Macroeconomic Consequences of Ageing and Directed Technological Change

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Dr. Serguei Kaniovski
Dr. Thomas Url
Österreichisches Institut für Wirtschaftsforschung

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Abstract

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Demographic projections foresee a pronounced population ageing process in the coming decades. The associated changes in quantity and quality of labour will have an impact on the long-term economic outlook. This study discusses economic implications of current demographic projections for a set of large industrialized economies, which include the largest member states of the EU, the USA and Japan, as well as Austria as an example of a small open economy. The focus of the study is the interplay between demographic and technological trends. The study extends the methodology of the European Commission's Ageing Report by considering the effects of size and composition of the working-age population on the productivity growth and productivity effect of the ICT-intensity as a measure of directed technological change.

Makroökonomische Folgen der Überalterung und des arbeitssparenden technologischen Wandels

Demographische Prognosen gehen von einem deutlichen Alterungsprozess der Bevölkerung in den kommenden Jahrzehnten aus. Die damit verbundenen Veränderungen in Quantität und Qualität der Arbeitskräfte werden sich auf die langfristigen wirtschaftlichen Perspektiven auswirken. Diese Studie untersucht die wirtschaftlichen Implikationen aktueller demografischer Prognosen für eine Reihe großer Industrieländer – die größten Mitgliedstaaten der EU, USA und Japan – und Österreich als Beispiel für eine kleine offene Volkswirtschaft. Im Mittelpunkt der Studie steht das Zusammenspiel von demografischen und technologischen Trends. Die Studie erweitert die Methodik des „Ageing Reports" der Europäischen Kommission, indem sie die Auswirkungen von Größe und Zusammensetzung der Bevölkerung im erwerbsfähigen Alter auf das Produktivitätswachstum und die Produktivitätswirkung der IKT-Intensität als Maß für den arbeitssparenden technologischen Wandel berücksichtigt.

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1 Introduction

This study discusses economic implications of current demographic projections for a set of large developed economies, focusing on the interplay between demographic and technological trends. The aim is to estimate and project the relationship between the age structure of the population and macroeconomic indicators. We consider the impact of population ageing on large developed economies such as France, Germany, Italy, Spain, USA and Japan, as well as Austria as an example of a small open economy.

Taking the European Commission Ageing Report (European Commission, 2018) as a starting point, we discuss how changes in the size (quantity) and the composition of the labour force (quality) influence investment in automation and digitisation (proxied by the share of information and communication technologies and software in the total capital stock), aggregate saving and growth of total factor productivity. Both the quantity and the quality effect have ambiguous consequences for long-term output growth. While a shrinking working-age population potentially reduces future labour supply, it may simultaneously provide an incentive for labour-substituting investment in automation technology, as a result increasing productivity. Similarly, while the increasing relative share of workers in the 55–65 age group is likely to reduce average labour productivity, it may also induce investment in automation and digitisation, eventually improving productivity. In addition to the effects on productivity growth, we consider the impact of ageing on investment, output growth, current account, aggregate saving and consumer price inflation.

In most cases, demographic trends occur slowly over time. Only large waves of immigration can create unexpected variation in demographic indicators. Consequently, population forecasts typically assume smooth developments for fertility and mortality rates, and they usually incorporate smooth migration patterns. One of the most persistent patterns emerging in population forecasts is a marked process of ageing in industrialized countries. Ageing will change the size of the working-age population. Gradual declines in fertility rates imply that large cohorts that retire will be followed by smaller cohorts. Ageing will shift the composition of the working-age population by lowering the share of young and middle-aged cohorts relative to older ones. In the case of industrialized countries both developments coincide.

The consequences of ageing on public spending have received considerable attention in economic literature and policy debate. Population ageing increases age-related public spending (Gruber – Wise, 1998; Bloom et al., 2010; CBO, 2019; European Commission, 2018). But the economic literature has also pointed out the subtler relationship between age and individual productivity (Verhaegen – Salthouse, 1997; Skirbekk, 2004, 2005). Studies based on microeconomic data have shown a hump-shaped relationship between age and productivity, indicating that individual productivity peaks well before the end of the economically active age. This relationship is likely to persist in view of the increasing complexity of the working environment and tasks, as well as foreseeable increases of statutory retirement ages. The empirical evidence shows that individual productivity peaks around the age of 50.

The evolution of individual human capital and the individual capacity to innovate change over the course of a career, typically resulting in hump-shaped lifetime individual productivity profiles. Training and experience augment human capital early on, increasing individual productivity. However, incentives to human capital accumulation vary over a lifetime, depending on the relation between the present value of investment costs and the present value of additional expected income (Becker, 1975). Fixed investment costs imply that the expected total return to investment in human capital should decrease with age, as the number of years over which the gains accrue diminishes. The incentive to improve human capital will thus decrease with age. The above appears to apply even more to the individual capacity to innovate. Since the individual capacity to innovate appears to reach its apex during younger ages, we should expect population ageing to diminish the innovative capacity of a society (Canton et al., 2002; Irmen – Litina, 2016).

Physical and cognitive abilities decrease with age, thus decreasing individual productivity. Studies by Skirbekk (2005, 2008) provide psychological and physiological evidence on lifetime productivity profiles. Productivity improves until age 25 and stays at an elevated level until age 45. Beyond this age, cognitive abilities, inductive reasoning and retentiveness start to decline, whereas reaction times tend to increase (Verhaegen – Salthouse, 1997; Skirbekk, 2004, 2005). This is a universal phenomenon common to all societies, sexes and people of different abilities. Training programs can slow or even halt the decline, but they are not universally available and not equally effective.

While the effects of changes in the quantity and the quality of labour on technical progress are complex, with several factors working in opposite directions, we would expect a negative productivity effect of ageing, which may be partially or fully offset by using more and better physical capital as the man-made means of production. The aim of this report is to estimate and forecast the relationship between the age structure of the population and the macroeconomic indicators, such as productivity and output, with an explicit focus on the productivity effect of the ICT intensity as a measure of directed technological change.

The report is divided into seven chapters and a comprehensive technical appendix. Following this introduction, Chapter 2 conveys the essence of the analysis presented by the European Commission in the EU-Ageing Report 2018 (European Commission, 2018). The Ageing Report provides a backdrop for the discussion of the recent economic literature on the ageing-productivity-automation nexus in Chapter 3, and the current demographic outlook in Chapter 4. The study extends the methodology of the Ageing Report by considering the effects of size and composition of the working-age population on the growth of total factor productivity, including the interplay between demographic trends and investment in automation and digitisation. The projections based on this extension are presented in Chapter 5, with technical details regarding the estimation and the projection methodology relegated to Appendix A. The final Chapter 6 offers concluding remarks.

2 EU-Ageing Report

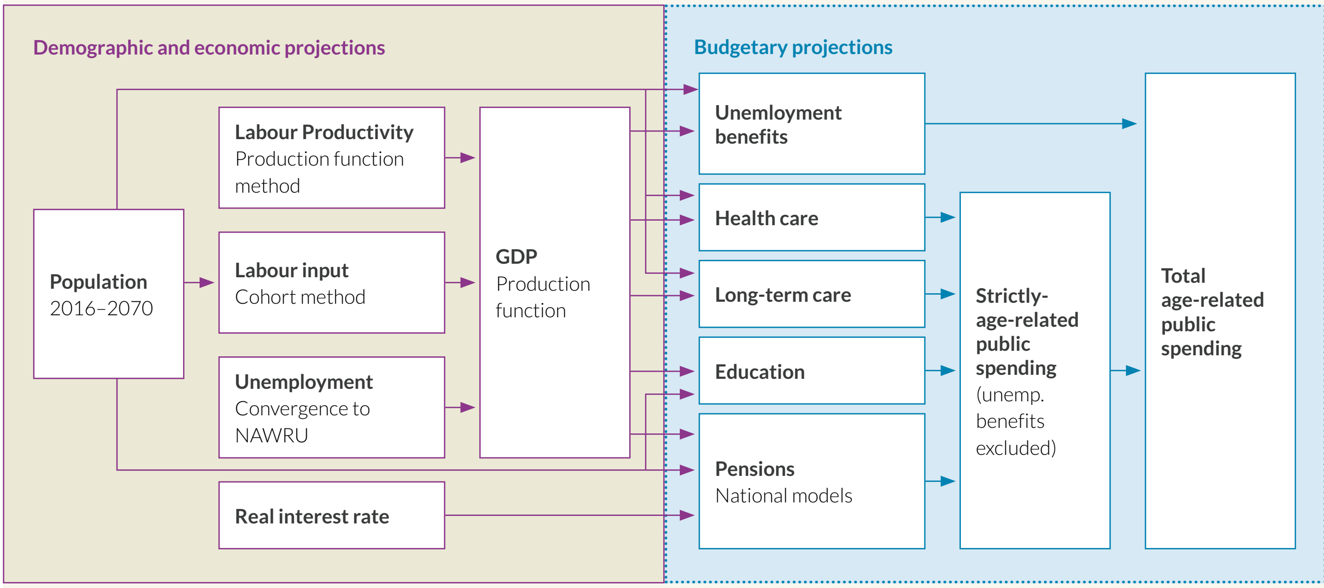
The first EU-Ageing report was published in 2009 (European Commission, 2009). This report was first envisaged by the European Council in 2001, when at the Stockholm meeting the council asked for a regular review of the long-term sustainability of public finances with respect to the expected tension created by projected changes in the population size and its structure. The European Policy Committee (EPC) created the Ageing Working Group (AWG), in which experts from the 27 member states, Norway, and the European Commission developed the set of assumptions underlying the report and coordinated national computations with the analysis and calculations provided by DG ECFIN. The report is supposed to highlight immediate and future policy challenges for the EU28 governments based on current projected demographic trends, compiled in a comparable and transparent manner. The projections feed into the European Semester, specifically, the Medium-Term budgetary Objectives (MTO) and the annual assessment of the sustainability of public finances within the Stability and Growth Pact. Four issues of the EU-Ageing report have been published to date; the latest as European Commission (2018) based on the 2016 Eurostat population projection.

The ageing report is centred around the main request by the council to analyse the long-term sustainability of the public budget. The parts on public spending summarise projections for spending categories that depend on the age structure of the population, such as unemployment benefits, health care, long-term care, education, and pension benefits (Figure 2.1). These are projected for each participating country based on recent population forecasts by Eurostat, a country-specific macroeconomic scenario, and a no-policy-change assumption. With respect to our topic, the underlying macroeconomic scenarios of the EU-Ageing report provide an interesting benchmark, because the discussion of economic and social policy issues at the European and national level, as well as national budgetary planning, respond to the projections presented in the EU-Ageing report.

As shown in Figure 2.1, the macroeconomic scenario comprises assumptions on the development of labour productivity, the labour force, and unemployment levels, which are combined through a production function to produce projections for gross domestic output, the wage bill and other economic variables influencing public revenues and spending. The real interest rate is fixed at a constant value. The output of the macroeconomic scenario provides the economic framework for the budgetary projections of the EU-Ageing report and the country assessments of the long-term sustainability of public finances by the European Commission.

Table 2.1 presents the most relevant demographic data for the European countries in our sample for which projection have been made in the EU-Ageing report. According to the Eurostat 2016 population projection, Austria, France, and Spain expected a growing total population between 2018 and 2060; only France also showed an increase in the working-age population. The total population in Germany and Italy was expected to decline, giving rise to a more pronounced drop in their working-age population. On top of the declining working-age population, all countries faced a structural change towards younger cohorts (15–24). This development was most pronounced in Spain, whereas Austria remained almost unaffected.

FIGURE 2.1 **Overview of the European Commission long-term projection exercise used for the EU Ageing report**



Source: European Commission (2018).

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TABLE 2.1 **Projected development of the total population, the working-age population and the population structure between 2018 and 2060**

	Total population	Working-age population	Share of ... in working age population		
			young	middle	old
	Change in %		Change in percentage points		
Austria	15.6	−1.6	0.4	−2.5	2.1
France	12.3	4.5	1.0	−0.1	−0.9
Germany	−2.8	−17.3	1.2	−1.0	−0.2
Italy	−6.3	−20.3	1.5	−3.4	1.8
Spain	6.6	−10.9	5.9	−4.4	−1.5

Source: Eurostat. 2016 projections. Young are 15–24 years old, middle are 25–54 years old, old are 55–64 years old, and the working-age population is aged between 15–64 years.

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Most of the gains in the younger cohorts came from a decline in middle-aged cohorts (25–54) with Spain and Italy showing the strongest shifts while France faced a stagnating share of this age group. By now, Eurostat and the United Nations published new demographic projections which will be the basis of the analysis in the study at hand.

According to individual productivity measurements collected in Skirbekk (2004, 2005, 2008), this shift could have a negative aggregate impact on labour productivity, because life-time productivity profiles are hump-shaped, and their peaks are around the age 40 and 50. France was the only country where most of the change in the age structure resulted from a reduced size of the oldest cohort (55–64). Austria and Italy, on the other hand, were the only countries in the sample for which Eurostat in 2016 expected an ageing working-age population.

The approach to compute the macroeconomic scenario used by the AWG and the European Commission starts with the labour force projection. Based on the dynamic cohort model of the OECD (Burnieaux et al., 2003; Carone, 2005), historical participation rates for females and males are used to generate values for the future, integrating the cohort dynamics of the past ten years. This approach gives constant steady state participation rates after a transition period of 45 years. Additionally, the AWG incorporates the likely outcome of future pension reforms on the labour market. Particularly the supply of older cohorts will increase if the mandatory retirement age increases or early retirement schemes become less accessible. The result from combining the dynamic cohort model with the estimated effects of pension reforms is presented in Table 2.2. The participation rate in the youngest age group (20–24) was expected to increase except for male Austrians, who were expected to slightly reduce their labour supply, and female Italians, whose labour supply was expected to remain constant. Females in the prime age and the old age group should increase their labour supply in all countries, particularly so in the oldest age group, where Spain and Italy recorded an impressive upswing between 2016 and 2070. This was mainly due to pension reforms. Higher levels of educational attainment of the younger cohorts will also push the future aggregate supply of labour upwards (Url et al., 2016).

Multiplying participation rates with the respective population age groups and summing over all ages gives the labour supply measured in persons. The next step is to compute the number of employed persons by subtracting the unemployed from labour supply. For this purpose, the European Commission takes current unemployment rates and its recent economic forecasts and combines these values with estimates of country-specific long-run anchor values for the Non-Accelerating Wage Rate of Unemployment (NAWRU). These estimates depend on the income replacement rate of the unemployment insurance scheme, the extent of active labour market policy, an indicator of labour market protection, and the tax wedge resulting from taxes and social security contributions. Countries with an unemployment rate above the EU-median level are supposed to converge towards the median. If the country-specific value in 2016 was below the median, the country would converge to its anchor value. The long-run values for the NAWRU in our sample are presented in Table 2.3. While

TABLE 2.2 **Development of participation rates in the EU-Ageing Report 2018, in %**

	Young	Prime age	Old	Young	Prime age	Old
		2016			2070	
Male						
Austria	75.5	91.8	61.2	75.3	91.6	63.5
France	66.4	92.4	56.0	67.1	91.4	70.9
Germany	69.8	92.0	77.1	70.6	89.9	74.5
Italy	51.8	88.2	65.9	52.0	85.3	78.6
Spain	57.7	92.5	67.0	57.9	91.2	79.7
Female						
Austria	72.2	84.9	42.7	74.3	89.5	59.1
France	58.2	82.7	51.3	59.3	84.4	65.4
Germany	66.6	82.7	65.9	67.8	84.9	73.8
Italy	39.4	66.8	41.7	39.4	67.4	67.5
Spain	52.4	82.3	51.7	52.5	88.1	83.9

Source: European Commission (2017). Young are 20–24 years old, prime age are 25–54 years old, old are 55–64 years old.

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France, Italy and Spain slowly converge from high levels of unemployment towards the EU-median level, Austria converges from a cyclically high unemployment rate to a lower long-run value. Germany, on the other hand, starts from a favorable labour market position and is expected to experience a small increase compared to the starting year.

The last step for the computation of the labour input in the production function used information on age- and sex-specific working time for full- and part-time workers, respectively. The European Commission used the number of working hours and the share of part-time workers from the year 2016 and fixed these values for the whole projection period. Future population dynamics and increasing participation rates produce variations in the aggregate numbers presented in Table 2.4. The share of part- and full-time workers increased a little in Austria, Germany, and Spain. It remained constant for France, while it was falling in Italy (cf. Table 2.4). This development depends mainly on the rising participation rate of women and their high take-up rate for part-time jobs. Throughout the EU28, total hours worked were expected to decline by 5 percent over the entire period from 2016 to 2070.

Finally, the AWG assumes the long-term rate of growth for Harrod-neutral labour augmenting technical progress. The central assumption is the convergence of all countries towards a common value of growth in total factor productivity of 1 percent per year, cf. Table 2.5. Because the labour share was assumed constant at 0.65, this corresponds to a growth in labour productivity of 1.5 percent annually. Countries start from various initial positions below or above this long-term growth rate, depending on their position in the business cycle. This position corresponds to the short-term forecasts of the European Commission and will converge afterwards in consistency with the medium-term projections, which are based on country-specific trends. For example, Italy was expected to experience a decline in productivity

TABLE 2.3 **Development of the unemployment rate in the EU-Ageing Report 2018, in %**

	2016	2026	2050	2070
Austria	6.1	4.9	4.9	4.9
France	10.2	8.7	7.9	7.9
Germany	4.2	4.8	4.8	4.8
Italy	11.9	9.1	7.9	7.9
Spain	19.7	15.4	7.9	7.9

Source: European Commission (2017). | BertelsmannStiftung

TABLE 2.4 **Development of weekly working hours and part-time ratios in the EU-Ageing report 2018**

	Weekly working hours	Part-time ratio (total) in %		
		2016	2030	2070
Germany	33.9	14.5	14.8	14.9
France	32.1	11.3	11.5	11.3
Spain	29.9	7.8	8.1	8.4
Italy	32.1	10.6	10.4	10.3
Austria	33.0	15.8	15.8	16.2

Source: European Commission (2017). The weekly working hours are average working hours per week. | BertelsmannStiftung

TABLE 2.5 **Development of total factor productivity growth in the EU-Ageing Report 2018, in %**

	2016–2020	2021–2030	2031–2040	2041–2050	2061–2070
Germany	0.9	0.9	0.9	1.0	1.0
France	0.4	0.6	0.8	1.0	1.0
Spain	0.4	0.6	0.8	1.0	1.0
Italy	–0.1	0.2	0.6	1.0	1.0
Austria	0.6	0.8	0.9	1.0	1.0

Source: European Commission (2017). Average rate of change over the period. | BertelsmannStiftung

TABLE 2.6 **Development of potential output in the EU-Ageing Report 2018, in %**

	2016–2020	2021–2030	2031–2040	2061–2070
Austria	1.5	1.7	1.7	1.3
France	1.2	1.1	1.4	1.7
Germany	1.6	1.1	1.0	1.2
Italy	0.2	0.5	0.4	1.3
Spain	0.8	1.2	1.1	2.1

Source: European Commission (2017). Average rate of change over the period. | BertelsmannStiftung

during 2016 through 2020, while Germany was already very close to the long-term value. The speed of convergence was determined by the level of per-capita GDP in 2016. Countries below the EU-average converge depending on their distance to the EU-average. The convergence process was to be accomplished in 2045 at the earliest.

The capital stock develops in accordance with the sum of the growth rate of total hours worked and the change in labour productivity, i.e. there will be no capital deepening in the macroeconomic scenario, rather the capital-to-output ratio will remain constant over time.

Given these assumptions and the Cobb-Douglas production technology, the path for potential output growth was very similar to the assumed rate of total factor productivity growth.

Table 2.6 shows that Germany and Austria start from comparatively high growth of potential output and converge from above to their long-run values. Italy, Spain, and France started from a weaker position in the years 2016 to 2020 and followed a catch-up process towards higher long-run growth rates. Italy was expected to need more than three decades to achieve potential output growth of more than 1 percent per year.

We will retain all assumptions made in the EU-Ageing report 2018 regarding the development on the labour market. We will only deviate from the EPC-approach by allowing for an interaction between ageing and investment in automation and digitisation induced by more rapid population ageing and the expected decline in the working-age population. We also want to include Japan and the USA in our analysis. Both countries are not covered in the EU-Ageing report, so we will apply the EU-Commission method to compute the potential output and extract the trend growth rate for total factor productivity from the time series for gross domestic output in both cases.

3 Ageing and Directed Technical Change

Firms are likely to respond to the expected shrinking of the labour force and its changing composition by substituting labour by capital. This requires additional investment and results in more machinery per unit of labour – i.e. the ratio of capital to hours worked increases over time and the production process becomes more capital-intensive. This process is called capital deepening and is best illustrated by looking at the history of agricultural production, where labour has been replaced by tractors, combine harvesters, milking robots, electronic pest detection systems, automated animal fattening plants and other sorts of capital. During the last couple of years, a similar development takes place among white-collar workers. Jobs in logistics, project management, retail trade, map drawing, accounting and many other activities are replaced by hardware and software.

This process of automation and digitisation cannot be modelled within the canonical Solow growth model featuring a Cobb-Douglas technology (Solow, 1956, Swan, 1956). The Cobb-Douglas technology directly relates factors of production, like labour, L, and capital, K, to the output of goods and services, Y, using a production function like

$$Y = f(A^k K, A^l L),$$

where A is a symbol for factor-augmenting technological progress, either enhancing the productivity of capital (A^k) or the productivity of labour (A^l). Variations of this approach are popular in Solow-type growth models assuming exogenous technological progress (Mankiw et al., 1992). Endogenous growth models added the stock of ideas (Romer, 1990) or the stock of human capital (Lucas, 1988) to the traditional inputs: capital and labour. Grossman – Helpman (1991) also stressed innovation in terms of new goods and services that satisfy an insatiable demand for new varieties. In this model class an increase in the amount of capital per worker will usually result in a higher share of income allocated to capital, i.e. a shift in the income distribution from labour towards capital. On the one hand, this contradicts the long-term stylised facts recognised by Kaldor (1961) and updated by Jones – Romer (2010), but it somehow reflects the experience of the last decade with a hollowing out of middle-income jobs and the city-premium for blue-collar workers in densely populated areas Autor (2019).

