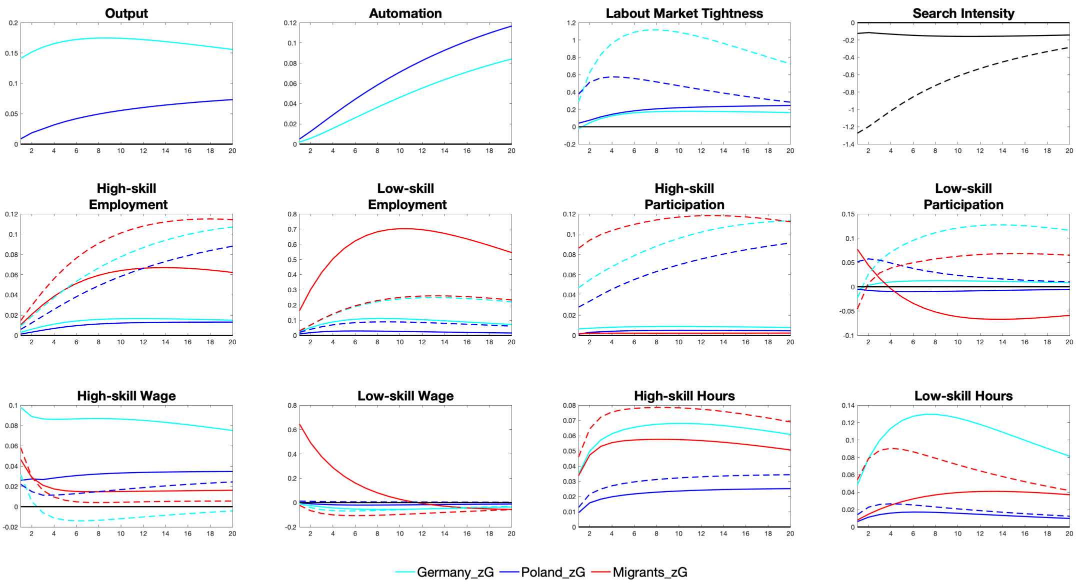
The model presented in the paper has shown that the threat of automation can weaken low-skill workers' bargaining power with respect to wages. Following automation and total productivity shocks, there would have been expansions in employment opportunities which have successfully increased participation rates, but had only short-lasting effects. As a counterfactual scenario, we eliminate the threat of automation by setting the probability of automation in both countries to their steady-state values. Since automation probability remains unchanged, we focus on the TFP shock.

In such a scenario, even with the pressures of automation set to their steady state values, some pressure on wages remains. To remove automation entirely would create a model where migration flows would not be comparable, due to the complexity of the model design. Hence, we have decided to retaining those features, while making automation probability constant (rather than zero), which enables an assessment of the impacts.

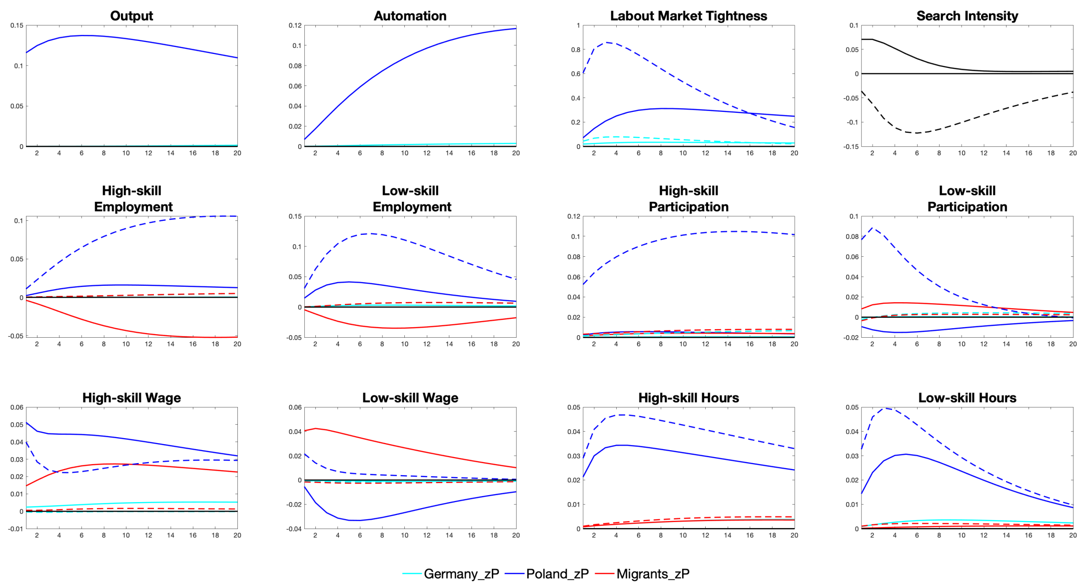
At the same time, under these assumptions, migration *increases* compared to the baseline model, though there is still a lot of competition for automation, with respect to the still-existing robots. To be in line with the rest of this report, in the context of ageing, any changes to the production sector would be driven from the labour market, so automation would not solve the challenges of ageing here, either. The dynamics from the results of a TFP shock follow through. The key conclusion from this scenario is that automation decreases low-skill migration.