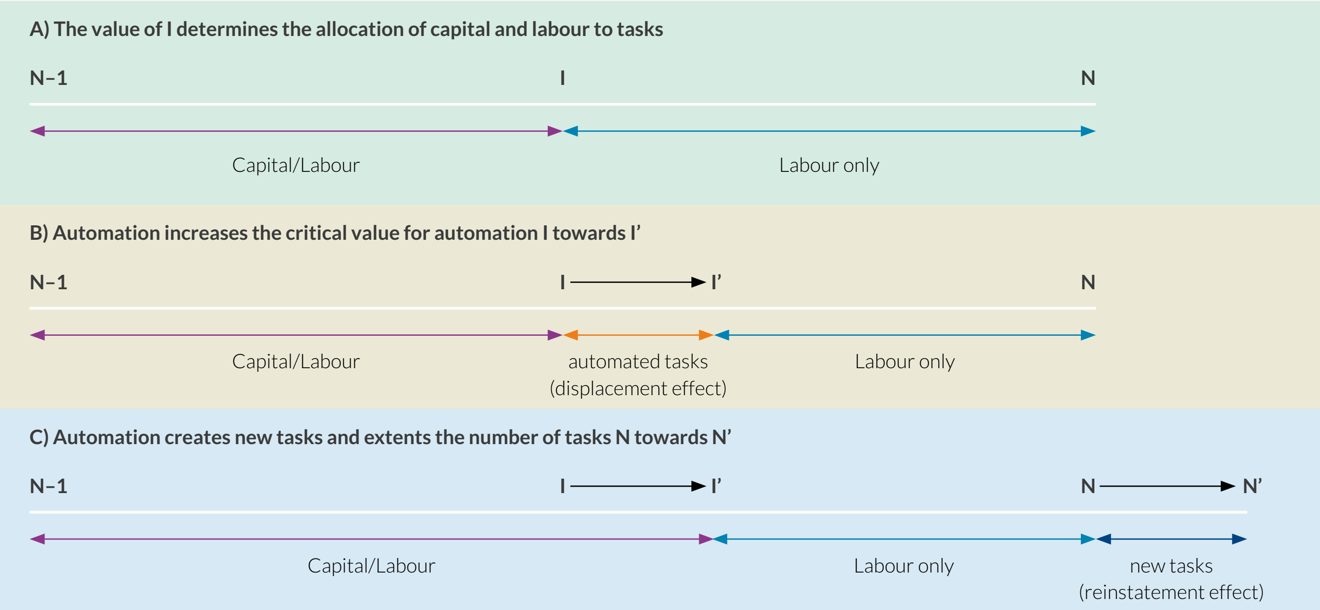
Acemoglu – Restrepo (2019A) instead suggest an endogenous growth model featuring a technology that uses tasks in combination with intermediate inputs to produce goods and services. They add an additional layer to the production process by introducing tasks and explain this new concept on the example of T-shirts' production. The first task in the production of T-shirts is their design. In production one can distinguish tasks like the extraction of fibres, the spinning of fibres into yarn, weaving, knitting, dyeing, and packaging. In the service area there are accounting, marketing, transportation, and sales activities, which can be considered as separate tasks, each requiring different combinations of labour and capital to be performed (Acemoglu – Restrepo, 2019B). Automation adopts newly developed technologies and substitutes capital for labour in the performance of a task. In the extreme case of full automation, a task will be completed by machines or software only and labour will be fully displaced. The displacement effect describes the consequence of making labour redundant in the performance of a task and it implies lower labour demand and a smaller share of labour in value added of this industry. If only the displacement effect is at work, the set of tasks for which labour would be needed shrinks with the ongoing implementation of new technologies. The extreme case would be a fully automated way to produce goods and services.

Automation and digitisation allocate tasks more flexibly to factors and thereby increase productivity. The productivity effect in turn powers aggregate demand for goods and services and thus also the demand for those tasks still using labour. Nevertheless, the productivity effect is unlikely to fully counterbalance job destruction resulting from automation. An important additional countervailing effect results from newly developed technologies creating new tasks featuring a comparative advantage for labour. Acemoglu – Restrepo (2019B) mention the disappearance of some white-collar jobs due to the implementation of new computing power and software. Although digitisation replaces some tasks, it contemporaneously creates many new tasks like programming, data base design and management, maintenance of high-tech equipment, or computer security, among others. Acemoglu and Restrepo call this type of automation-induced job creation the reinstatement effect. By creating new tasks with a comparative advantage for labour, labour is reinstated into a broader range of tasks and consequently labour demand increases. If the displacement effect were balanced by the productivity and the reinstatement effect together, Kaldor's observation of a stable share of labour in income would emerge.

We illustrate the consequences of automation in Figure 3.1. Production combines the output of a range of tasks that is shown as the horizontal line in panel A of Figure 3.1. The length of this line indicates the total range of tasks and it is normalised between N-1 and N. Tasks can be produced either by a combination of capital and labour or by labour only. For tasks above the critical value I, labour has a comparative and absolute advantage, such that these tasks are not automated. We assume that it is cost minimising for firms that all tasks below I are automated and produced by a combination of labour and capital. The introduction of a new technology shifts the critical value to the right. In panel B the critical value I increases to I', creating more automated tasks. Industries affected by automation will shed labour and replace it by machines or software (displacement effect). Panel C shows the countervailing effect of new additional tasks, having a comparative and absolute cost advantage for labour, as an extension of the range of tasks from N–1 to N towards N–1 to N'. New labour-intensive tasks create additional demand for labour (reinstatement effect) and increase the share of labour in value added, with new jobs created in other, perhaps new, industries.

Automation and digitisation can also be a response to actual or expected labour scarcity. In this case, the displacement effect can be used to save labour input. Acemoglu – Restrepo (2017) use this argument to explain the missing empirical relation between the growth rate of per-capita GDP and population ageing. If the shrinking labour force results in lower value added, GDP per capita would decrease because pensioners stop working while they are still part of the population. A cross-plot of both variables shows an unstructured cloud, and even separating between developed and developing countries does not result in a clear picture. More automation and a more capital-intensive production are possible explanations because this would allow higher levels of output for a given amount of labour. Acemoglu – Restrepo (2019A) model the relation between demographic change and automation, concentrating on manufacturing and middle-aged blue-collar workers. They chose the age limit for middle-aged workers as between 21 and 55, because this age group is more likely to be substituted by robots. The tasks typically replaced by robots require strength and physical dexterity from workers, hence they are performed by middle-aged rather than older workers. The applications for industrial robots in manufacturing are aimed at replacing labour-intensive tasks and they increase productivity. Acemoglu – Restrepo (2017) show that countries with a rapidly ageing work force, e.g. South Korea, Germany, and Denmark, increase the number of robots per hour worked much faster than countries ageing at a slower pace.

FIGURE 3.1 **The consequences of automation on the use of capital and labour**



Source: Authors building on Acemoglu-Restrepo (2017). Production requires the performance of tasks, normalised in the range N–1 and N. For tasks above the critical value I, labour has a comparative advantage such that these tasks are not automated. Tasks below I are automated and produced by a combination of labour and capital. The introduction of new technology shifts the critical value from I to I' creating more automation (displacement effect) and to new additional tasks with a comparative cast advantage for labour (reinstatement effect).

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The endogenous growth model by Acemoglu – Restrepo (2019A) is based on a production function that combines tasks with services provided by older workers (56 and older) and intermediate goods. The tasks themselves are performed by combining labour input from middle-aged workers and capital. We will not go through the mathematics of the model and refer the reader to the original text. Instead, we focus on the implications of automation on productivity. In their model, the ageing of the workforce will increase productivity in industries with greater opportunities for automation relative to industries with smaller potential for automation. Value added in these industries will also show a declining labour share, although wages for middle-aged workers go up due to the relative scarcity. Because of higher wages, industries relying more intensively on middle-aged workers have stronger incentives to invest in automation and increase productivity. The overall effect of ageing on productivity is nevertheless ambiguous.

In their empirical application Acemoglu – Restrepo (2019A) use indicators for automation such as the stock and number of newly installed robots per 1000 manufacturing workers, imports or exports of robots and other automation-related machinery (numerically controlled machines, automatic welding machines, automatic machine tools, weaving and knitting machines, and various dedicated industrial machines), and robotics-related patents. To eliminate business cycle variations and account for the long investment horizon for industrial robots, they use long-term growth rates between 1990 and 2015 in their regressions. The explanatory variables in a cross section of developed and developing countries are forward-looking demographic variables, e.g. the change in the ratio of older to middle-aged workers between 1990 and 2025, region dummies (World Bank regions), initial log in per capita GDP, the log population, and the average years of schooling. They estimate cross section regressions in long-differences using the birth rates of the 1960, 1965, 1970, 1975, and 1980 cohorts as instruments for demographic variables, thus purging it from endogenous variations in population due to migration or changing mortality, which could respond to changes in per capita GDP, cf. Table 1 in Acemoglu – Restrepo (2019A). The estimates reveal a positive and statistically significant relationship between population ageing and automation in the full sample; the estimates for the sample of OECD members are smaller and insignificant. The results from a sensitivity analysis using bilateral trade data, imports, and exports of automation technologies are similar. It is interesting that Acemoglu and Restrepo consider computers – together with manual machine tools and non-automatic machines as labour augmenting technology rather than automation capital. This interpretation, however, could be a result of their focus on manufacturing rather than the service sector, where computerisation is expected to result in a reduction of routine-based labour input (Bonin et al., 2015; Arnold et al., 2016; Frey – Osborne, 2017).

While Acemoglu and Restrepo focus on the structure of the working-age population, Abeliansky – Prettner (2017) integrate the shrinking working-age population directly into a Solow-type growth model assuming a constant savings rate, inelastic labour supply, full employment, and time periods with a length of 25 years. Firms combine three factors of production: human labour, traditional capital (machines, assembly lines, buildings, automobiles), and automation capital (robots, 3-D-printers, driverless cars). The critical assumption in their model is the degree of substitutability between labour and both types of capital. Whereas traditional capital is an imperfect substitute for labour, automation capital is a perfect substitute. Thus, automation capital takes the role of a production factor that can be accumulated and that is perfectly substitutable for labour. Once a task is automated, human labour becomes part of a reproducible factor. Aggregate saving is a constant fraction of wage income and can be saved either by investing in traditional capital or by accumulating automation capital. A no-arbitrage condition between both types of capital implies that their returns are equal. In this set-up, automation and digitisation offer an opportunity to counteract the expected labour shortages in demographic forecasts.

Abeliansky – Prettner (2017) use a simple Cobb-Douglas production function with labour and automation capital forming perfect substitutes and traditional capital being an imperfect substitute. This model structure has the effect that investment in automation capital reduces the marginal product of labour while simultaneously increasing the marginal product of traditional capital. If the exogenous savings ratio is large enough, sustainable accumulation of automation capital sets in and labour productivity (measured as output per worker) grows over time without assuming factor-augmenting technological progress. The level of output per-capita depends on the parameters of the Cobb-Douglas production function and increases with higher automation density, i.e. more automation capital per worker. The automation density in this model is endogenous and depends on the parameters of the production function, the lagged automation density, the rate of growth of the population, and the savings rate. An interesting proposition by Abeliansky – Prettner (2017) is that, within their model, a country with lower population growth will always have a higher automation density. The intuition of this result relies on the relative rate of return on investment in automation capital as compared to the rate of return on traditional capital. While the return on automation capital is higher in countries with stable or shrinking populations, the return on traditional capital is lower in these countries. In countries with a rising population, on the other hand, the relative returns are the other way around. Examples for a potentially low return on automation capital are African countries with a low stock of traditional capital and high population growth creating a low return on automation capital. Ageing industrial countries face the opposite situation with a shrinking working-age population and potentially high returns on automation capital.

Abeliansky – Prettner (2017) test the model predictions on the growth rate of installed robots in a panel of 60 countries with 3-year time averages of the data, providing them with 7 periods between 1993 and 2013. They control for the population rate of change and add the investment share in GDP, per-capita income in the starting year of the panel, a measure of openness to international trade, and the gross enrolment ratio in secondary school to their model. In several different specifications the relation between the change in the robot density and population growth is significantly negative.

The theoretical relation between demographic variables and robot density (Acemoglu – Restrepo, 2019A; Abeliansky – Prettner, 2017) motivates our empirical approach to model trend TFP growth as a function of the demographic structure and the expected future size of the population of a country.

Before going into the details of the empirical implementation, we will present the current population projections for our sample of countries in the following section and show that most countries will experience a smaller working-age population and a sizeable shift in its structure.

4 Current Demographic Projections

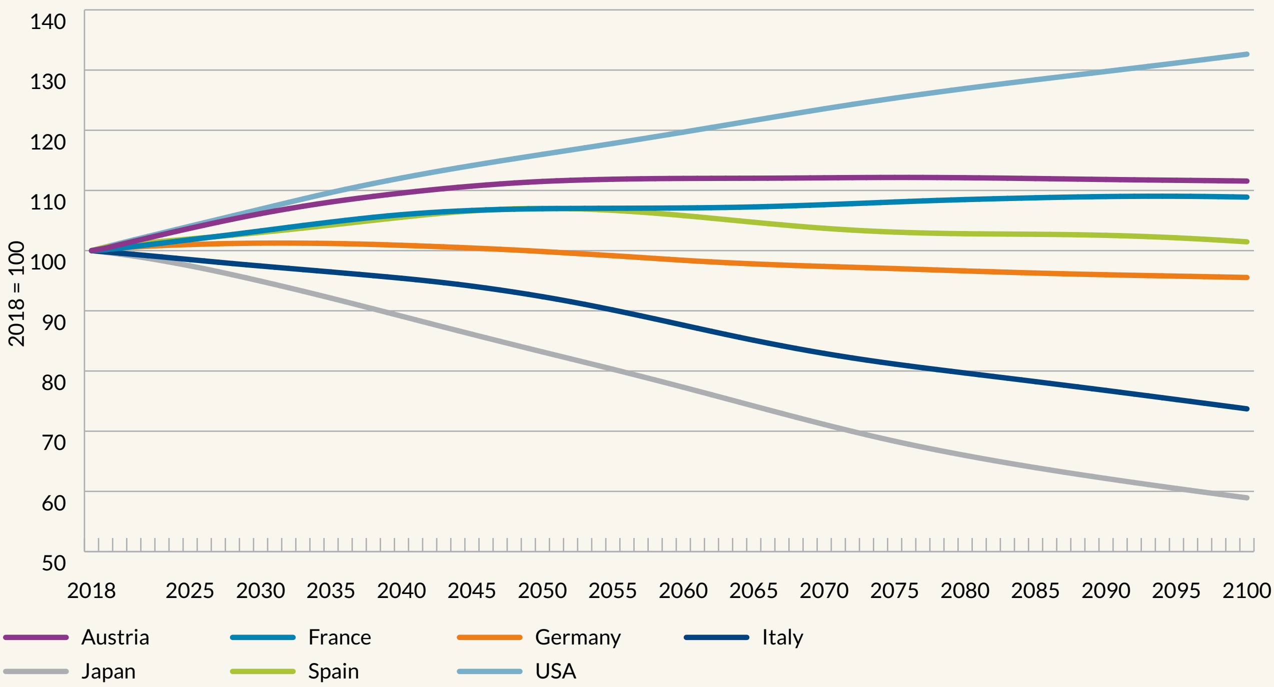
In July 2019 Eurostat presented a new set of population projections based on realisations up to 1 January 2018 and on updated assumptions on fertility, mortality and new net migration patterns. The projection horizon starts in 2018 and covers the period up to 2100. Eurostat applies a deterministic projection method, which shows how the size and structure of the population changes over time if the assumptions made on fertility, mortality, and migration prove true. The fertility rate, for example, will recover throughout Europe and converges towards 1.75. Mortality rates will further decline, with the average life expectancy at birth increasing by almost 10 years, and net migration will be positive in all member states from 2030 onwards.

Over the next 80 years Eurostat expects a fluctuating population size resulting in a small increase in the population by 2040 towards 525 mio. persons; afterwards, a decline will set in, resulting in 493 mio. persons in the year 2100. The changing size of the population will be accompanied by a pronounced shift in its age structure towards a more elderly society. We use the 2019 Eurostat projections for all European countries in our sample. The other two big industrial countries in our sample are Japan and the USA. For these countries we use the United Nations world population prospects 2019. While the United Nations projection expects an increasing population for the USA, the Japanese population will decline over the next 80 years.

Figure 4.1 provides an illustration of the population development for the big industrial European countries Japan, the USA, and Austria. Given the different size of their populations we normalise the total population for each country such that the value in the base year 2018 is equal to 100. A growing population after 2018 will result in a value above 100 and a declining population will be represented by a value below 100. In Figure 4.1 two countries, Italy (−26.3 percent) and Japan (−41.1 percent), stand out with the magnitude of their population decline between 2018 and 2100. The other extreme case is the US population (+32.6 percent) with a marked increase. The big European countries either show a modest decline (Germany: −4.5 percent) or moderate growth (Spain: +1.5 percent; France: +8.9 percent; Austria: +11.6 percent) in their total population numbers.

We define the working-age population in accordance with the OECD as all persons aged between 15 and 64. This group provides the pool for the labour supply of an economy. The dynamic of expected size of the working-age population is comparable to that of the total population, cf. Figure 4.2. Italy, Japan, and the USA are again forming the extreme boundaries on the bottom and top of Figure 4.2, while the remaining European countries lie in between. Figure 4.2 also shows historical data going back to 1980 and by normalising again with respect to the base year 2018 we can show that Japan is an extreme example somehow leading the other industrial countries. The working-age population in Japan peaked around 1995 and has since declined. The United Nation's forecast does not expect a reversal of this movement within the projection horizon. Germany shows a similar hump-shaped pattern with a peak around 1998 followed by a modest decline. Between 2011 and 2015, however, the German working-age population took a break and stabilised. After 2020 the Germany population development shows a more wave-like pattern. A comparison of Eurostat population

FIGURE 4.1 **Expected development of total population, 2018–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database.

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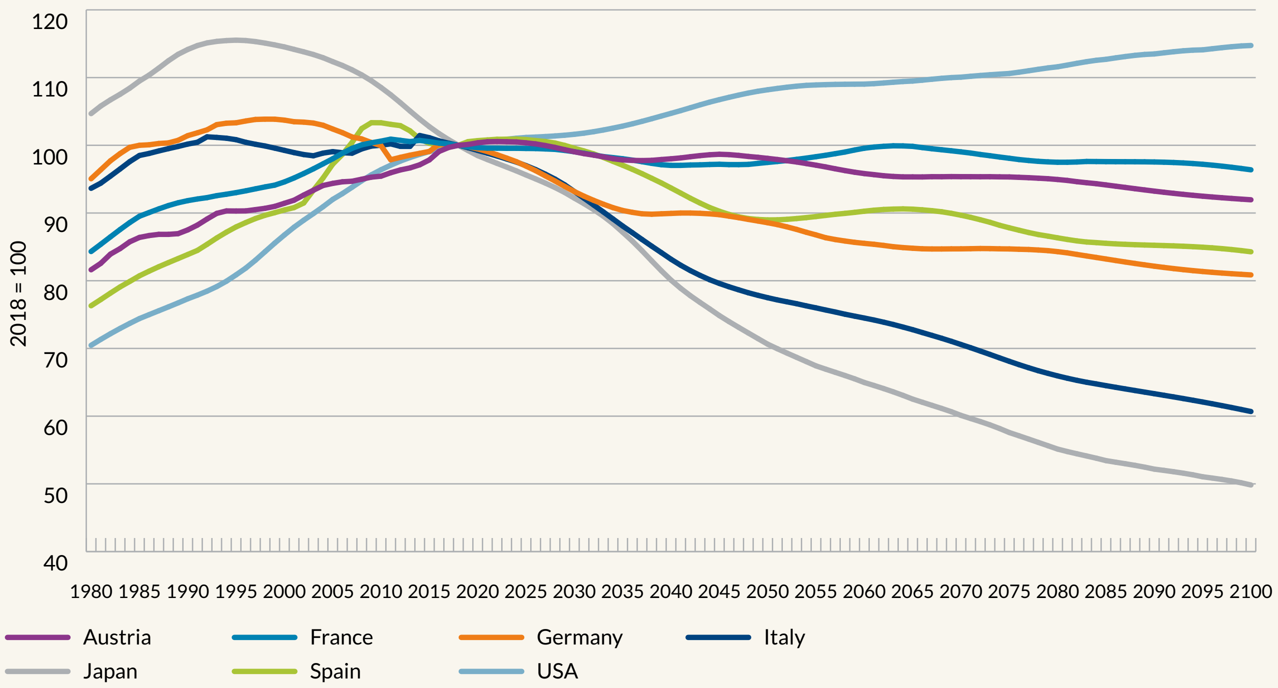
projections with those from the United Nations reveals greater dynamics, i.e. more intensive ups and downs in the total population (except for Italy). Both institutions expect some divergence of the total population from the working-age population. Only the USA will experience an increase in the working-age population (+14.7 percent), although at half the speed of the population growth. All other countries in Figure 4.2 end up with a lower number of working-age people in the year 2100.

This pattern is a direct consequence of population ageing, i.e. the share of persons aged 65 or older will increase over time. The process of ageing started around 1985. At that time, the share of persons aged 65 or older across countries was in a narrow band between 10 percent and 14 percent of the total population. Until 2018 the spread of this ratio in our sample has widened from 16 percent to 28 percent, and in 2100 it will have reached 28 percent to 37 percent, i.e. the share of old people in the population will almost triple in comparison to 1980. Again, Japan leads this development, while the USA will face a delayed and less dynamic process of ageing. European countries will be in between those two extreme cases, with Italy almost reaching Japanese values first around 2035 and then again around 2100. The process of ageing is a regular topic in discussions on the future perspective of public budgets. Specifically, social expenditures depend on the age of entitled persons because pension payments set in after the retirement age, health expenditures increase with respect to age, the share of persons requiring long-term care starts to increase sharply above 80, and elderly people are more often and longer affected by unemployment.

With respect to directed technological change adoption another population group is more interesting: the group of older workers aged between 55 and 64. The theoretical model of directed technology adoption by Acemoglu – Restrepo (2019A) predicts that firms have a higher incentive to develop new automation technology if the wage level for middle-aged workers (between 21–54) is high (Lemma 1).

FIGURE 4.2 **Historic and expected development of working-age population, 1980–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database.

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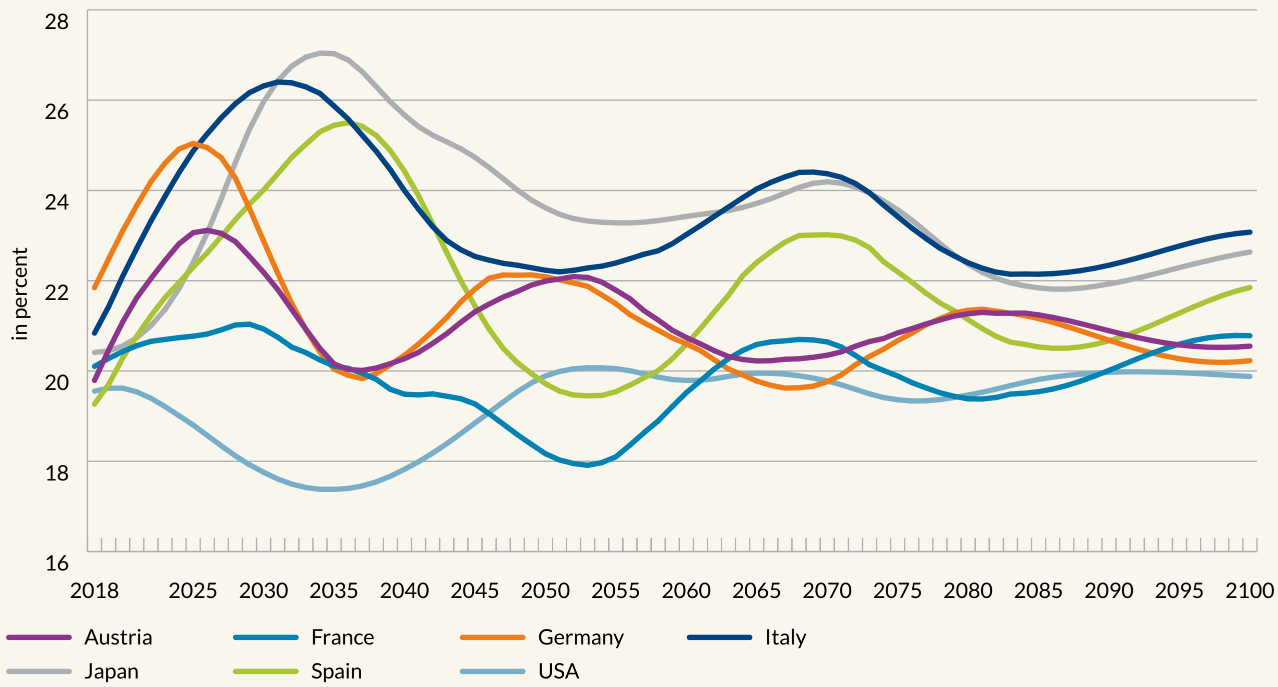
In this case, the substitution of middle-aged workers by machines is more profitable for firms. When restricting the set of admissible equilibria, the authors can prove that ageing will increase the wage level of middle-aged workers and, consequently, a larger number of industries will adopt automation technologies. Figure 4.3 shows the expected share of older workers (55–64) in the total working-age population (15–64) from 2018 to 2100. Across the six countries shown in Figure 4.3 this share currently varies between 19 and 22 percent (2018) and it shows strong dynamics. Apart from the USA, all countries will experience substantial ageing over the next years. France will be less affected, but Austria and Germany will see their ratio climb by 3.3 percentage points until the first peak around 2025. Italy's share will increase by 5.6 percentage points by 2031, and in the remaining two countries the old-ratio will increase by 2035 by roughly 6.4 percentage points. The biggest spread across countries will happen in 2034 when the US-old-age ratio will be at 17.4 percent while Japan will reach its highest value of 27 percent. Afterwards dampening swings will create a convergence to a range between 20 percent and 23 percent.

The wave-like pattern in Figure 4.3 has an important implication for the relation between ageing and TFP growth: While ageing may increase TFP growth over the first few years of our forecast horizon, the reversal of ageing setting in after 2025 through 2035 may then exert a dampening effect on TFP growth.

Figure 4.4 shows the development of the middle-aged group of workers. Over the first years of the population forecast, this share moves in the opposite direction to the old-age ratio, with the USA being the only exception. Starting from values around 63 percent, the share of middle-aged workers in the working-age population will decline over the first decade by around 2.5 percentage points in Austria, Germany, and France. Other countries like Italy and Spain will see a more pronounced reduction in the share of middle-aged workers by around 6 percentage points; Japan lies in the middle of this range. The

FIGURE 4.3 **Expected development of the share of old workers in the working-age population, 2018–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database. – Old are defined by age 55–64 and the working-age population is defined by 15–64 years.

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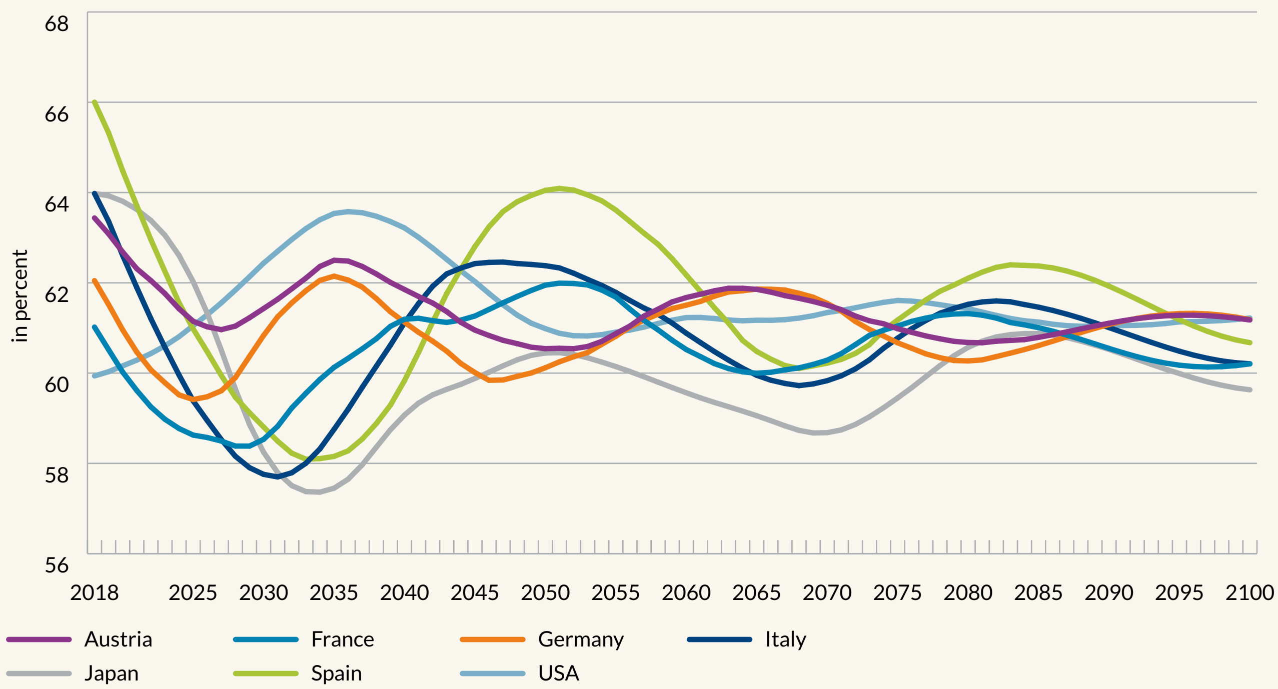
FIGURE 4.4 **Expected development of the share of middle-aged workers in the working-age population, 2018–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database. – Middle are defined by age 25–54 and the working-age population is defined by 15–64 years.

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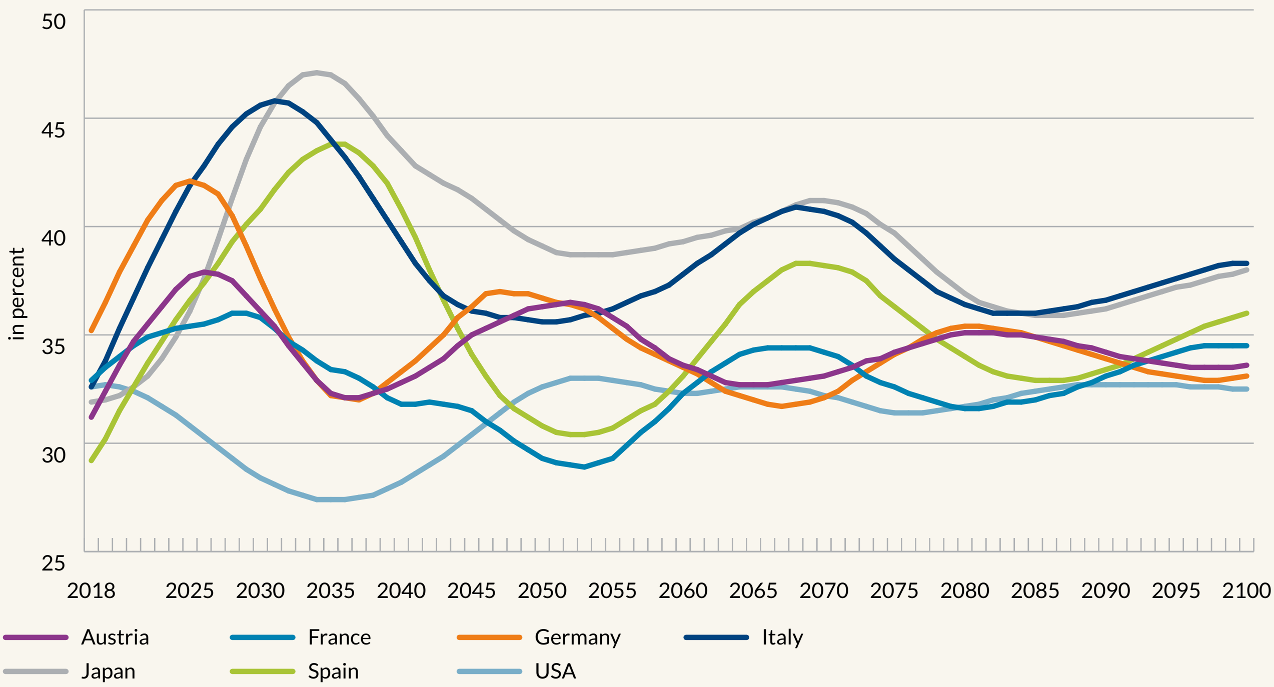
FIGURE 4.5 **Expected development of the share of old to middle-aged workers, 2018–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database. – The old to middle-aged worker ratio is defined as 55–64 years old to the 25–54 years old population.

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middle-age ratio also shows dampened swings over the next 80 years and converges to values of around 61 percent.

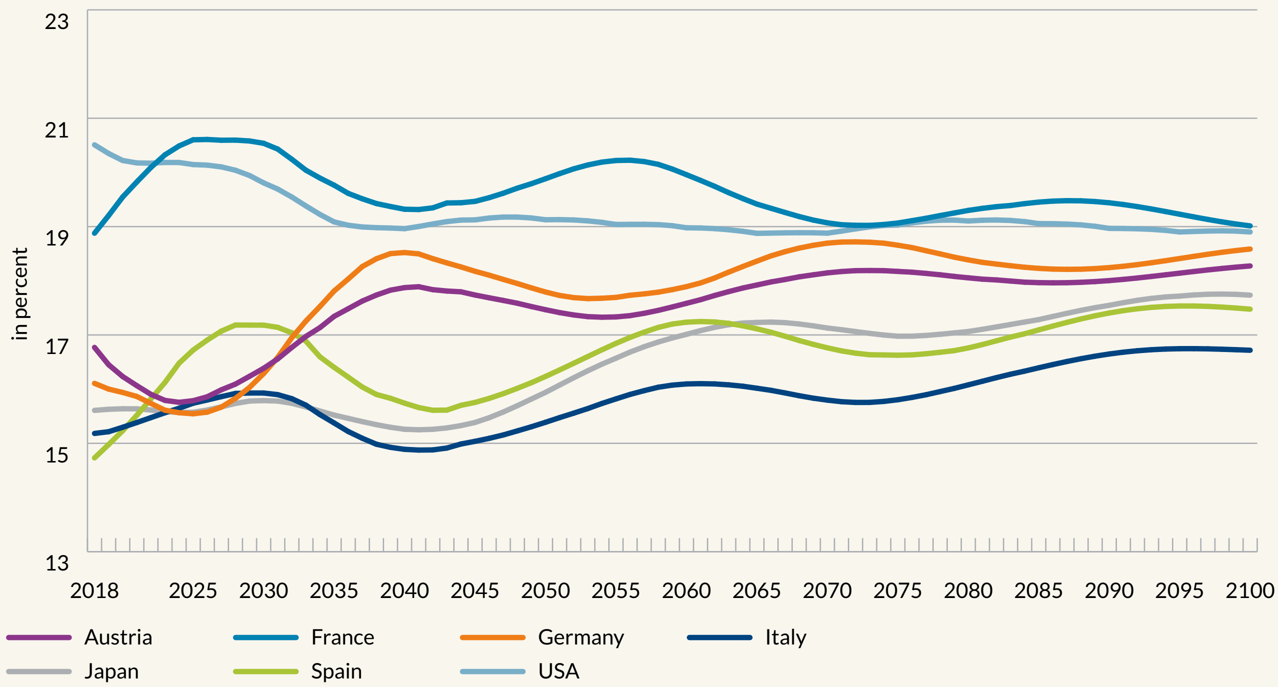
The countercyclical movement with respect to the old-age-ratio has one consequence: The measure for ageing used by Acemoglu – Restrepo in their theoretical model, i.e. the ratio of old to middle-aged workers in the population, will have more violent swings over the next decades. We can see this in Figure 4.5, where the spread between the lowest and highest value for this ratio starts at 6 percentage points and increases to 20 percentage points in 2034, which is double the size of the spread for the old-age workers ratio in Figure 4.3. The wave-like pattern, nevertheless, implies the possibility for periods of heightened and dampened TFP growth over the forecast horizon.

The share of young workers in the working-age population does not vary substantially over time, cf. Figure 4.6, although the strong variation across countries is obvious. While the USA and France appear as young societies, the remaining countries start with comparatively low young-age ratios in 2018 and gradually converge to the younger French and US populations.

4.1 The long-run relation between demographic and economic indicators

The first impression of the new 2019 population forecasts by Eurostat and the United Nations provides clear evidence that the old- and middle-aged worker ratios will move in opposite directions. This will strengthen potential demographic effects on directed automation adoption and the future development of total factor productivity. We will now continue with a short descriptive illustration of the relation between the long-run demographic development between 1980 and 2018 and several economic indicators suggested in the growth literature. For this purpose, we compute the average growth rates over this period, or in the case of ratios, the difference between their values in 2018 and 1980, respectively.

FIGURE 4.6 **Expected development of the share of young workers in the working-age population, 2018–2100**



Source: UNO – Department of Economic and social Affairs, Eurostat database. – Young are defined by age 15–24 and the working-age population is defined by 15–64 years.

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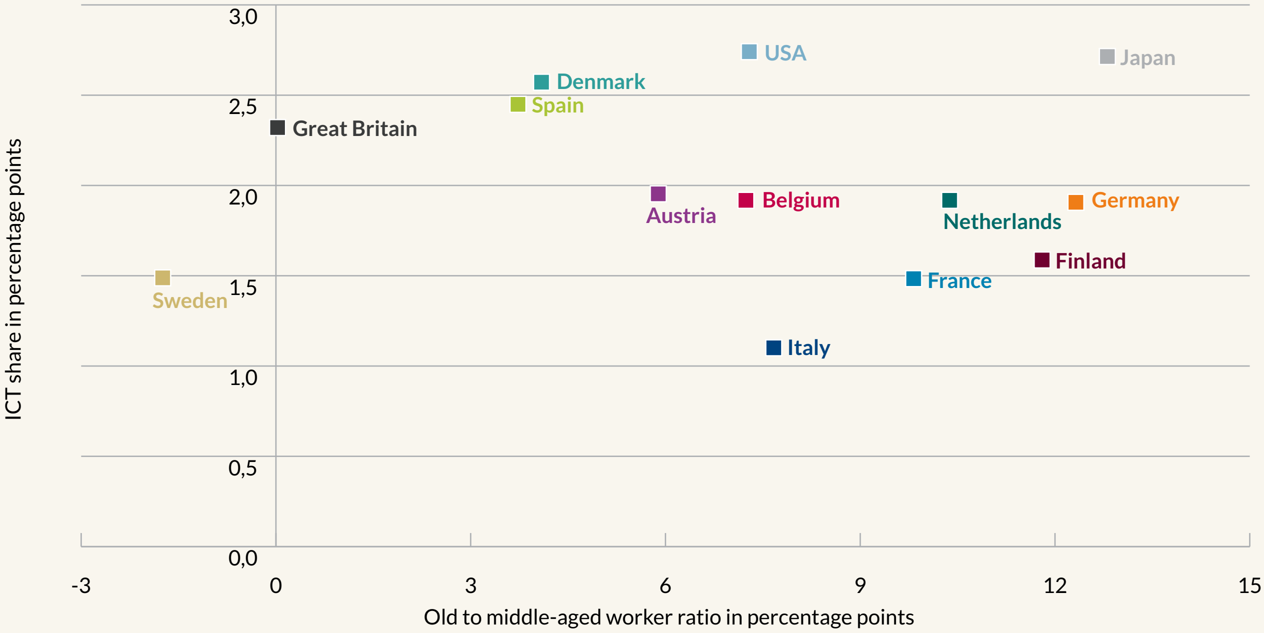
Acemoglu – Restrepo (2017) claim that the missing negative relation between ageing and per-capita GDP growth is due to an offsetting development between ageing and automation. Countries experiencing more rapid ageing are more actively installing industrial robots. The authors define ageing as an increase in the ratio of the working-age population above 50 to those aged 20 to 49 and compare this difference to the change in the number of robots (per million labour hours) between the early 1990s and 2015. In a set of 49 countries, for which data on industrial robots are available, a clearly positive relation emerges, i.e. more rapidly ageing countries have increased their robot intensity more strongly. They confirm their descriptive findings in a multiple regression framework.

We do not have data on installed industrial robots, while constructing foreign trade-based measures of automation would have been beyond the scope of this project. Thus, we approximate automation by the share of Information and Communication Technology and software (ICT) in aggregate capital, as, e.g., in Eden – Gaggl (2018). This indicator does not precisely measure automation though industrial robots contain ICT, however, business and other service sectors are increasingly subject to automation and digitisation. Thus, we expect the ICT intensity to be a good measure for the extent of directed technical change in the total economy.

Figure 4.7 compares the change in the old to middle-aged worker ratio between 1980 and 2016 to the change in the ICT intensity of the total capital stock, i.e. the share of ICT in the aggregate capital stock. For this comparison we extend the sample by EU-members providing the necessary data in sufficiently high quality. According to the hypothesis of Acemoglu – Restrepo (2019A), we expect a positive relation between this measure of ageing and our proxy for automation. Figure 4.7 shows no obvious relation between ageing and a higher ICT intensity and the correlation coefficient in this sample[1] is close to zero (−0.05).

1 We use Austria, Belgium, Germany, Denmark, Spain, Finland, France, Great Britain, Italy, Japan, the Netherlands, Sweden, and the USA in this sample.

FIGURE 4.7 **Historical comparison of the changes in the ICT investment share and the old to middle-aged worker ratio, 1980–2016**



Source: Eurostat, OECD, United Nations. – Share of investment in Information and Communication Technology (ICT) in gross capital accumulation. The old to middle-aged worker ratio is defined as 55–64 years old to the 25–54 years old population.

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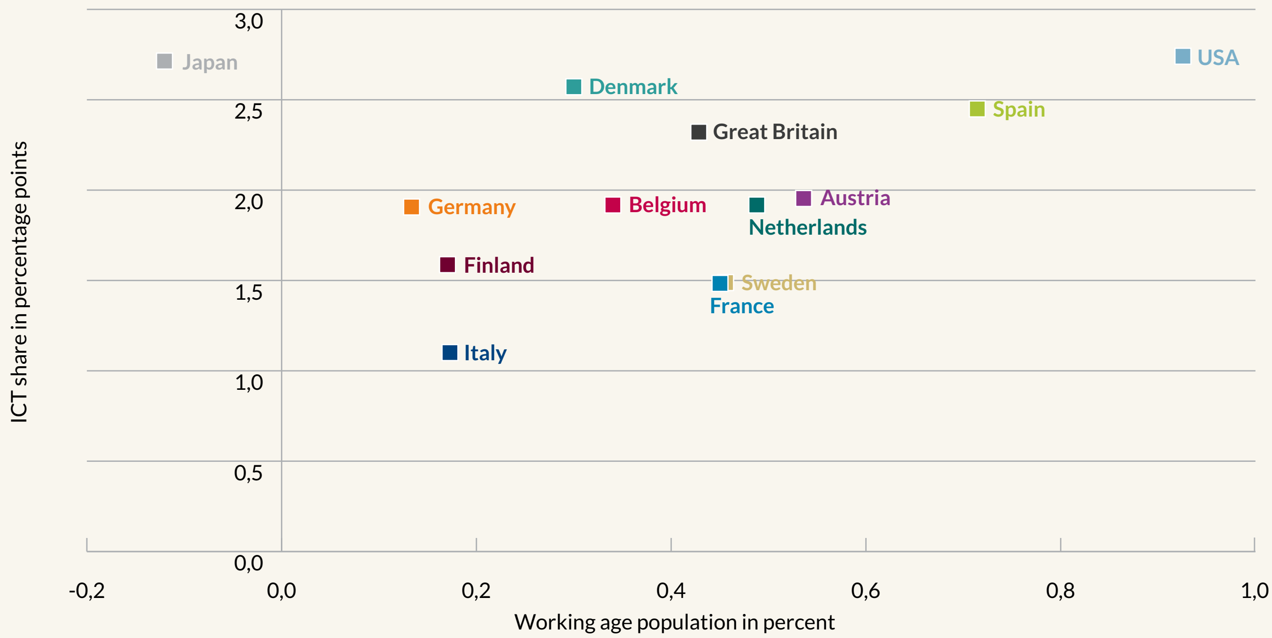
If we compare the average rate of change in the working-age population – a measure used by Abeliansky – Prettner (2017) to indicate labour shortages – in Figure 4.8 to the change in ICT intensity, we find a weak positive relation (0.22). A possible explanation for the weak relation may be the outlier position of Japan in Figure 4.8. If we account for year-to-year variations, use a more forward-looking concept of ageing, account for additional explanatory variables, and control for country-fixed effects, a closer relation may appear.