5.4 Discussion

The research presented in this report has examined the interplay of migration and job automation in the context of population ageing. The results show that the increases in automation in 'Western' countries, such as Germany, will have a mixed effect on the job



(a) A 1SD increase to TFP in Germany



(b) A 1SD increase to TFP in Poland

Figure 6: Country-Specific TFP Shocks

The figures show impulse-response functions (IRF) for a one standard deviation shock to Automative Productivity in (a) Germany and (b) Poland. The cyan line identifies Germany, the blue line is specific to Poland, and the red line identifies the migrants. For labour market tightness and search intensity, a dashed line corresponds to the low-skill sector, as opposed to the solid line for high-skill sectors. For all other household specific variables, the dashed lines identify the corresponding retiree households.

searches. The overall impact of increased productivity is an important migration driver; however, for the low-skill migrants, after the wage premium and labour market effects have reduced, the incentive to migrate is also expected to decline. High-skill workers see a small shift in their intensity to work relative to the low-skill workers. Until the wage premium has declined, for both skill levels, there will be a strong incentive to migrate.

The choice of job search by households is in turn highly dependent on the steady-state wage premium. Since automation has a greater downward pressure on the low-skill wages, the flow of migration is likely to reduce with the increase in automation. However, as long as there is a large wage premium, the effect will be small. Nevertheless, neither automation nor migration are able to fully address the labour market challenges of population ageing. The different shocks do increase labour force participation in both the high- and low-skill sectors but still not to the sufficiently high levels to make a material difference. As for the downwards pressure on low-skill wages, a balance needs to be found between the value placed on vacancies and automation. If the productivity of the low-skill workers increases, the wage composition is dominated by wages. If the value of a vacancy, and thus the automation, is not included in the bargaining process, then there is upwards pressure on the wage, as in the case of high-skill workers.

A Western European country with advanced automation, such as Germany, will at least in the mid-range future retain a significant wage premium over Central and Eastern European countries, such as Poland, and indeed much of the world, so will long remain an attractive destination for migrants. Other research shows that migration alone is not a 'solution' to the challenges of ageing, and in the short to medium run, nor will be automation. However, the most economically developed countries are not the only ones to face the most advanced ageing. Some other countries, as was the case in Poland, at least until recently, do not have such high wage premiums and are not able to attract migrants to replace those that are leaving for Western Europe. One obvious policy option for such governments is that the country itself has to become more attractive for migrants, especially high-skill, especially in sectors, where qualified labour may be locally lacking.

Some of the CEE countries that are EU members, notably Czechia, Slovenia and Slovakia have progressed significantly with respect to their GDP and automation rates, but the other CEE EU member countries of the region still lag behind in both aspects. Those countries that are lagging behind have a choices either to catch up in the automation race or to fall further behind. Poland, albeit a country that has seen much progress both in terms of economic growth and (most recently) automation, is still at an increased risk of high-skill emigration and brain drain compared to other countries in Europe. Reducing the attractiveness of emigration and brain drain would be a complex task, indeed stabilising more areas of the economy and making the economy attractive to (high-)skilled workers, both local and foreign.

6 Conclusion

The main findings of the work presented in this report can be summarised as follows: the automation of jobs in the migration destination country causes a reduction in migration flows, as such, any type of shock that increases the relative productivity of robots relative to migrant workers, reduces the flows of migration to the host country due to the decrease in relative wage premium. In the opposite scenario, any change to increase the productivity of robots over workers in the origin country, and higher relative to the effects in the destination country, causes migration to increase.

Welfare effects for high-skill workers improve with higher levels of automation since, the labour of these workers and robots are complementary, however, there are small welfare losses to the low-skill workers due to reduction in bargaining power. Owing to the existing inequalities between the origin and destination countries, such as Poland and Germany, the majority of business cycle shocks cause a reduction in the differentials in automation capital. These inequalities can still relatively increase the attraction of the destination (Germany) over origin (Poland) for potential migrants.