Acemoglu – Restrepo (2019A) stress that the relation between ageing and productivity is ambiguous. On the one hand, ageing directly increases the number of lower-productivity old-aged workers relative to the number of higher-productivity middle-aged workers, cf. Skirbekk (2004). On the other hand, ageing may induce directed technical change and thereby increase productivity through the displacement effect shown in Figure 3.1. The empirical results indicate an overall negative relation, but they are not robust to using alternative measures of economic activity. As a first descriptive analysis, we show in Figure 4.9 a cross-plot of average trend TFP growth and the speed of ageing. We cannot see a strong positive or negative relation between the old- to middle-aged workers ratio and TFP growth; the correlation coefficient is small (0.28). This supports the ambiguous prediction by Acemoglu – Restrepo (2019A). If we compare the average rate of change in the working-age population with trend TFP growth in Figure 4.10, the associated correlation coefficient remains small but becomes negative (−0.32), indicating that a shrinking working-age population may foster TFP growth. This descriptive analysis again shows that a more sophisticated empirical approach is necessary to find a closer relation.

FIGURE 4.8 **Historical comparison of the changes in the ICT investment share and the average growth rate of the working-age population, 1980–2016**



Source: Eurostat, OECD, United Nations. – Share of investment in Information and Communication Technology (ICT) in the capital stock. The working-age population is 15–64 years old.

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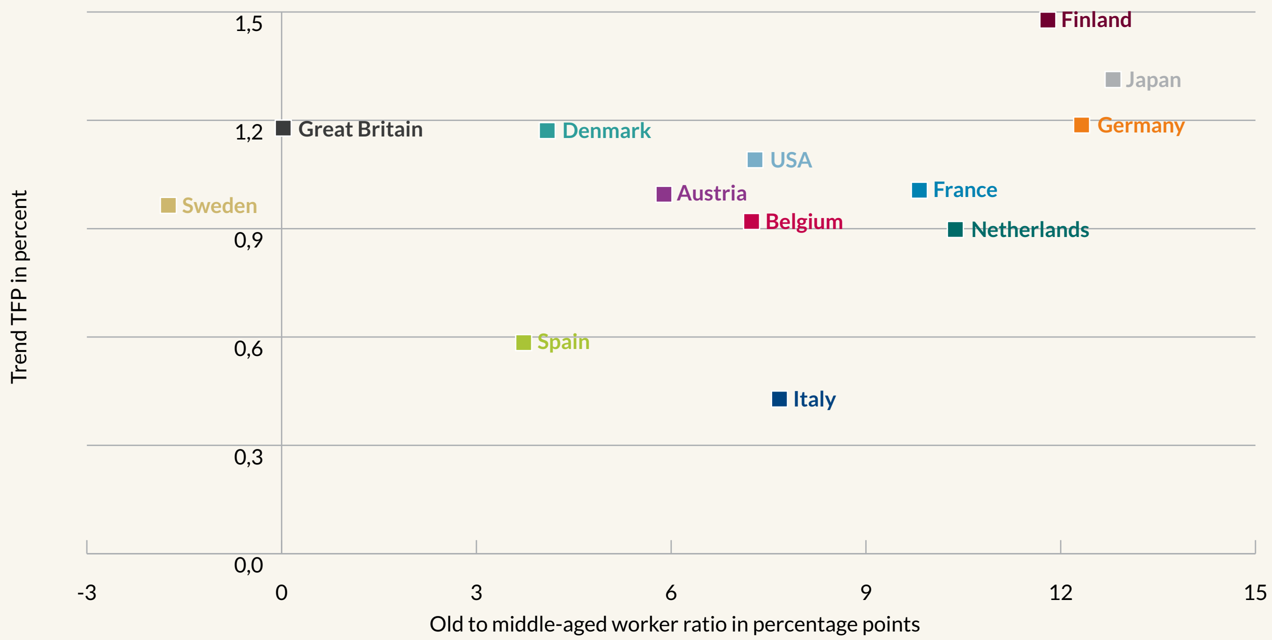
FIGURE 4.9 **Historical comparison of average growth rate in trend TFP with the change in the ratio of old to middle-aged population, 1980–2016**



Source: Eurostat, United Nations, WIFO calculations. – Trend TFP computation based on the EU-Commission method. The old to middle-aged worker ratio is defined as 55–64 years old to the 25–54 years old population.

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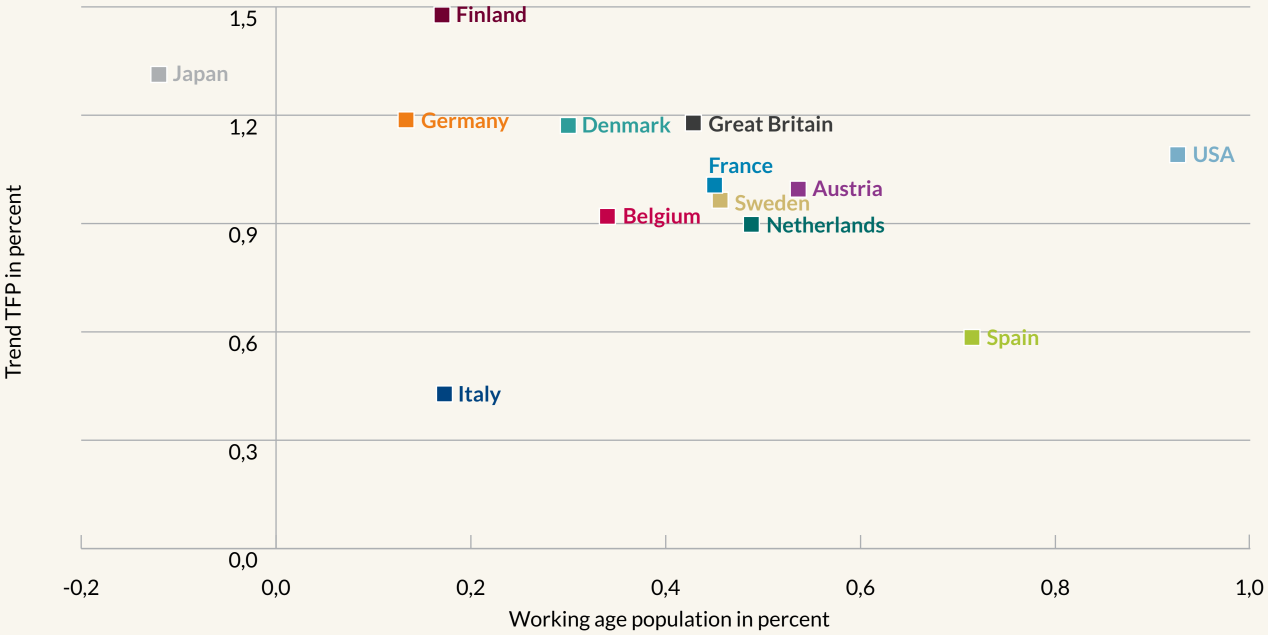
FIGURE 4.10 **Historical comparison of average growth rates in trend TFP and the working-age population, 1980–2016**



Source: Eurostat, United Nations, WIFO calculations. – Trend TFP computation based on the EU-Commission method. Working-age population is 15–64 years old.

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5 Modeling Age-Dependent Technical Change

The long but comparatively flat expansion of the US-economy since the financial crisis in 2008 and the experience of subdued growth within the European Union raised the issue of secular stagnation among developed economies (Teulings – Baldwin, 2014). Secular stagnation implies that negative interest rates are needed to equate saving and investment with full employment, and that it will be much harder to achieve full employment with low inflation at the zero lower bound of target interest rates. Furthermore, financial stability may be hard to achieve with real interest rates close to or below the growth rate of real output. Reinhart – Rogoff (2009) proposed an alternative explanation for the moderate growth experience of the past years by showing that financial crises do have severe medium-term consequences in terms of lost output growth, higher unemployment, and rapidly increasing public debt.

Empirical economics thus faces the question of whether the slowdown in output and productivity growth owes to the unwinding of excessive debt accumulated before and during a crisis, or whether long-run growth deficiencies have emerged. Statistical analysis by Antolin-Diaz et al. (2017), Crafts – Mills (2017), and Fritz et al. (2019) shows that US-trend-GDP, labour productivity growth and multifactor productivity growth are lower compared to the years before 2000 and have since stagnated. Gordon – Sayed (2019) show at the sectoral level that multi-factor productivity growth in the USA and Europe suffered from sagging innovation in the same set of industries. They find a high correlation between industries in the USA and a sample of ten EU-member countries with the largest slowdowns in multi-factor productivity growth. This leads them to the conclusion of a common diminishing impact of innovations that has driven early postwar growth, particularly in the commodity-producing industries. Alternatively, Decker et al. (2017) suggest that a general lack of entrepreneurship and the decline in gross job and worker flows indicate a reduction in allocative efficiency which dampens the movement of resources to their most productive uses, i.e. the US-economy suffers from declining business dynamism rather than a lack of technical innovation. Goldin – Katz (2008) propose yet another explanation for the slowdown in productivity growth. They argue that the post war expansion of educational attainment reached its limit after 2000 because the marginal effect of further expanding higher education diminishes as the share of high school graduates in each age grows over time.

Crafts – Mills (2017) argue, nevertheless, that some empirical approaches put too much weight on more recent data and, consequently, they are at risk of under-estimating the recent trend growth rate of output or the rate of TFP growth. For example, the average annual TFP growth in the USA, measured over individual decades, shows large variations in a range of 0.4 percent to 2 percent per year. They conclude that the past performance of an economy is not a good guide to future TFP growth.

We share this view in line with Mokyr (2014) and bring the hypothesis that a decline in the working-age population and its ageing induces investment in automation and digitisation to the data of the large Western European economies, Japan, the USA, and Austria. Our concentration on mature developed economies is imposed by the availability of historical data, which is needed to make robust empirical inference on the relation between demographic change and macroeconomic variables.

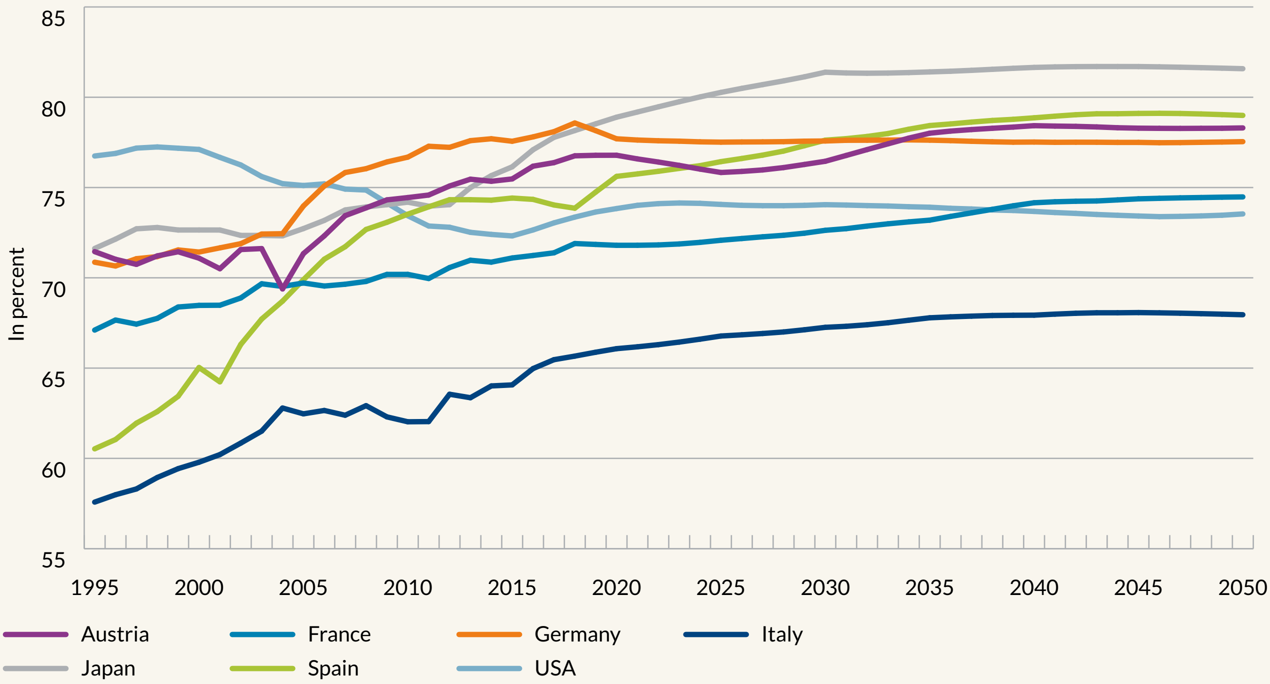
Our analysis starts with the European Commission's approach, combining short and medium-term forecasts with the long-term projections as documented in the EU-Ageing Reports, cf. European Commission (2018). The EU-Ageing report has been published in 2018 for the fourth time and combines the knowledge of national experts with a common framework provided by the European Commission. The macroeconomic framework has already been described in Section 2 and integrates current population forecasts from Eurostat, a set of assumptions resting on steady state properties of growth models, and the concept of convergence of European economies into a neoclassical growth model.

This approach already includes the direct effect of future population dynamics on economic growth because projections for the working-age population directly determine the volume of labour used in the production of goods and services. We extend this approach and build on the work by Lindh – Malmberg (2010) and Lindh et al. (2010) and account for indirect effects of demographic change on macroeconomic variables through induced adjustments in the structure of investment, the amount of aggregate savings, the extent of TFP growth, and the inflation rate. We integrate the coefficients estimated by a set of panel data regressions into a small system of simultaneous equations and use identities to derive per-capita GDP, the aggregate investment-to-GDP ratio and the current account balance relative to GDP. The technical appendix shows the details of the empirical analysis and the simulation model.

5.1 Trend growth in Total Factor Productivity (TFP)

We deviate from the assumptions used in the EU-Ageing report in one important dimension only: We assume that the rate of total factor productivity growth does not converge to the common value of 1 percent per year, cf. Table 2.5, and rather we allow country-specific population dynamics to drive productivity growth, conditional on a few additional variables suggested by the literature on

FIGURE 5.1A **Participation rates**



Source: OECD, WIFO calculations. – Participation rate: Labour force in percent of total working-age population (15 to 64 years).

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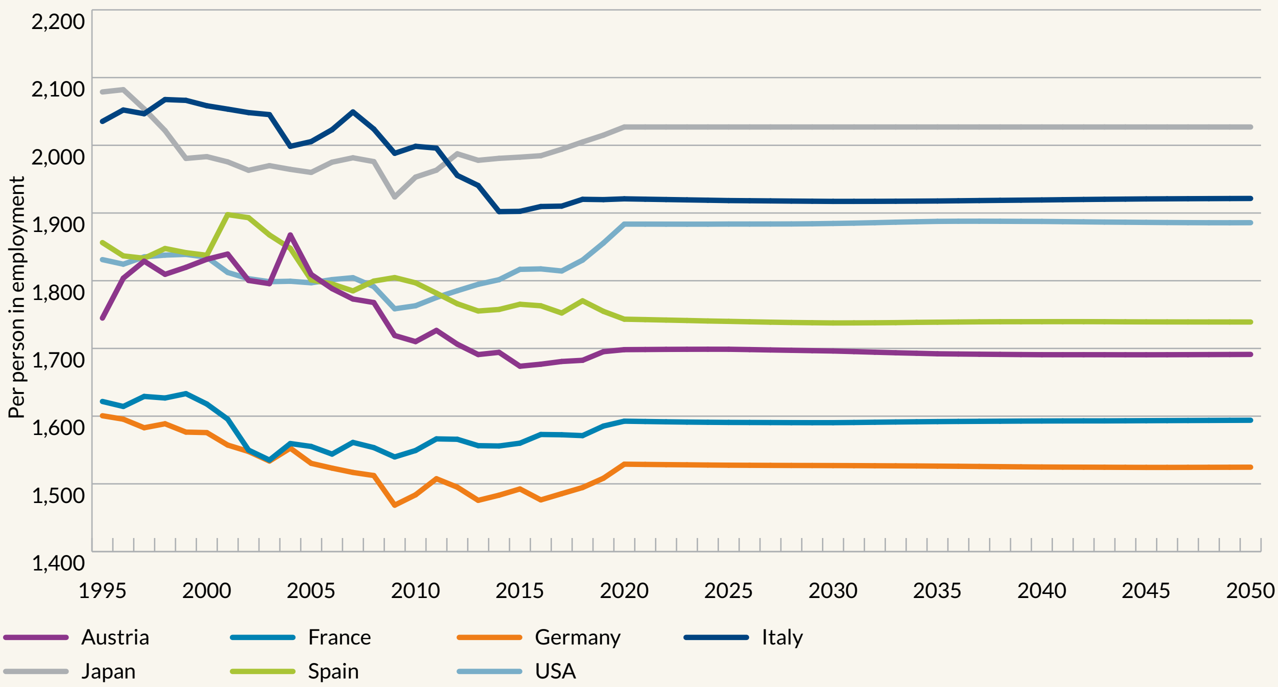
FIGURE 5.1B **Average hours worked**



Source: OECD, WIFO calculations. – Participation rate: Labour force in percent of total working-age population (15 to 64 years).

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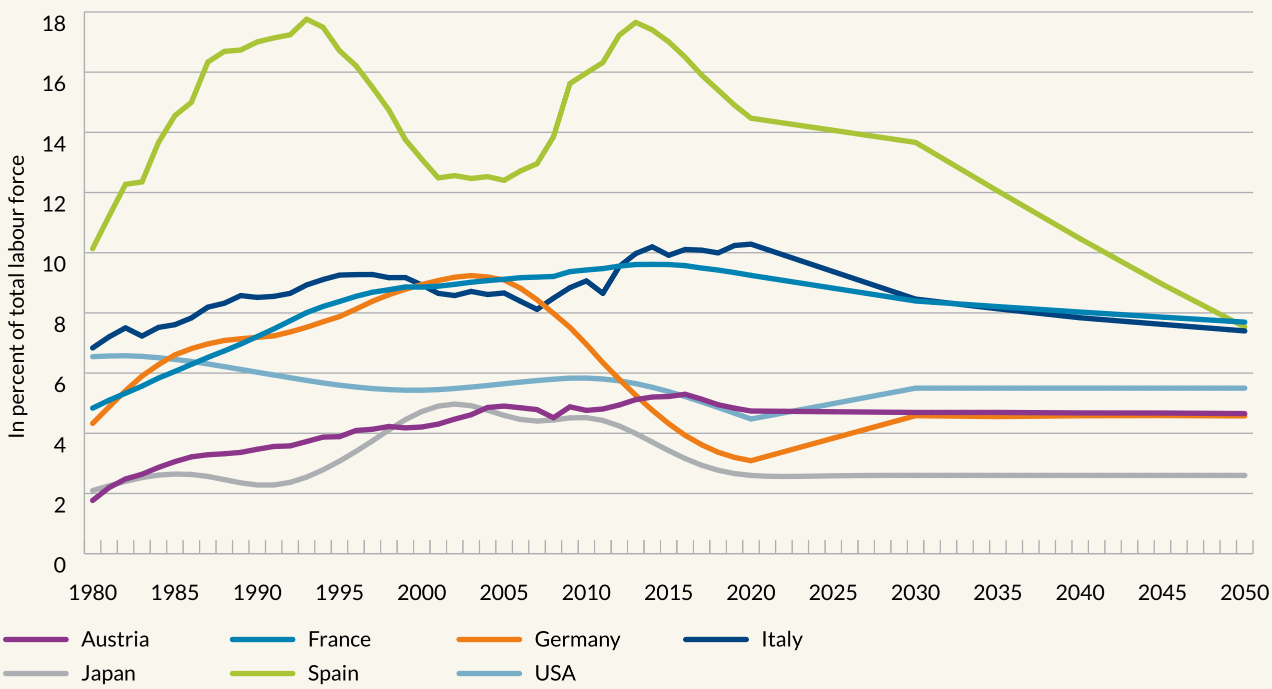
FIGURE 5.2 **Non-accelerating wage rate of unemployment (NAWRU)**



Source: European Commission, WIFO calculations.

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empirical growth dynamics. Population change operates through three channels on output growth and total factor productivity. First, there is the conventional direct effect that a shrinking working-age population reduces labour input. This effect is dampened in most countries by the increase in participation rates (Figure 5.1) and the falling natural unemployment rate in some countries (Figure 5.2). On the other hand, the hours worked only change in line with demographic shifts across age groups and both sexes due to their different part-time work habits. For example, growth accounting for Germany shows that the contribution of labour to the annual average GDP growth rate of 1.2 percent is expected to be −0.3 percentage points per year, with TFP and capital contributing 1.0 and 0.5 percentage points, respectively (European Commission, 2018: Table I.2.3).

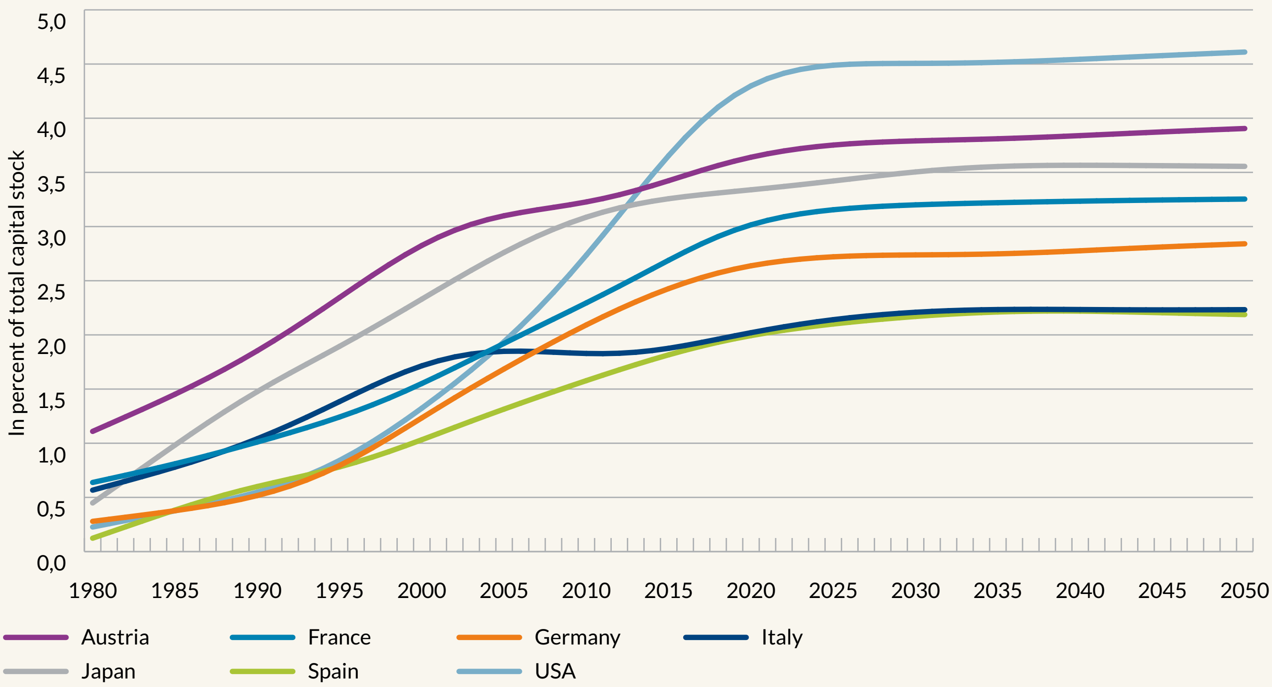
We add two interactions between ageing and total factor productivity growth to the European Commission approach, thus allowing for indirect demographic effects. Rather than exogenously prescribing a convergence path starting from the short-term projection and the medium-term adjustment, we introduce an instant response of TFP growth to the changing age structure of the population. The theoretical analysis by Acemoglu – Restrepo (2019A), empirical results by Skirbekk (2004), and our own empirical analysis suggest that technical progress responds to the ratio of old to middle-aged workers. We expect a negative quality effect on TFP growth and our estimates indicate a marginal effect of ageing between −0.1 and −0.02, depending on the model specification and the estimation method (cf. section A1.2.1 for technical details). Based on the model selection criteria, we choose the lowest value of 0.02 for our long-run simulations. This implies that an increase in the old to middle-age worker ratio by one percentage point reduces the average TFP growth rate by 0.02 percentage points annually. Here, a second glance at Figure 4.5 is helpful, because it shows the variation in the old to middle-aged worker ratio over the simulation horizon. Taking the example of Japan, the ratio increases by 7.2 percentage points between 2018 and 2050, implying an average negative effect on the TFP growth of 0,14 percentage points. In addition to the negative quality effect of ageing on TFP growth, we also take up the idea that the expected decline in the working-age population will create a strong incentive to invest in the automation and digitisation of tasks. Managers will implement technical innovations allowing for labour-substituting technical progress (directed technical change) if they expect labour scarcity within the next ten years. We choose this window length because automation machinery has a depreciation period of roughly ten years (Graetz – Michaels, 2018). This quantity effect of ageing will be positive, and it works indirectly through the installation of automation and digitisation equipment. We approximate this type of investment goods by the ICT intensity of the aggregate capital stock (Figure 5.3).

The choice of additional macroeconomic factors is motivated by Danquah et al. (2011), who look for robust covariates of TFP growth by applying Data Envelopment Analysis and Bayesian Model Averaging to a large set of candidate models. Their study covers 67 countries over the period 1967–2000 and 19 potential determinants of TFP growth. For the sample of OECD countries, they identify the investment deflator, the savings rate, trade openness and the size of the economically active population (labour force) as robustly correlated with TFP growth. Additional robust correlates include country-fixed effects and the initial real GDP per capita that captures unobserved heterogeneity among the countries.

5.2 Share of Information and Communication Technologies (ICT)

Rising productivity in the production of digital equipment and from the more intensive use of ICT equipment and software has been the main source of productivity gains in recent decades (van Ark, 2016). Growing expenditure on ICT and software reflects ongoing efforts by businesses to expand data capabilities, improve the efficiency of operations and increase productivity. The strong decline in the price of ICT equipment has helped accelerate the rapid adoption of the new technology.

FIGURE 5.3 **ICT intensity**



Source: OECD, EU KLEMS, WIFO calculations. – ICT: includes Software.

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The second set of regressions models the change in the ICT intensity of the capital stock. The model by Abeliansky – Prettner (2017) implies that an expected labour shortage provides an incentive for additional investment in automation. The change in ICT intensity is related to the ICT investment net of depreciation due to economic obsolescence, wear and tear, etc.[2] Investment is a forward-looking activity aimed at changing production capacity and improving future productivity. This suggests the use of expected rather than of current demographic indicators. Anticipated labour shortages in the future should provide an incentive to invest in automation, as proxied by the ICT. We assume the expectation horizon of ten years. This planning horizon roughly corresponds to the economic lifespan of machinery and equipment in general.

As an additional variable we include the output gap as a measure of the cyclical position and the deflator of ICT capital as the relevant price (Jorgenson – Stiroh, 2000; Gust – Marquez, 2004). The use of the output gap as a control variable is appropriate since ICT investment is highly procyclical and may contain traces of a business cycle even after smoothing. Since a positive output gap indicates economic upturns and relaxing financial constraints, it should be positively correlated with the change in the ICT intensity. The ICT price is measured by the US deflator of ICT capital. We choose the US deflator since similar time series for several other countries in the extended sample are not available or too short, and because the USA is the largest user of ICT equipment and the largest user and exporter of software. We forecast the deflator for ICT capital using the univariate exponential smoothing method described in section A1.3.1. The resulting forecast can be seen in Figure A1.2. Whereas the history of the deflator shows a steep decline in prices, the univariate forecast converges quickly to a steadier path contributing to the weak forecasts for ICT intensity.

2 This change would be equal to net investment if the total capital stock remained constant.

It should be noted that the resulting empirical model is rather eclectic in that it excludes many institutional factors that may impede the diffusion of ICT as a general-purpose technology. If these factors are constant over time, however, they will be controlled for by the country-fixed effects in the panel regression.

The estimates confirm the negative relation between expected population growth and labour-saving investment (cf. section A1.2.2 for technical details). The preferred specification is on the upper bound and implies an increase in the share of ICT capital by 0.1 percentage points if the expected working-age population decreases by 1 percent. Figure 4.2 provides some perspective on the potential size of this effect. It shows the expected change in the working-age population for the countries in our sample. While the working-age population in the USA will increase over the full simulation period, Austria's and France's working-age population will remain stable. Only the remaining countries will receive a positive impulse on TFP growth resulting from higher incentives to implement directed technical change. Specifically, starting in 2018 and looking forward over the next decade, Germany, Italy, and Japan will experience a decline in their working-age population. The decline by 5 percent in Germany implies an increase in the ICT intensity by 0.5 percentage points.

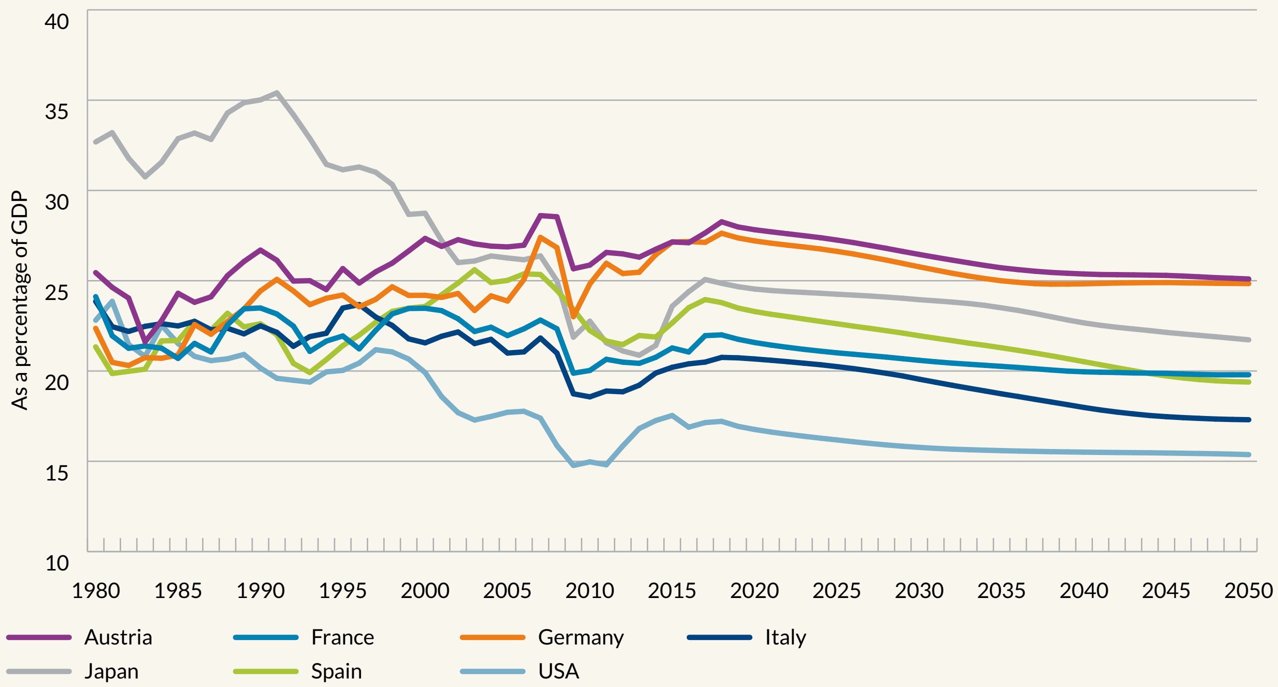
The increase in ICT intensity is only half the story. If our proxy for automation and digitisation-related investment would not eventually improve the TFP growth rate, this channel would not work in our simulation. For this reason, we include the ICT ratio in our model for TFP growth, creating a simultaneous system in which ICT spending responds to demographic change and TFP growth in turn depends on the ICT share in the capital stock. Our estimates for the effect of the ICT capital share on TFP growth are in the range between 1.1 to 3.0, depending on the model specification and the estimation method (cf. section A1.2.1 for technical details). Our preferred model delivers a value of 1.3 showing that an increase in the share of ICT in the aggregate capital stock by one percentage point lifts the average TFP growth rate by 1.3 percentage points per year. Although the positive effect of ICT investment on TFP growth has been recently disputed (van Ark, 2016), we follow Crafts – Mills (2017), who argue that the most recent data can be misleading and refer to the literature supporting a long-run positive effect instead (Mokyr, 2014; Mokyr et al., 2015).

5.3 Aggregate Saving

The models for TFP growth include another channel through which demographic effects are transmitted into long-run growth. The aggregate savings rate is a likely candidate for another transmission channel from changes in the population structure towards macroeconomic variables. Though the aggregate savings ratio is hard to model because the savings motives of private households, enterprises, the government, and the foreign sector will not be identical, we suggest a model including the young and old dependency ratios (relative to the total population) separately as demographic explanatory variables. The main reason to include dependency ratios in a model explaining the savings rate is that persons in their youth (ages 0–24) and in their retirement phase either have no own income or they receive a lower income from a public pension and run down their assets, which they accumulated within occupational and private pension plans.

Our empirical analysis gives values for the response of the savings rate to a change in the young dependency ratio roughly between −0.4 and −0.2. The latter value implies that an increase in the young dependency ratio by one percentage point reduces the aggregate savings rate by 0.2 percentage points. The results for the elasticity with respect to the old dependency ratio varies roughly in a range between −0.9 and −0.3, depending on the specification and the estimation method. Our model selection criterion indicates a preferred coefficient on the old dependency ratio of −0.3. To put the above figures in perspective, the demographic forecasts for Austria, Germany, and the USA expect a decline in the youth dependency ratio around 1 percentage point over the next decade. This would raise the savings rate over the next ten years by a total of 0.2 percentage points. The old age dependency ratio, on the other hand,

FIGURE 5.4 **Gross domestic saving**



Source: European Commission, WIFO calculations.

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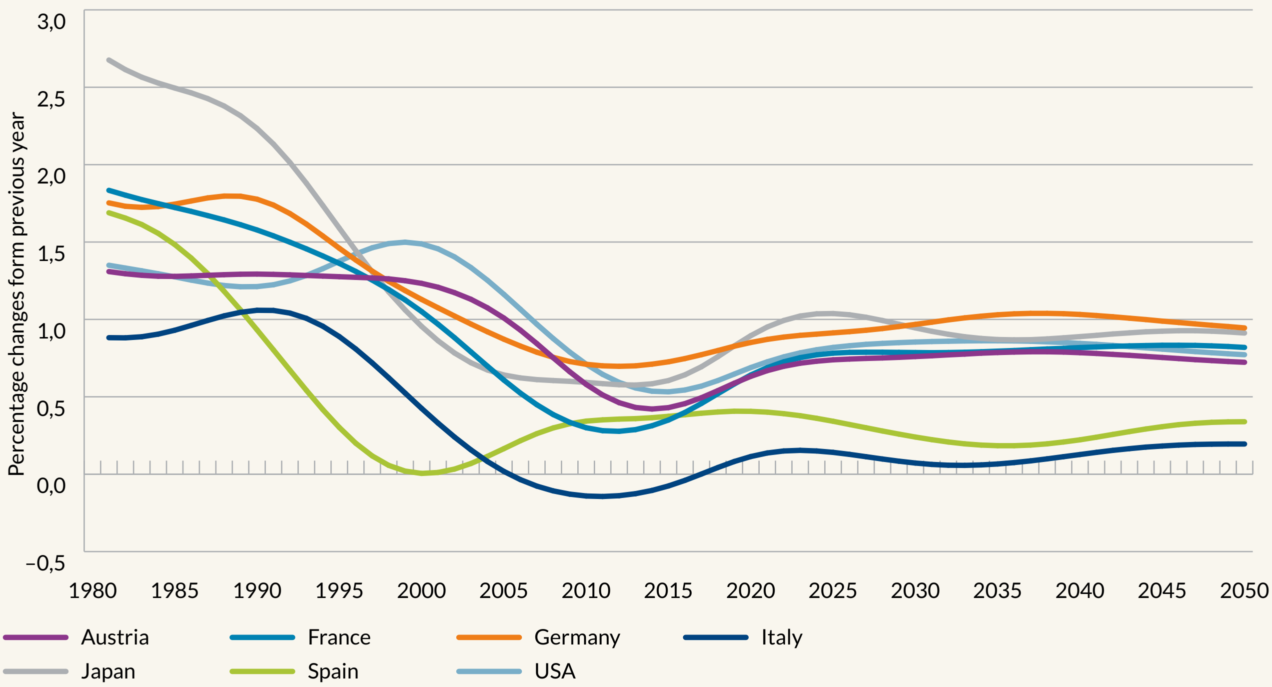
will increase by 3.5 percentage points, reducing the aggregate savings rate by 1.2 percentage points (applying exact numbers from Table A1.3); the net effect is one percentage point.

Figure 5.4 shows that the net effect of the ageing process will reduce the aggregate savings rate over the coming decades. The USA will be less affected than the remaining countries because the expected ageing process there is not very pronounced. Our projections show a decrease in the savings rates due to ageing ranging from −1.8 percentage points in the USA to −4,4 percentage points in Spain.

Similarly, to the indirect transmission of future developments in the working-age population through ICT intensity into TFP growth, we also allow for a transmission of movements in the dependency ratios through the savings rate into TFP growth. The motivation for this indirect channel is empirical evidence that the savings rate is a robust explanatory variable in growth regression using Bayesian model averaging methods (Danquah et al., 2011). Furthermore, simple economic reasoning points to the relevance of relaxed financing constraints for gross fixed capital formation in economies with a higher savings rate. These countries do not have to tap international capital markets for domestic investment purposes thus avoiding severe asymmetric information problems. Our empirical analysis provides estimates for the response TFP growth to a variation of the savings rate in a range between 0.003 and 0.06, depending on the model specification and the estimation method. The preferred model giving a coefficient of 0.01, i.e. an increase in the savings rate by 1 percentage point will improve the TFP growth rate by 0.01 percentage points. Although the coefficient is significantly different from zero in the preferred model, the size of the feedback mechanism between demographic variables and TFP growth transmitted through the savings rate is small. Picking up the example from the last paragraph, we expect a net reduction in the savings rate of one percentage points over the next decade, giving rise to a total reduction in the growth rate of TFP in the size of 0.01, or less than one hundredth of a

FIGURE 5.5 **TFP trend**



Source: European Commission, WIFO calculations.

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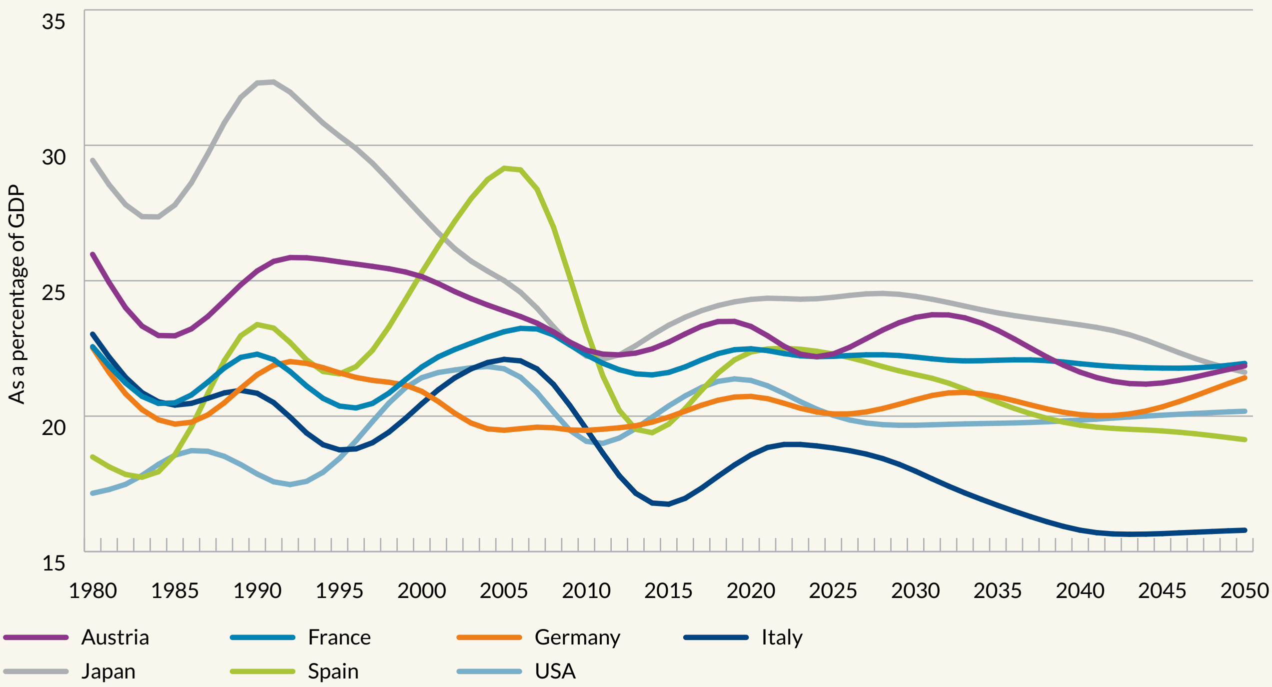
percentage point. All in all, given the interaction within the system of simultaneous equations and the moderate continuation of the trend towards more open economies, the TFP growth rate will improve over the next few years reaching a peak around the middle of the next decade (Figure 5.5). Japan, Italy, and Spain will then experience a period of decreasing TFP growth rates due to demographic headwinds. Overall, the situation will have improved with respect to the starting year of our simulation, but Spain and Italy will form a distinct group with TFP growth of 0.1 and 0.3 percent per year, while the remaining countries – including the USA – will settle in the range between 0.7 percent and 1 percent per year.

The development of gross fixed capital formation in Figure 5.6 shows pronounced and long cycles. These cycles follow the change in the labour volume and the rate of growth of labour productivity. This rule allows a rising capital labour ratio, but it stabilizes the capital output ratio. The European Commission applies the same method. The share of capital in GDP remains between 19 and 22 percent for all countries. In the long run, we expect only moderate changes in the investment rate not exceeding 2.1 percent of GDP for all countries. Investment activity will be sluggish or declining in Japan, Spain and Italy.

The production function approach combines productivity trends with the development in the labour market and the accumulation of capital, and it produces a path for potential output.