A problem that specifically Poland is now facing, is the onward migration of many of the Ukrainian nationals who are protected under the temporary directive[16]. As reported by Zymnin et al. (2023)[17], an increasing number of Ukrainians are moving from Poland to Germany in search of higher wages. The migrants are not necessarily focused to one industry, though one of the reasons that deters Ukrainians from moving to Germany is the language barrier. It is arguable that, if a worker could be replaced by a robot, then

[16]Since the Russian invasion in February 2022, the EU policy granted Ukrainian citizens rights to stay and work in the EU (initially for a year, with possible renewal for up to three years), by applying the Temporary Protection Directive based on citizenship and residence grounds, removing the need to individually claim asylum. The temporary protection status is easier to obtain, and comes with many rights (residence, work, choice of an EU country, access to services) but is also time-limited and potentially less stable than a refugee status, which is more difficult to secure.

[17]https://ewl.com.pl/wp-content/uploads/2023/09/Report_From-Poland-to-Germany_New-trends-in-Ukrainian-refugee-migration_.pdf

the language barrier would become irrelevant. Nevertheless, the inflow of Ukrainians presented the opportunities to fill gaps in the Polish labour force, but once Ukrainians have the comfort or security – and legal options – to be able to move in search for higher wages, as is already the case with Polish natives, the problem recurs.

There are a number of policy implications from the results presented in this report. The ageing process is simply a demographic feature of contemporary European societies. Nevertheless, to maintain the ratio of active labour market participants to dependents, rather than simply focusing on the dependency ratio, a reasonable policy option is to focus on increasing the labour market participation rate, especially for working-age people. Neither robots, nor migration, offer full solutions to the challenges of ageing. In the horizon of a few years, migration can offer some solution to filling some acute labour market gaps, but it is a short-term fix. The incentive for workers to search for jobs internationally can experience a temporary increase, but is eventually expected to return to a steady-state, and in the long-run potentially decrease. At the same time, while automation could be a future problem-solver, this is not going to be a short-term fix for labour market challenges. The technology is insufficient in terms of the availability (volume) and cost: for some sectors, such as care, workers may be still preferable. In other cases, such as for high-skill jobs, automation may not be feasible or economical.

Other measures that could be introduced, as modelled here, might include flexibly changing the number of hours worked. This was a policy of some firms during the post COVID-19 recovery, increasing employee hours instead of the number of employees. In Hungary, the maximum number of overtime hours was increased from 250 to 400 in 2019.[18] even though Hungarians already work some of the longest hours each year compared to their EU-counterparts[19]. Under the EU law, employees in EU countries have the right to an average maximum workweek of 48 hours. Increasing working hours, however, is unlikely to be popular with the workers, who form a large part of the electorate. Flexible hours, or a decrease in hours, are another spillover from the pandemic. Yet another option is to increase the minimum wage, which would increase the employment of the lowest skilled workers, who have the highest non-participation rate across all skill groups.

[18] https://www.ft.com/content/a0268234-fd59-11e8-aebf-99e208d3e521, as of 29 August 2023.
[19] Source: Eurostat Table lfsa_ewhun2

With increases in minimum wages, there is a risk, though, of creating an imbalance with jobs that require some post-secondary education or training, such as craftspeople, tradespeople or social care workers. For example, large companies such as supermarkets or fast food chains can afford to pay over the minimum wage for unskilled workers, but some other companies employing the post-secondary education workers, might be unable to compete and therefore lose workers who can then change jobs in search of higher wages. This would be the start of the erosion of the skill premium, which, when migrant host countries are often in search of high-skilled labour, reduces the attractiveness relative to countries with a higher premium for skills. A reduction in the skill premium also deters future generations from following high-skilled careers, and education. In countries where a university education is expensive for students, such as the UK or US, the net payoff from achieving a tertiary education reduces. This small, yet visible deterrent has the potential shift towards needing more high-skill immigrants to fill the gaps left by natives.

Whilst the jobs most closely associated with automation are the low- and medium-skill jobs, particularly in the manufacturing industry, attempts have been made to expand this further. For high-skill workers, one archetypal example could be having computer software that works faster or is able to simplify tasks that previously workers would have to do themselves. Seen through this lens, the automation of jobs can also cause the demand for labour to expand and create further labour shortages rather than replacing existing labour leading to job losses. At the same time, the effect of high-skill robotics or artificial intelligence (AI) on the economy has only recently begun to be explored, in particular since the rise in popularity or availability of AI tools, such as ChatGPT. Early works suggest decreases in the skill premium (Bloom et al., 2023). At the same time, for all its promises, neither AI nor robots, is likely to address the challenges of ageing on its own, as is the case with migration. Still, all these solutions can be a part of a more comprehensive socio-economic policy mix, as long as they are not overly relied upon as 'magic bullets', and their limitations are clearly recognised.

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