Figure 5.7 presents the growth rate of potential output. Real output growth will be in a range between −0.2 and 1.6 percent annually. The higher end of this range will be achieved in the USA, France, Austria and Germany, as the demographic trends are more favorable in these groups. This is due to relatively high fertility rates in the USA and France, while Austria and Germany experience high immigration. The largest decline in output growth between 2018 and 2050 will be in Italy. This is a consequence of low expected TFP growth, the strong decline in the working-age population, and sluggish capital accumulation. The pessimistic

FIGURE 5.6 **Gross fixed capital formation**



Source: European Commission, WIFO calculations.

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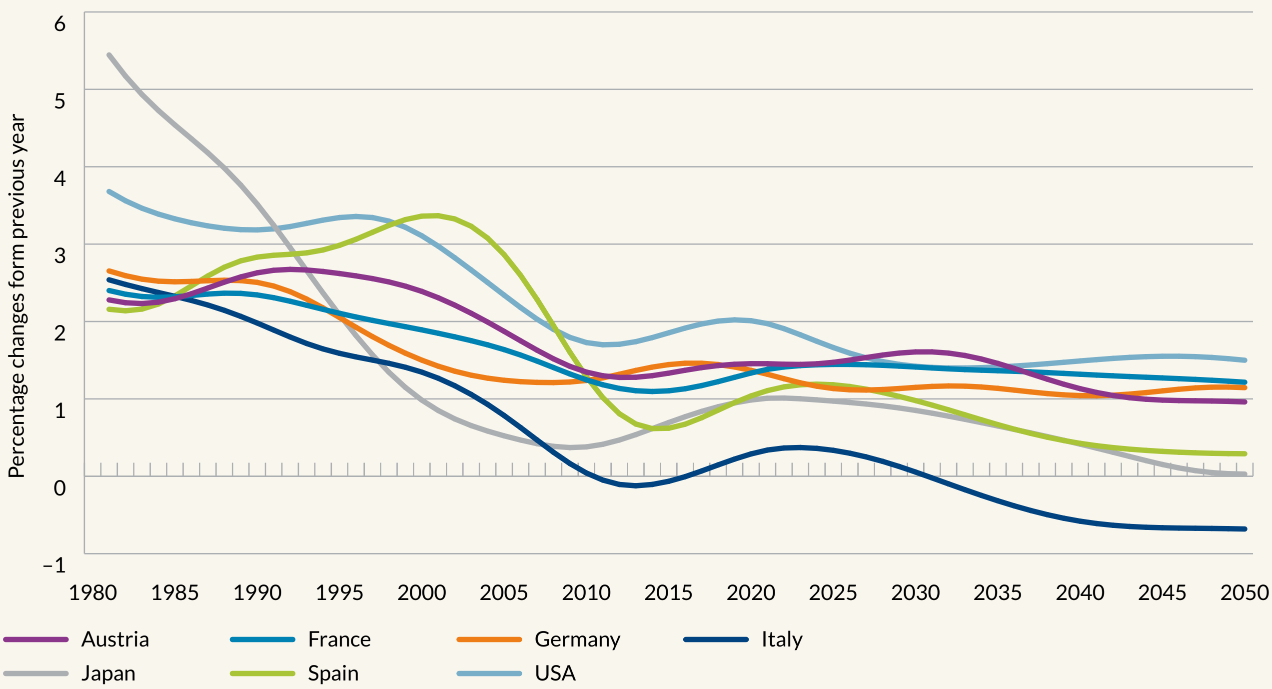
FIGURE 5.7 **Potential output**



Source: European Commission, WIFO calculations.

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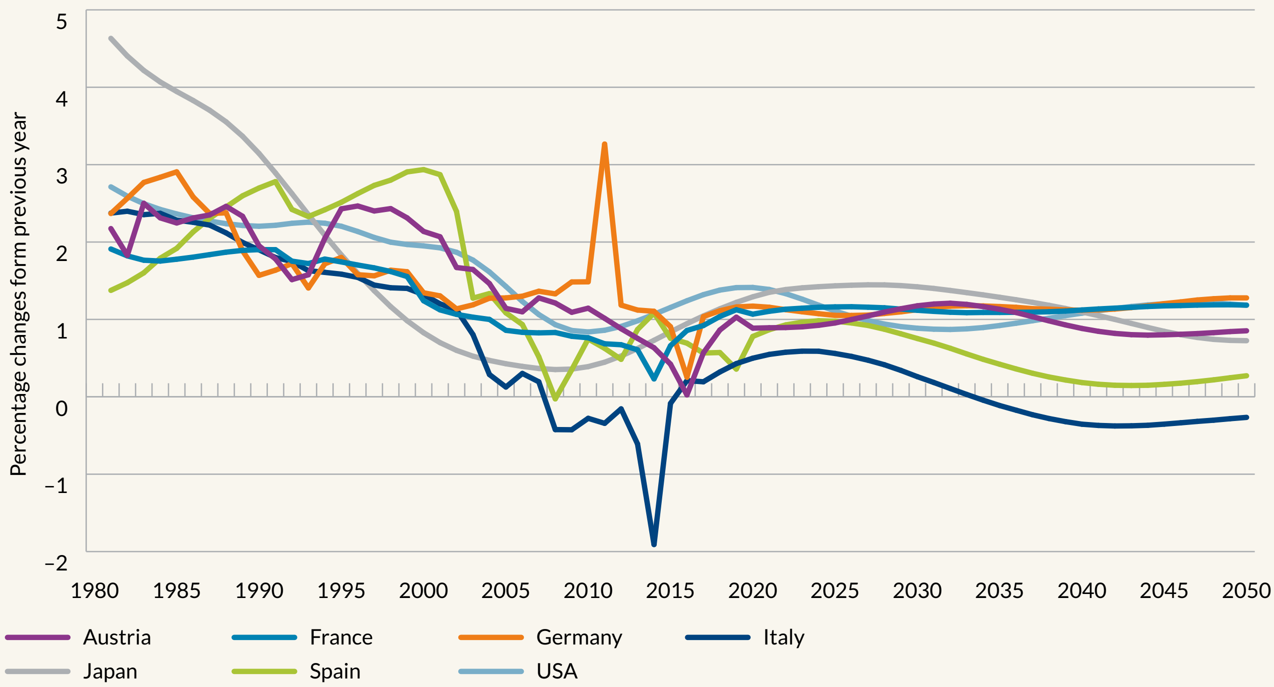
FIGURE 5.8 **Potential output per capita**



Source: European Commission, WIFO calculations. The peak in Germany 2011 results from a reduction in the population due to the new census method. The trough in Italy 2014 results from a jump in the population published by Eurostat, which is not matched in the United Nations data.

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outlook for Italy and, to a lesser extent, also for Spain appears to be influenced by weak TFP growth in these countries in the past. Our estimates extrapolate past performance, partially negating the favorable effects from the interaction of ageing with directed technological change.

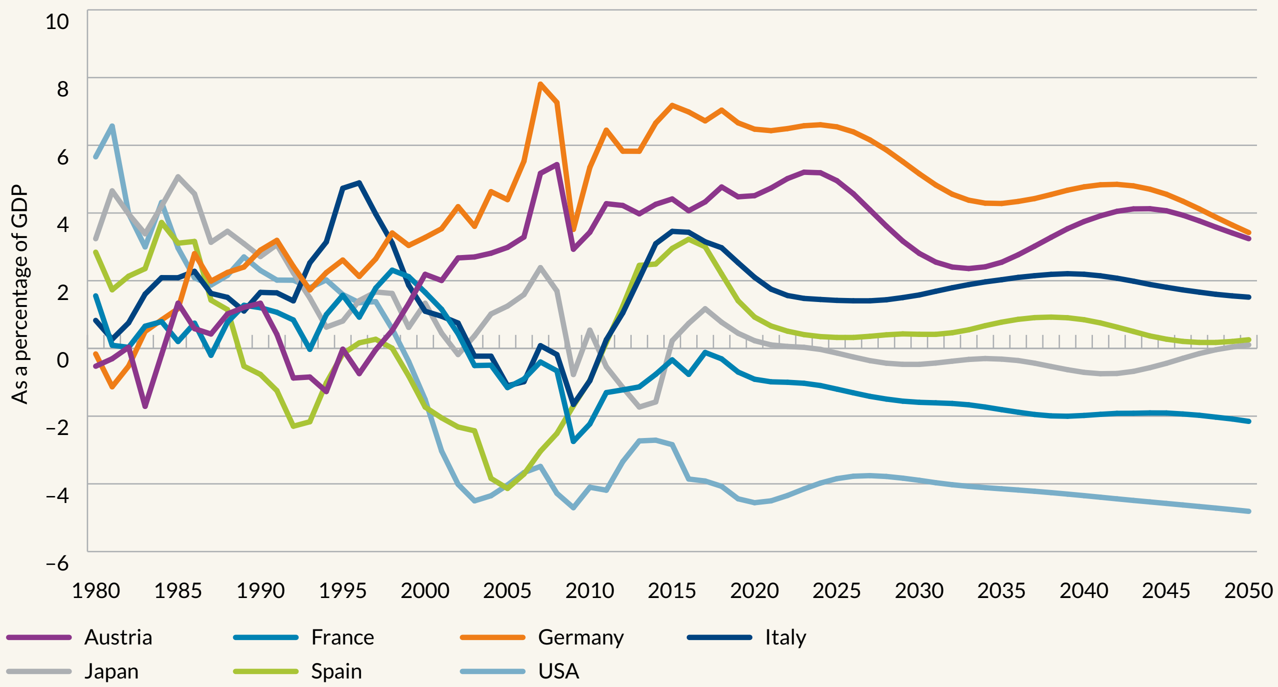
Dividing potential output by the total population gives a better and well-known measure for the expected change in welfare than potential output, which is often used in international comparisons. The total population also comprises persons who are not gainfully employed and thus responds to changes in the population structure, even if the head-count is constant.

Figure 5.8 reveals the importance of adjustments in total factor productivity as a compensation to adverse demographic trends. For Italy we expect not only a reduction in real output starting around 2030 but also a decline in GDP per capita a few years later. Contrary to this development will be the situation in Japan, where GDP per capita will grow at a similar pace as in Austria, France and Germany, the difference owing to higher productivity growth (cf. Figure 5.5). Spain, as a country with comparatively low expected productivity growth, also stands out in Figure 5.8, with growth in GDP per capita converging towards +0.2 percent per year.

5.4 The Relation Between Saving, Investment and the Current Account

The development of the net international investment position is a mirror image of past domestic savings and investment decisions. This variable measures the assets and liabilities of each country vis-à-vis the rest of the world including foreign direct investment, portfolio investment, other investments, financial derivatives and reserve assets. The development of the net international investment position over time is determined by the current account balance.

FIGURE 5.9 **Current account balance**



Source: European Commission, WIFO calculations.

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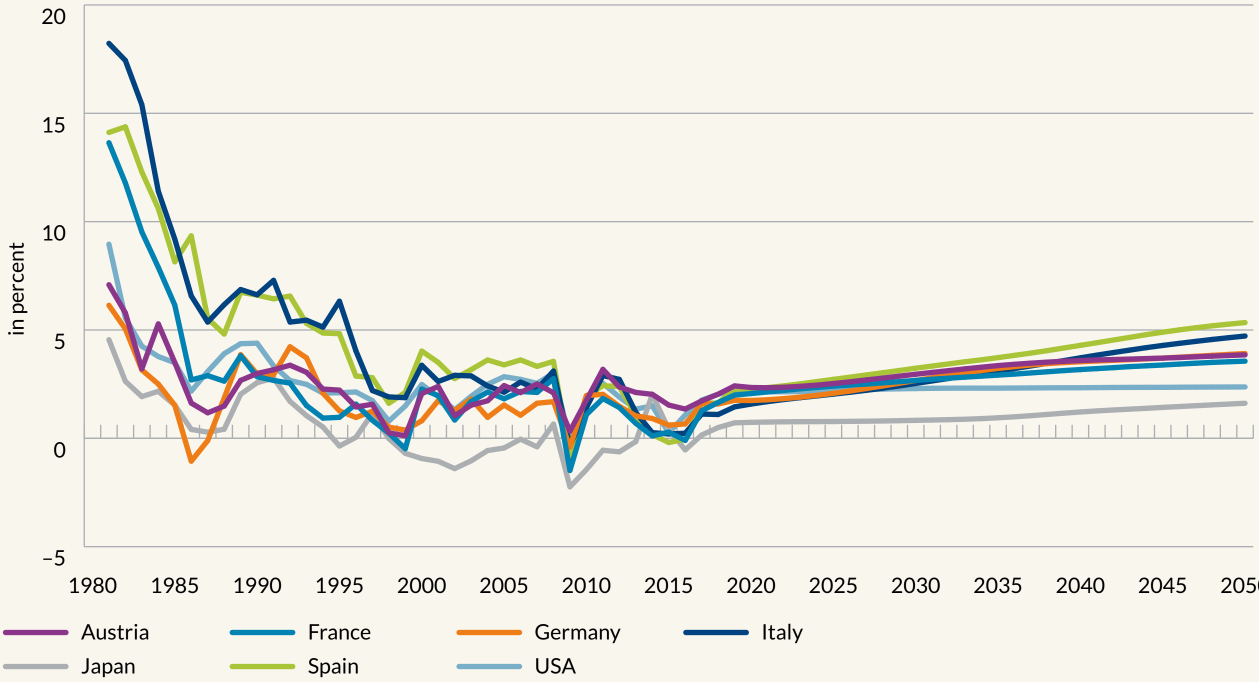
Countries with a history of current account surpluses are international net investors, while countries with current account deficits will be net international debtors. Consequently, countries with a balanced current account will accumulate neither international assets nor debt. The current account reflects the difference between aggregate savings and investment in an open economy. Because we have modelled the response of the savings ratio to demographic change and our aggregate investment ratio reflects changes in labour productivity induced by demographic movements, we are also able to present the expected development of the current account in Figure 5.9. Being a balance between savings and investment, the current account would immediately reflect misspecification in our model set-up by showing non-stable patterns. A view on Figure 5.9 shows that the current account indicates some instability in response to the ageing population, but the direction and extent remain in a reasonable range. Germany, as the country with the highest current account surplus in the starting period, will reduce this position substantially but will in 2050 still accumulate foreign assets. The USA, as the country with the highest current account deficit in 2018, will reduce the deficit slightly until 2025. Values for the current account deficit around −4 percent of GDP over such a long period are likely to deteriorate the confidence of international investors and may enforce a more drastic correction. The production function approach, however, does not consider financial market expectations. Of the large European economies France appears to follow an unstable course over time. From the beginning its current account balance is negative, converging to −2.2 percent of GDP by 2050. Again, a change in the attitude of international investors may impose a correction of this expected trend. Japan and Spain follow a balanced growth path until the end of the simulation period, while Austria and Germany are expected to have comparatively large swings in their current future account surpluses.

5.5 Inflation

Conventional macroeconomic wisdom holds that inflation, by and large, is a monetary phenomenon. Over the past decades, monetary authorities in developed countries held inflation rates in check, partly by following inflation targets, partly by installing currency boards and partly by joining the European Monetary Union, with Germany providing a stable anchor currency. During the past two decades, annual average inflation rates were roughly in the range between 1 and 2 percent. Our empirical analysis builds on a model for inflation rates using the young and old dependency ratios as demographic indicators. This choice is based on recent work by Juselius – Takáts (2018), proving that in a sample of 22 advanced economies from 1870 to 2016 the increase in the dependent population ratio (children, adolescents, young adults and retirees) tends to positively correlate with higher inflation rates. Their findings are consistent with the life-cycle hypothesis as these groups tend to consume without fully participating in the production process thus potentially creating excess demand. Our empirical results show that both dependency ratios correlate positively with inflation rates, i.e. periods of high inflation tend to come together with periods showing high dependency ratios. Particularly, the youth dependency ratio appears to have an intensively positive relation to the inflation rate. The estimates for the response of the inflation rate to a change in the youth dependency ratio varies between 0.2 and 0.9, depending on the model specification and estimation method. Our preferred model picks the lowest estimate in this range, i.e. 0.2. This implies that an increase in the youth dependency ratio by 1 percentage point is associated with an upward shift in the inflation rate by 0.2 percentage points. The variation for the coefficient of the old age dependency ratio is smaller. Our estimates are in the range of 0.1 to 0.5, depending on the model specification and estimation method. The preferred model again features the lowest estimate of 0.1 from this range. The interpretation of this coefficient is equivalent to the previous discussion. Our projections are shown in Figure 5.10 and show a rising inflationary

FIGURE 5.10 **Consumer price inflation rate**



Source: European Commission, WIFO calculations.

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pressure resulting from the increasing share of elderly people (65+). While Japan appears to be able to escape the deflationary trap in the future, we still expect Japan to have the lowest inflation rate in our sample. Because the USA faces the slowest ageing process, the change in the US-inflation rate will remain negligibly small, while all European countries see their inflation rates respond to demographic pressures from 2030 onwards.

5.6 Decomposing the Direct and Indirect Effects of Demographic Change

The results presented up to now compounded the direct effects of expected changes in the size of the population with indirect effects operating through changes in the quality of labour and induced directed technical change. The direct effect operates through the amount of labour used in the production of goods and services, while indirect effects account for changes in the productivity of the labour force, directed technical change, and adjustments of the savings rate.

In this section we disentangle the direct from the indirect effect by using our model to simulate the future economic development under the assumption of a constant population, i.e. we freeze the population at the level and structure of the year 2018. This corresponds to the last observed value for all countries in our sample. By freezing the population, we eliminate all indirect effects that work through induced changes in TFP growth, ICT intensity, and the savings rate. We are thus able to present a hypothetical scenario that mimics the assumption of a TFP growth path, which is independent of demographic developments. We call this scenario the baseline scenario and we will compare two alternative scenarios to this baseline.

The first alternative scenario uses the current population forecasts for the simulation, but eliminates the response of TFP growth, the ICT intensity, and the savings rate to changes in the demographic development from the model. This scenario reveals the direct effect of the changing size of the working-age population on economic variables. We call this scenario the "TFP growth at constant population" scenario because in this case TFP growth does not respond to changes in the population.

The second alternative scenario turns on the estimated response of TFP growth, ICT intensity, and the savings rate to demographic changes in our model and thus corresponds to the compounded results presented in the previous sections. We call this scenario the "TFP growth at projected population" scenario because in this case current demographic projections influence all endogenous variables.

The comparison of the "TFP growth at constant population" scenario with the baseline in Table 5.1 shows zeros only because both the baseline as well as the alternative feature the same TFP growth path by assumption. On the other hand, if we allow for indirect effects of demographic changes on the economy, Table 5.1 shows that the model generates either weakly negative (Germany, France), or a negative (Austria, Italy, Spain, and Japan), or a weakly positive (USA) effect of demographic change on TFP growth. The effect also varies over time because the population structure reverses its development over the years (cf. Figure 4.5). The decomposition shows that the expected net effect from changes in the quality of labour, induced ICT intensity, and the response of the savings ratio on TFP growth throughout European countries is either negligible or negative.

Although the figures in Table 5.1 appear small, the impact on the level of GDP per capita is magnified by the effect of growth rate compounding, whereby small differences in growth rates generate large differences in the level of per capita income over a prolonged period. Table 5.2 repeats the comparison of our two alternative scenarios to the baseline at constant population and without TFP effects in the simultaneous system for per capita GDP in 2010 euros. We chose three years for this comparison because averaging a growing variable such as GDP per capita over, say, a decade does not yield a sensible quantity for comparisons. For example, the value of −1,002 € for Germany in 2030 indicates that in the scenario "TFP growth at

TABLE 5.1 **Decomposition of direct and indirect effects from demographics on TFP trend – TFP growth – Average annual percentage changes**

	Szenario: TFP-growth at …	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	0.00	0.00	0.00
	projected population	–0.10	–0.07	–0.09
France	constant population	0.00	0.00	0.00
	projected population	–0.05	–0.04	0.01
Germany	constant population	0.00	0.00	0.00
	projected population	–0.09	0.00	–0.03
Italy	constant population	0.00	0.00	0.00
	projected population	–0.16	–0.24	–0.13
Spain	constant population	0.00	0.00	0.00
	projected population	–0.14	–0.29	–0.18
Japan	constant population	0.00	0.00	0.00
	projected population	–0.10	–0.29	–0.23
USA	constant population	0.00	0.00	0.00
	projected population	0.03	0.07	0.03

Note: Baseline assumes constant population fixed at values from 2018.

Source: WIFO calculations. – Baseline assumes constant population fixed at values from 2018. The alternative scenario with „TFP-growth at constant population" combines the projected population dynamics with TFP-growth from the baseline. This makes the direct effect of demographic change on productivity growth visible.
The alternative scenario with „TFP-growth at projected population" combines the projected population dynamics with TFP-growth under directed technical change. This makes the quality effect and the effect of labour-saving technical progress on productivity growth visible.

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constant population" per capita GDP in the year 2030 in Germany would be lower by 1,002 € if we only account for the reduced labour input in our model. If we allow for all direct and indirect effects of population ageing on the TFP growth, the decline in per capita GDP increases to −1,612 € in 2030. In this "TFP growth at projected population" scenario, annual per capita GDP in Germany would be lower by 6,053 € in 2050. Countries with more pronounced losses in TFP growth also show more severe reductions in per capita GDP relative to the baseline; the most extreme case being Japan with an expected decrease of 12,423 € by 2050.

Another interesting result from our decomposition in Table 5.2 are negative values for the USA under both scenarios. Given the favorable population dynamics in the USA one would have expected a higher per capita GDP level in the scenario based on the projected population as compared to the baseline under constant population; Table 5.1 shows that US TFP growth responds positively to this impulse but Figure 4.1 and Figure 4.2 show that total population growth in the USA is considerably higher than the increase in its working-age population. During the years 2020 through 2035, the gap between both growth rates varies between 0.2 and 0.5 percentage points per year, giving rise to higher population dynamics relative to GDP growth, and consequently lower values for per capita GDP in the scenarios based on the projected population. The slightly better performance in terms of TFP growth corrects only part of the negative direct effect resulting from comparatively lower labour input.

TABLE 5.2 **Decomposition of direct and indirect effects from demographics on TFP trend – Potential output per capita in 2010 Euro**

	Szenario: TFP-growth at …	2030	2040	2050
		Deviation from baseline in €		
Austria	constant population	–1.099	–2.848	–5.044
	projected population	–1.821	–4.230	–7.219
France	constant population	–1.004	–2.780	–4.149
	projected population	–1.332	–3.374	–4.785
Germany	constant population	–1.002	–2.948	–5.029
	projected population	–1.612	–3.732	–6.053
Italy	constant population	–117	–1.514	–3.567
	projected population	–968	–3.420	–6.077
Spain	constant population	15	–1.342	–3.525
	projected population	–723	–3.387	–6.565
Japan	constant population	–1.937	–3.333	–7.037
	projected population	–2.759	–6.377	–12.423
USA	constant population	–1.381	–3.024	–3.525
	projected population	–1.146	–2.222	–2.314

Note: Baseline assumes constant population fixed at values from 2018.

Source: WIFO calculations. – Baseline assumes constant population fixed at values from 2018. The alternative scenario with „TFP-growth at constant population" combines the projected population dynamics with TFP-growth from the baseline. This makes the direct effect of demographic change on productivity growth visible.
The alternative scenario with „TFP-growth at projected population" combines the projected population dynamics with TFP-growth under directed technical change. This makes the quality effect and the effect of labour-saving technical progress on productivity growth visible.

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6 Conclusions

Current demographic projections for large industrialized economies convey a clear picture with respect to the future size of the working-age population. In the next thirty years, the working-age population is expected to decline in most industrialized countries. The changing size of the population will be accompanied by a shift in its age structure towards a more elderly working-age population.

A smaller working-age population does not necessarily entail fewer people employed. Rising labour market participation rates and falling unemployment rates may assuage the decline in the working-age population. The participation rates are indeed expected to increase in most large industrialized countries, continuing the trend observed over the past fifty years. The exceptions are Germany and the USA, where participation rates are expected to decline or stagnate. The trend is largely driven by increasing participation rates of women, increasing participation rates of elderly workers due to better health conditions, higher statutory retirement ages and the positive effect from higher educational attainment.

The effect of higher participation rates is reinforced by lower unemployment rates. This positive employment effect is most pronounced in Spain and Italy. For these countries, the European Commission expects a gradual but significant decrease of the currently high unemployment rates in the future. Decreasing unemployment rates are consistent with increasing scarcity of labour implied by demographic projections. Labour demand forecasts are much less certain than projections of labour supply, as the former is more affected by patterns in the international division of labour (globalisation) and the unpredictable nature of economic crises. The bottom line is that the assumption of rising participation rates and falling unemployment rates implies that potential and actual employees can offer the right mix of skills required to acquire or retain jobs, the implicit assumption being that their health, mobility, education and experience match demand. Our labour market projections closely follow the methodology of the Ageing Report published by the European Commission. The results of this methodology imply increasing employment rates, except in Germany and the USA.

Recent work on endogenous growth models suggests that investment in automation and digitisation may solve the problem of the reduced quantity and quality of labour due to population ageing. To account for this possibility, we consider the share of ICT capital goods and software in the total capital stock as a measure of automation and digitisation investment. Our empirical results confirm the negative impact of ageing on total factor productivity and the positive impact of future ageing on the incentive to invest in the quality of capital today.

The EU-Ageing Report sidesteps the interaction between ageing and directed technological change by assuming convergence of productivity growth rates among EU-member states. This is motivated by the idea that perfect capital and labour mobility should enforce convergence. Our results show significant heterogeneity across countries, thus exposing the forces working against convergence. The annual average growth of total factor productivity in Austria, France, Germany, Japan and the USA between 2018 and 2050 should be in the range of 0.7 to 1.0 percent. This is roughly consistent with the assumptions of the European Commission. Yet, the growth of total factor productivity in Spain and Italy should be considerably smaller, ranging from 0.1 percent in the case of Italy to 0.3 percent in Spain. Whether capital and labour mobility in the EU would diminish these differences remains an open question, but the experience in the aftermath of the global financial and economic crisis of 2008 refutes convergence.

The accumulation of physical capital depends on prospects for the future and the means of today. Projections show a decrease in the savings rates in percent of GDP due to ageing in all countries, ranging from −1.8 percentage points in the USA to −4.4 percentage points in Spain. In the long run, capital accumulation should adjust to productivity growth, stabilizing the capital-to-output ratio. We expect only moderate changes in the investment-to-output ratio, with investment activity being weakest in Japan, Italy and Spain.

The trend of total factor productivity coupled with trends in the labour market and the adjustment in capital accumulation result in annual average growth rates of real output between −0.2 in Italy and 1.6 percent in the USA. The higher growth rates are expected in the USA, France, Austria and Germany, as the demographic trends are least obstructive to growth in these countries. This is due to comparatively high fertility rates in the USA and France, and to migration in the case of Austria and Germany. Compared to the period between 2000 and 2018, economic growth is likely to slow down in most countries considered in this study, with the difference being largest for Italy and Spain.

Conventional macroeconomic wisdom holds that inflation, by and large, is a monetary phenomenon. During the past decades, monetary authorities in developed countries were able to hold inflation in check, despite rising structural pressures due to ageing. From 2000 to 2018, annual average inflation rates were between 1 and 2 percent – except in Japan, which has experienced an average negative inflation rate (deflation). Our projections show rising inflationary pressures that are due to the increasing share of economically dependent persons in the population, with average annual inflation rates in the range of 1.1 (Japan) to 3.7 (Spain) percent. Our projections show that over the next three decades Japan will continue to experience lower inflation rates compared to other industrialized countries.

Population ageing slows the growth of working-age population and thus has a direct negative effect on output growth. Projections based on directed technical change suggest that technical progress is unlikely to fully offset the additional negative effect of demographic trends on the growth of total factor productivity. One reason for this is that our estimates produce relatively conservative projections for the ICT intensity – the factor that is supposed to offset the combined negative effect of ageing on the quantity (labour input in hours) and quality (productivity) of labour through automation and digitisation. The increase in the share of ICT and software will slacken in the next five years. The ICT intensity must continue to increase to have a permanent effect on productivity growth. To balance the negative ageing effect on TFP growth over the next three decades (quality effect), the share of ICT capital and software in capital stock would have to increase by a factor of 2.5 to 3.5 in Italy, Japan and Spain, and by roughly 1.5 in Austria, France and Germany. In order to compensate for both, the direct (quantity) and the indirect (quality) effects of ageing, the share of ICT capital and software in the capital stock would have to increase by a factor of roughly 4.5 to 5.5 in Italy, Japan and Spain, and by 2.0 to 3.0 in Austria, France and Germany. We conjecture that relying on data from 1980 onwards, our results implicitly lean heavily on the experiences of the past two decades, which have been exceptional in several respects. The ICT revolution that began in the 1990s has largely come to a halt, while a severe global financial and economic crisis has left a long-lasting scar on many economies, especially southern European economies have subsequently experienced a sovereign debt crisis. Extrapolating the recent experience may lead to overly pessimistic projections. As a final caveat, we would like to emphasise that our analysis focuses on a facet of the complex interplay between demography, technology and growth. Although our projections try to account for simultaneity between the determinants of technical progress, savings and capital accumulation, our analysis remains fragmentary against the backdrop of the vast complexity of the studied phenomena.

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A1 The Extended Production Function Methodology

This technical appendix details the theoretical and empirical methodology used in the recent Ageing Report of the European Commission (EC) and the extensions of this methodology pursued in this study. The principal aim of this study is to account for the interplay of demographic factors and technical progress, and to extend the EC methodology that assumes an exogenous technical progress. The second aim is to discuss the consequences of demographic trends for key macroeconomic quantities, such as the change in the consumer price index and the ratios of savings, investment, and the current account to output.

The EC methodology views potential output as a trend around which the actual output fluctuates over the course of a business cycle. This trend describes the output trajectory of an economy in the medium and long term. The EC uses extensions of short-term forecasts for fiscal planning up to t+10 and for assessments of the budgetary impact of the ageing population till 2070. Short-term forecasts are published twice a year. The spring forecast covers the current and next year (t+1), whereas the autumn forecast updates the spring forecast and extends it by an additional year (t+2). The medium-term forecast extends the short-term forecast by three more years (t+3 through t+5, currently until 2023). The medium-term forecast essentially describes the transition from short-term business cycle fluctuations to a long-term steady-state growth driven independently by demographic developments and technical progress. The output gap is assumed to close at the end of the medium-term horizon (t+5), and the unemployment rate converges to an equilibrium unemployment rate, which is determined by labour market institutions, as well as several non-structural factors and persistent cyclical factors. The long-term projections underlying the EC-Ageing Reports (t+30) typically assume a gradual convergence of country-specific trend estimates towards common values.

This appendix is structured as follows. The next section summarises the EC methodology for estimating potential output (Section A1.1). Section A1.2 presents estimates based on longitudinal (panel) data, which are then used to extend the projection methodology of the EC. This is followed by a section summarising the extended projection methodology (Section A1.3). The final section describes data sources (Section A1.4).

A1.1 The Production Function Methodology

The output gap as the relative deviation of real GDP from potential output indicates the cyclical position of an economy. Gauging the current cyclical position is important for economic forecasting and for formulating economic policy. The potential output is defined as the level of output compatible with stable (wage) inflation. As a key indicator of inflationary pressures, the output gap is highly relevant for monetary policy. Estimates of the output gap also guide fiscal policy, whose aim is to mitigate the effect of business cycles on incomes, while ensuring the sustainability of public finances in the medium term. Finally, and most relevant to this study, the change in potential output describes the long-run growth path of an economy, laying a foundation for long-term macroeconomic projections and scenarios.

The output gap as a deviation from a long-run trend is a common element of many macroeconomic models today. An early example of contemporary formalism is the paper by Perloff – Wachter (1979), whose ideas were further developed by the IMF and the OECD in the late 1980s. Since the 1990s these institutions have published estimates of potential output and output gaps as a part of their macroeconomic forecasts. The output gap is the central concept in the New Keynesian theory, where it enters the New Keynesian Economics Phillips curve and the Taylor Rule governing the monetary policy (Clarida et al., 1999).

The EC uses a production function methodology to estimate potential output for the EU Member States and the USA[3]. In this study we will concentrate on the big economies of the euro area and Austria, as well as the USA and Japan. The estimates of potential output are based on a sample of historical data extended by the short-term (t+2) forecast from spring 2019.

The point of departure is an aggregate production function that describes the current level of actual real GDP (chain-linked volumes at 2010 reference levels). The production function models real GDP, Y_t, using a Cobb-Douglas production function, with capital stock (K_t) and total hours worked (L_t) as factor inputs:

$$Y_t = TFP_t \cdot L_t^{\alpha} \cdot K_t^{1-\alpha}, \text{ where } \alpha \in (0,1). \qquad (A1)$$

The observed total factor productivity (TFP_t) represents the part of the actual output which cannot be explained by labour and capital inputs. The growth rate of the observed total factor productivity is usually called the Solow Residual, or the part of growth in real GDP that is not explained by changes in labour and capital used in production.

Potential output is defined as the level of output associated with constant (wage) inflation. The output gap as the relative deviation of real GDP from trend output describes the aggregate capacity utilization, so that a positive output gap indicates overutilization and rising inflationary pressure, which should ease once the capacity converges to normal levels. To identify the average utilization of labour, we first decompose total hours worked:

$$L_t = POP_t \cdot PRT_t \cdot (1 - U_t) \cdot H_t, \qquad (A2)$$

where POP_t denotes the population aged between 15 and 64 (working-age population), PRT_t the participation rate in percent of the working-age population, U_t the unemployment rate, and H_t are hours worked per person gainfully employed, i.e. employees and self-employed. The above definition uses the identity $LS_t \cdot (1-U_t) = LD_t$, involving the labour supply LS_t, the number of persons gainfully employed LD_t, and the unemployment rate U_t. Then,

$$L_T = POP_t \cdot \frac{LS_t}{POP_t} \cdot (1-U_t) \cdot \frac{L_t}{LD_t}, \qquad (A3)$$

where LS_t/POP_t represents PRT_t and L_t/LD_t represents H_t.

The output gap is defined as the relative deviation of real GDP from the potential output, $\overline{Y}_t$:

$$GAP_t = 100 \cdot \frac{Y_t - \overline{Y}_t}{\overline{Y}_t} \qquad (A4)$$

The business cycle influences the current total factor productivity TFP_t, the participation rate in percent of the working-age population PRT_t, the unemployment rate U_t and the hours worked per person employed H_t, while the trend components, indicated by an upper bar, depend on structural factors. We can decompose each of these series into a trend and cyclical component, the latter being removed when computing potential output.

The contributions of labour and capital to the growth of potential output are defined as follows:

$$\bar{l}_t = 100 \cdot \alpha \left(\frac{\overline{L}_t - \overline{L}_{t-1}}{\overline{L}_{t-1}}\right) \text{ where}$$

$$\overline{L}_t = POP_t \cdot \overline{PRT}_t (1 - \bar{v}_t) \cdot \overline{H}_t \qquad (A5)$$

3 The methodology is constantly being updated and improved. This conceptual work is carried out by the Output Gap Working Group (OGWG) in cooperation with the EU member states. For a detailed exposition, see Havik et al. (2014).

$$\bar{k}_t = 100 \cdot (1-\alpha)(\frac{K_t - K_{t-1}}{K_{t-1}}). \qquad (A6)$$

Here $\bar{v}_t$ denotes the natural rate of unemployment (NAWRU), or the trend unemployment rate. The contribution of TFP to the growth of potential output, g_t, is computed as a remainder:

$$\bar{f}_t = \bar{g}_t - \bar{l}_t - \bar{k}_t \text{ where } \bar{g}_t = 100 \cdot (\frac{\bar{Y}_t - \bar{Y}_{t-1}}{\bar{Y}_{t-1}}) \qquad (A7)$$

A1.1.1 Participation Rate and Average Hours-Worked

Labour force participation rates experience moderate business cycle fluctuations. The degree of cyclicality of participation rates is not uniform for all cohorts. For instance, womens' and older workers' labour market participation tends to react differently than that of prime-age male workers. Social and economic background can also play a role. Labour force participation rates have only recently recovered following a decrease after the Great Recession. Estimates for the US labour market suggest that cyclical fluctuations of aggregate participation rates may have become more pronounced (van Zandweghe, 2017).

The average hours-worked have traditionally been subject to pronounced business cycle fluctuations. Significant hiring and firing costs make adjusting hours worked („intensive margin") preferable to adjusting employment („extensive margin"). Empirical evidence shows that working hours have become more volatile over time, with marked differences between the Western European labour markets and the US labour market (Ohanian – Raffo, 2011).

Cyclical fluctuations of the participation rate and the average working hours must be removed when computing potential output. The EC methodology follows a pragmatic approach by applying the Hodrick – Prescott (1997) (HP) filter. The value of the smoothing parameter ($\lambda = 10$) follows the recommendations for annual data in Baxter – King (1999). This value is higher than the 6.25 advocated for annual real GDP by Ravn – Uhlig (2002).

A1.1.2 Unobserved Component Model

The trend in total factor productivity and the natural rate of unemployment (NAWRU) are estimated using unobserved component models. The following example of a simple unobserved component model splits the main observable variable into a trend and a cycle. The cycle is assumed to be influenced by another observable variable. This adds a second measurement equation to the system. The model can include exogenous variables.

Consider a simple unobserved component model:

$$X_t = \tau_t + c_t, \qquad (A8a)$$

$$\Delta\tau_t = \mu + a_t^p \sim N(0,\sigma_{a^p}^2) \qquad \text{trend, (A8b),}$$

$$\left.\begin{array}{l} c_t = \varphi_1 c_{t-1} + a_t^c \\ \Phi_t = \mu_{cu} + \beta c_t + a_t^{cu} \sim N(0,\sigma_{a^{cu}}^2) \end{array}\right\} \text{cycle (A8c, A8d)}$$

The first measurement equation decomposes the observed variable X_t in an unobserved trend τ_t and an unobserved cycle c_t. The trend is a simple (Gaussian) random walk with drift that fluctuates around a deterministic linear trend with the slope μ. This specification implies an $I(1)$ process for the trend. The cycle is an $AR(1)$ process with a (Gaussian) white noise error. The cycle feeds into an observable cyclical variable Φ_t. All error terms, a_t^p, a_t^c, and a_t^{cu}, are assumed to be independent and identically distributed, but their distributional parameters can differ in the cross section. In the case of the TFP trend, $X_t = \log(TFP_t)$ is the observed total factor productivity and Φ_t is the rate of capacity utilization. In the case of the NAWRU, X_t is the actual unemployment rate and Φ_t is the change in wage inflation (Phillips curve). Since the cycle feeds into an observable variable Φ_t, the above system has two measurement equations (A8a, A8d) and two state equations (A8b and A8c). A Phillips curve typically features exogenous determinants of price or wage inflation as independent variables – for example, the change in terms of trade, labour productivity and labour share.

Remark (Random Walk): The implementation used by the EC allows three specifications for the unobserved trend (A8b). These are a random walk with a constant drift, a second-order (nested) random walk, and a random walk whose drift follows a stationary $AR(1)$ process, respectively. The first and third option implies that the trend follows an $I(1)$ process, i.e. it becomes stationary after first differencing. A second-order random walk results in an $I(2)$ trend. The EC estimates a random walk with an $AR(1)$ drift for all countries under consideration in this study, which is important for the empirical modelling choices of Section A1.2, where we extend the exogenous trend model of the EC using panel-econometric estimates.

Remark (Bayesian Estimation): An unobserved component model can be estimated using the method of Maximum Likelihood or using Bayesian techniques. The EC uses a Bayesian estimate for the TFP trend and a Maximum Likelihood estimate for the NAWRU (Planas – Rossi, 2018). The Maximum Likelihood variant of the EC implementation can be applied to a richer set of models. The main advantage of using Bayesian techniques is that the bounds imposed on the various parameters of the model in the Maximum Likelihood estimation can be relaxed using prior distributions, effectively eliminating any boundary solutions for the estimates. On the other hand, the error bands for the productivity trend cannot be transferred to the estimate of potential output, negating the main benefit of a Bayesian approach.

A1.1.3 Trend of Total Factor Productivity (TFP)

The Cobb-Douglas functional form for the production function (A1) entails the equivalence of the Hicks-neutral and factor-augmenting technical change. This implies that the observed total factor productivity TFP_t conflates the efficiency in the use of the two inputs (EL_t, EK_t) with the degree of their utilization (UL_t, UK_t)

$$TFP_t = EL_t^a \cdot EK_t^{1-a} \cdot UL_t^a \cdot UK_t^{1-a}, \qquad (A9)$$

or, taking the natural logarithms,

$$log(TFP_t) = log(EL_t^a \cdot EK_t^{1-a}) + log(UL_t^a \cdot UK_t^{1-a}), \qquad (A10)$$

where $\log(EL_t^a \cdot EK_t^{1-a})$ represents τ_t and $\log(UL_t^a \cdot UK_t^{1-a})$ represents c_t.

Neither of the two components can be observed. Identifying the trend τ_t thus requires removing cyclical fluctuations in the two input factors L_t and K_t given by c_t. The cycle c_t is identified using the variations in the rate of capacity utilization sourced from business sentiment surveys.

A1.1.4 Non-Accelerating Wage Rate of Unemployment (NAWRU).

The trend of the unemployment rate is defined as the non-accelerating wage rate of unemployment (NAWRU), the dominant macroeconomic equilibrium concept for the labour market (Layard et al., 2005). The existing approaches for modelling the NAWRU and its companion concept of the non-accelerating inflation rate of unemployment (NAIRU) come in many flavours. Structural specifications of a Phillips curve view inflation as a function of discounted expected future marginal costs, where unobservable marginal costs are approximated by the labour share. Purely structural models often incorporate price and wage stickiness characteristic of the New Keynesian paradigm (Schorfheide, 2008). The NAWRU follows from a set of structural equations under the assumption that the labour market is in a long-term equilibrium. The second group of methods estimates the NAWRU directly using a variety of statistical techniques for decomposing the unemployment rate into a cycle and a trend. The EC methodology follows a midway between purely structural and purely reduced-form models. It allows the NAWRU to be estimated based on a Phillips curve, while also retaining flexibility by assuming that it follows a random walk (Gordon, 1997). This approach has the advantage that an equilibrium unemployment rate can be determined directly by imposing the condition of stable wage inflation (Hristov et al., 2017).

The Phillips curve postulates a negative relationship between wage inflation and the unemployment gap. An actual unemployment rate above the NAWRU puts a downward pressure on the rate of growth of nominal wages. The opposite is the case if the unemployment rate falls below the NAWRU. The other key variables include labour productivity and marginal costs approximated by the labour share. The terms of trade may play a role if the wage setters target the GDP inflation rather than consumer price inflation, or when the export sector dominates the outcomes of wage bargaining (Galí – Gertler, 1999). The Phillips curve thus captures the short-term variation of nominal wage inflation to changes in labour productivity, aggregate marginal costs and the employment gap represented by the cyclical component of the actual unemployment rate.

A1.1.5 Capital Stock

The capital stock describes the available inventory of gross fixed assets. The capital stock is accumulated using a perpetual inventory method. The EC methodology does not model capital utilization directly; formally, $\overline{K_t}=K_t$. Any cyclical fluctuation in capital utilization is assumed to be removed by the cyclical adjustment of the total factor productivity in the decomposition (A9).

A1.2 Extensions Using Panel Data

The hypothesis of directed technological change implies that the implementation of labour-saving technical change is not exogenously given, rather it is related to either the age structure of the working-age population (Acemoglu – Restrepo, 2019A) or the expected change in the size of the working-age population (Abeliansky – Prettner, 2017). Earlier work by Skirbekk (2004) points towards a negative impact of ageing on TFP growth resulting from hump-shaped life-cycle productivity profiles. These hypotheses motivate our departure from the EC-approach of country-specific TFP growth, which converges to a common value of 1 percent per year (cf. Table 2.5). We will use the relation between trend total factor productivity growth and demographic measures, an indicator of automation relying on ICT investment, and other variables often shown to drive long-term growth in output, in a series of panel data regressions. For the other macroeconomic variables of interest, we will use the same approach to create endogenous responses to demographic variations.

The prevalence of technological trends and macroeconomic cycles common to a group of countries makes panel data the preferred choice for an empirical inquiry of the economic consequences of demographic trends. Panel data convey time-variation in individual countries and cross-sectional variation. The existence of common trends and cycles induces inter-temporal and cross-sectional dependencies in model disturbances, which must be accounted for either explicitly or by using robust inference.

All model specifications include country-fixed effects to capture heterogeneity between countries that is not accounted for by the explanatory variables. In addition, some specifications also feature time effects, which help explain common time variation in the dependent variable that is not fully accounted for by the explanatory variables. The inclusion of fixed effects in empirical work is very common, where they serve as a kind of catch-all for factors that might affect the dependent variable but have been left out in the specification, and sometimes also for checking the robustness of the explanatory variables in explaining the variation of the dependent variable.

To obtain more representative estimates, the main group of countries under consideration (Austria, France, Germany, Italy, Japan, Spain, USA) is extended by including the following European Union member countries: Belgium, Denmark, Finland, Netherlands, Sweden and the United Kingdom. The estimation sample thus covers thirteen mature, advanced and not-too-small economies on an annual basis between 1980 and 2015. The following four sections present the models and estimates for the growth rate of the TFP trend, the change in the share of ICT capital in the capital stock, the aggregate rate of saving, and the consumer price inflation, respectively. For these variables we expect a direct relation to demographic developments, the remaining variables react indirectly, or they are exogenously given. If possible, we draw on values of the exogenous variables as published by the European Commission (2018).

To get an impression of how robust the estimates are to the choice of the model specification and the estimation method, we present several approaches for each variable. We select across the models for the long-term projections by using the Bayesian Information Criterion (BIC). The BIC is a popular model selection criterion that accounts for the variance of errors and the number of model parameters. When choosing between two models, the one with the lowest BIC is preferred. This measure penalizes overfitting by preferring a simpler model to a more complex model, unless the residual sum of squares of the more complex model is much smaller. Therefore, introducing time-fixed effects into a model does not necessarily produce a better model according to the BIC-criterion.

A1.2.1 Trend growth in Total Factor Productivity (TFP)

Let us begin with a few remarks on the dependent variable, the annual growth rate of trend TFP obtained using the unobserved component models by the EC. In Section A1.1.2, we already emphasized the stationarity of these growth rates. Secondly, contrary to most existing empirical studies, the use of trend estimates allows us to use the full set of annual observations rather than using time averages as a crude (but effective) means of getting rid of business cycles. The growth rates of actual TFP are strongly procyclical, whereas the growth rates of trend TFP should be free of cyclical fluctuations. The EC estimates of potential output, and similar estimates by other institutions, typically still include some cyclical fluctuations. The critique of excessive procyclicality of potential output estimates is frequently voiced in their evaluations (EU IFIs, 2018). For this reason, we control for the business cycle by adding the output gap to the regression model.

Turning to the empirical determinants of TFP growth, we begin with a general remark on demographic variables. In general, we seek to disentangle the scarcity effect related to the size of the labour force from the quality effect related to the change in its age structure. In the case of productivity growth, the quality effect is negative, as an older labour force is expected to be less productive.

The scarcity effect, on the other hand, should induce automation and thus work only indirectly through the improved structure of physical investments. The structural effect is represented by the ratio of the share of older (55–64) to middle-aged (25–54) workers, cf. Acemoglu – Restrepo (2019A). We capture the scarcity effect by the change in the Information and Communication Technology and software intensity of the capital stock (ICT), our proxy for labour-saving automation (Brynjolfsson – Hitt, 2000; Basu et al., 2001). Our definition of ICT includes software in addition to information and communication equipment. This is important since software as a means of production plays a crucial role in the process of automation and digitisation of business processes (van Ark, 2016). The ICT intensity is given by the share of ICT equipment and software in the total capital stock. The change in the ICT intensity of the capital stock is related to ICT investment, which tends to be volatile and procyclical like most investment expenditures. We therefore smooth the ICT intensity using an HP-Filter with smoothing parameter ($\lambda = 10$) to remove excessive fluctuations that are predominantly related to the business cycle.

In view of Danquah et al. (2011), we select the savings rate, trade openness and country-fixed effects as additional explanatory variables. The more an economy saves, the more it can invest. Conventional wisdom suggests that more open economies feature higher levels of competition on domestic markets, and they have better access to new technology. Some of this technology is embodied in the goods traded, but other transmission channels via trade in services and foreign direct investment can also be important. Danquah et al. (2011), however, find that openness is negatively correlated with technical progress, surmising that openness is important in the catching-up phase of economic development, but becomes detrimental once the economy nears the technological frontier[4]. Even though some of our models corroborate the negative effect of openness, we find the sign of the effect implausible and the explanation rather unconvincing. It is reasonable to assume that rising openness ceases

4 Although, they find openness to be positively correlated with changes in economic efficiency.

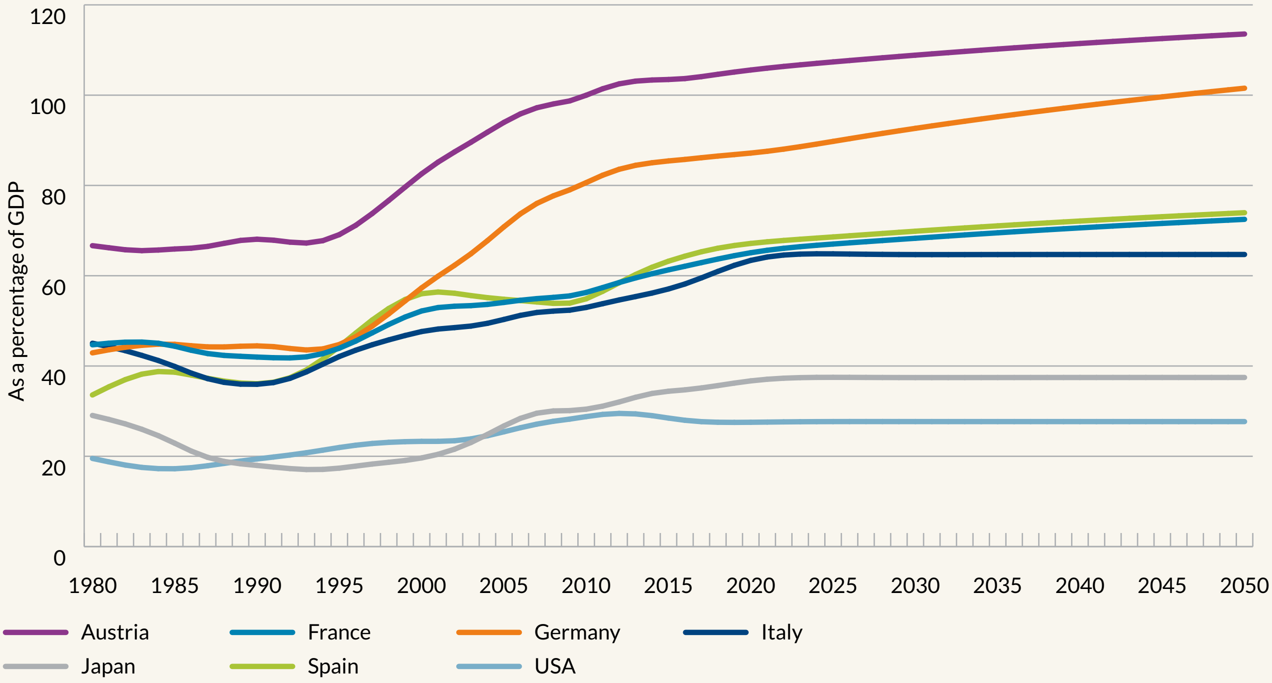
to increase the spread of technology once a certain level of development has been attained. Figure A1.1 shows the history for the ratio of exports and imports to GDP and the forecast resulting from a univariate exponential smoothing method (cf. section A1.3.1). The forecasts show a moderate increase in openness over the next decades with the USA, Italy, and Japan converging quickly to stable values. The negative effect of openness is also at odds with other empirical findings, e.g. Miller – Upadhyay, 2000. The effect of initial GDP is relevant for developing economies, where it can contribute to explaining high rates of growth during a catching-up process. In our models this effect is subsumed in the country-fixed effect.

Table A1.1 presents these sets of estimates, separately for the age structure and the change in the ICT intensity, and for the full model that includes all explanatory variables. The estimates of all other models will be presented in this way. The first two columns show fixed-effect (FE) estimates with Driscoll – Kraay (1998) standard errors. These standard errors are robust to heteroskedasticity, serial correlation and cross-sectional correlation. The use of robust standard errors is justified by the three tests that assert the presence of serial correlation and cross-sectional dependence. These tests are: Pesaran (2004) parametric testing procedure for cross-sectional dependence, Wooldridge (2002) test for serial correlation, and a (modified) Wald heteroskedasticity test. They reveal significant serial correlation and cross-sectional correlation in disturbances. Based on these tests, we reject FE in favour of Feasible Generalised Least Squares (FGLS) and Prais-Winsten (PW), as likely more efficient and more robust alternatives. This also better reflects the structure of our panel (small N and large T) in comparison to what is assumed by the asymptotic properties of the FE-estimator. The FGLS estimate (shown in columns 3 through 5) assumes general cross-sectional dependence and country-specific first-order autocorrelation. Beck – Katz (1995) have shown that FGLS standard errors can be too optimistic (anticonservative) in small to medium-sized panels. They recommend using the PW regression instead, for which results are shown in columns 6 through 8 of Table A1.1.

Most estimates confirm significant negative effects of age-structure and positive effects of the ICT intensity. Being a ratio of shares, our age structure variable is unit-free. A negative coefficient of α implies that a unit change in the ratio of old to middle-aged workers decreases the growth of TFP trend by α percentage points. The negative sign confirms the dampening effect of bigger cohorts entering the age group of 55 through 65 years resulting from the hump-shaped lifetime productivity profile. The inclusion of time-fixed effects tends to make the effect of the ageing variable smaller. The growth of TFP trend increases by β percentage points following an increase in the ICT intensity by one percent. The positive sign of the coefficient for ICT intensity, on the other hand, confirms the indirect productivity enhancement from ageing, associated with the shift in the population age structure from middle-aged towards elderly workers. In most specifications, the effects of the output gap and the savings rate have the expected positive sign. Several specifications return a negative and statistically significant effect of openness, corroborating the conclusions reached in Danquah et al. (2011). This effect disappears when time-fixed effects enter the model.

The BIC identifies FGLS without time-fixed effects as the best fit. Since this specification returns an implausible sign on the openness variable, we deviate from the best-fit principle and choose the FGLS with time-fixed effects instead. This model has the lower BIC of the two models with time-fixed effects. The analysis of country-specific regressions shows that Spain may be an outlier, nevertheless, eliminating Spain from the panel leaves the estimates almost unchanged.

FIGURE A1.1 **Exports and imports (openness)**



Source: European Commission, WIFO calculations.

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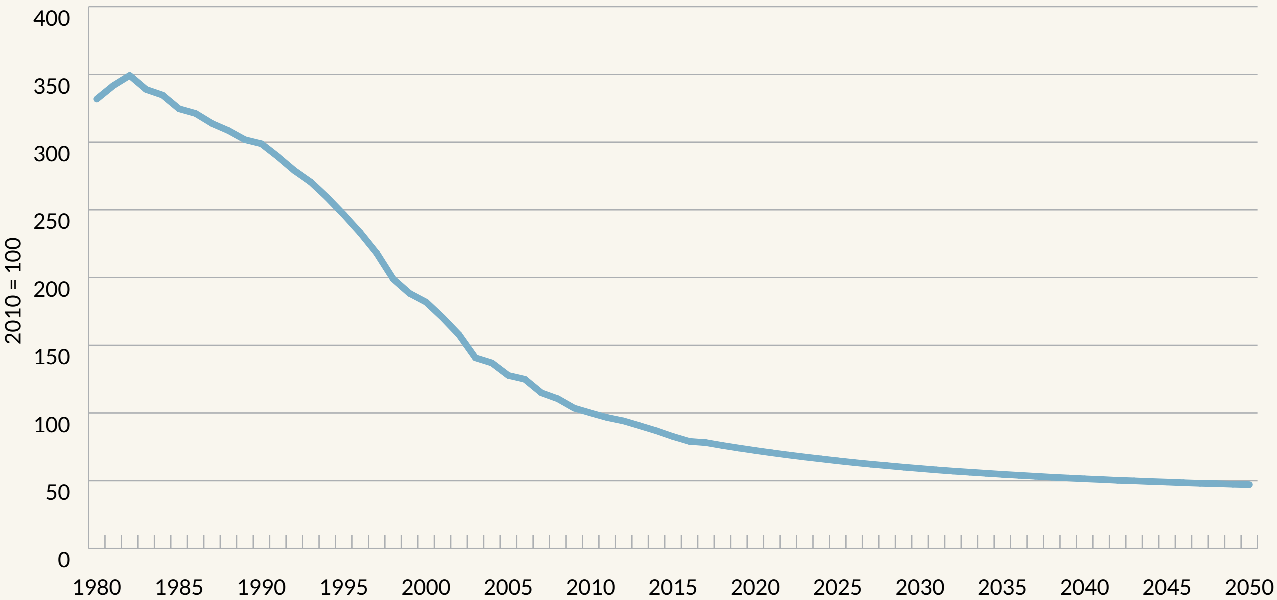
FIGURE A1.2 **USA: ICT price index**



Source: OECD, WIFO calculations.

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TABLE A1.1 **Trend growth of total factor productivity (TFP)**

	F.E.[1]	F.E.[1]	FGLS	FGLS	**FGLS**	PW	PW	PW
Ageing indicators								
Ratio of old to middle-aged workers	−0.0994 *** (−8.13)	−0.0485 *** (−5.49)	−0.0481 *** (−12.69)	−0.0588 *** (−18.93)	−0.0200 *** (−4.93)	−0.0549 *** (−5.28)	−0.0621 *** (−6.88)	−0.0225 * (−1.97)
Macroeconomic indicators								
Change in ICT intensity	2.6 ** (2.85)	3.0 *** (4.61)	1.1 *** (4.00)	1.4 *** (5.75)	1.3 *** (4.41)	1.7 * (2.14)	1.4 * (2.13)	1.6 (1.92)
Output gap		−0.0263 (−1.84)		0.0138 *** (5.84)	0.00482 * (2.04)		0.0116 * (2.01)	0.00357 (0.58)
Trade openness		−0.0246 *** (−10.18)		−0.00344 *** (−4.98)	0.000306 (0.57)		−0.00571 ** (−3.21)	0.000923 (0.49)
Savings rate		0.0637 *** (7.50)		0.00253 (0.78)	0.0108 *** (3.82)		0.0107 (1.22)	0.0125 (1.46)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes
Time dummies	no	no	no	no	yes	no	no	yes
H0: Cross-sectional independence	17.5 ***	4.9 ***						
H0: Absence of serial correlation	13087.1 ***	12848.5 ***						
H0: Groupwise hemogeneity	13504.2 ***	708.4 ***						
BIC				3213	**3490**		3459	3654
Years	35	35	35	35	35	35	35	35
Countries	13	13	13	13	13	13	13	13

[1] Driscoll-Kraay standard errors.
Numbers in parenthesis are t-statistics; *** 1 percent; ** 5 percent; * 10 percent level of significance.

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A1.2.2 Share of Information and Communication Technologies (ICT)

The second set of regressions models the change in the ICT intensity of the capital stock. Investment is a forward-looking activity aimed at changing production capacity and improving future productivity. This suggests the use of expected rather than current demographic indicators. Table A1.2 reports the estimates. As an additional variable we include the output gap as a measure of the cyclical position and the deflator of ICT capital as the relevant price (Jorgenson – Stiroh, 2000; Gust – Marquez, 2004).

The FGLS and the PW models are estimated with or without time-fixed effects. Including time effects is reasonable in view of the pronounced upward trend in ICT intensity observed in the past. A negative coefficient of α on the expected population growth tells us that a decrease in the expected growth by one percentage point increases the ICT share by α percent. The estimates imply that an anticipated future labour shortage should spur investment in automation and, in combination with our model for TFP growth, strengthen productivity today. The size of the coefficient on the ageing indicator in the FGLS and the PW models varies between −0.1 and −0.4, depending on the number of explanatory variables, the inclusion of time-fixed effects and the estimation method. Our preferred choice according to the BIC criterion of goodness of fit is the FGLS regression including time-fixed effects. The coefficient on the output gap tends to be positive, but it is not statistically significantly different from zero. The negative coefficient on the ICT price is statistically significant, showing the importance of declining ICT prices on the ICT investment and consequently the ICT intensity of the capital stock.

A1.2.3 Aggregate Saving

Aggregate saving comprises the savings of private households, the savings of enterprises, the savings of the general government (budget balance), and the savings of the foreign sector (current account balance). All four types of saving have their own quite diverse determinants, which we will briefly discuss in the following.

We can identify three main motives for private households to save: for retirement and bequests, for large expenses (e.g., housing, education) and as a precaution for economically bad times. The main theoretical explanation for a relationship between age and saving is the life-cycle hypothesis. This hypothesis aims at explaining the consumption and saving behaviour of a private household over the life-span of an individual. It assumes that the members of a household prefer to maintain a stable lifestyle over time. To achieve this, they smooth their consumption by saving during periods of high economic activity and dissaving during periods without income from economic activity (Browning – Crossley, 2001). This pattern is most pronounced over the life-cycle because children, adolescents and young adults typically cannot save, as they have no income. Similarly, retirees will have to finance their consumption expenditures through public pensions and annuities paid out from occupational or private capital-based pension systems.

A similar smoothing effect can be expected with respect to income fluctuations associated with the business cycle. Private households have means for spending in times of economic upturns, but also an incentive to save for economically less fortunate times. On the other hand, they will draw from their reserves during a downturn when income from bonus payments and overtime hours is curtailed or during episodes of unemployment. Our empirical model therefore features the current young dependency ratio and the old dependency ratio as demographic indicators. They are defined as the share of individuals aged between 0 and 24, and those 65 or older in the total population, respectively. We prefer two separate measures because the savings behaviour of families with kids may deviate from the behaviour of retirees.

TABLE A1.2 **Change in share of information and communication technologies (ICT)**

	F.E.[1]	F.E.[1]	FGLS	FGLS	**FGLS**	PW	PW	PW
Ageing indicators								
Expected growth of working-age population	−1.2 *** (−7.66)	−0.1 ** (−2.78)	−0.3 *** (−30.54)	−0.2 *** (−34.45)	−0.1 *** (−22.46)	−0.4 *** (−4.32)	−0.2 *** (−4.31)	−0.1 * (−2.53)
Macroeconomic indicators								
Output gap		−0.0102 (−1.44)		0.000642 (1.92)	0.000278 (1.25)		0.000953 (0.32)	0.000982 (0.57)
US deflator of ICT-capital		−0.00771 *** (−37.87)		−0.00689 *** (−161.07)	−0.00857 *** (−372.21)		−0.00684 *** (−13.22)	0.00380 *** (7.36)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes
Time dummies	no	no	no	no	yes	no	no	yes
H0: Cross-sectional independence	38.8 ***	2.1 **						
H0: Absence of serial correlation	14855.7 ***	308.4 ***						
H0: Groupwise hemogeneity	1340.4 ***	549.5 ***						
BIC				3530	**2207**		3276	3536
Years	35	35	35	35	35	35	35	35
Countries	13	13	13	13	13	13	13	13

[1] Driscoll-Kraay standard errors.
Numbers in parenthesis are t-statistics; *** 1 percent; ** 5 percent; * 10 percent level of significance.

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Turning to the additional control variables in the regression model, household saving depends on many institutional factors, including the coverage and generosity of the social security and welfare systems. The more inclusive and generous these systems are, the lower the incentive to save for retirement or to save against the loss of income due to disability will be. Household saving may also depend on the tax system. The relevant parameters of the tax code may include the tax burden on consumption relative to household income, or taxes on capital gains and inheritance. The effect of the real interest rate can be ambiguous, as the income and substitution effect associated with a higher interest rate affect saving in opposite ways. The substitution effect of the real interest rate depends on the change in the relative price between current and future consumption. A rising interest rate makes current consumption more expensive relative to future consumption, because the higher rate of return would permit a relatively higher future consumption level. The substitution effect will always lead to an increase in savings in response to higher interest rates. The income effect accrues from higher interest income resulting from an upward shift in the interest rate. This allows households to reach their target level of savings more quickly and it will therefore dampen their capital accumulation.

Turning to business saving, a higher interest rate increases the user cost of capital, which is the theoretical price of capital for a profit-maximizing firm. The concept of the user costs of capital, or its shadow price, plays a prominent role in the neoclassical theory of investment. Higher interest rates should make business investment less attractive. In the two recent decades, however, investment expenditure has been remarkably insensitive to changes in the interest rate, so that the sign of the overall effect of real interest rate remains an open empirical question. The user costs of capital also depend on the tax and subsidy system. We would expect the overall effect of the real interest rate to be negative, especially since investment is likely to be sensitive to the interest rate. The effect of the business cycle on firm saving is ambiguous, as both cash flow (profits) and financing constraints as well as investment spending tend to follow the cycle.

Finally, government deficits generally tend to be procyclical (Lane, 2003; Alesina et al., 2008) and strongly depend on the political system as well as financing constraints building up in times of financial distress.

Table A1.3 presents the estimates. In all specifications we see the expected negative effect of demographic dependency ratios, whereby both the share of young and the share of retirees in total population reduce aggregate saving. Since dependency ratios are unit-free, their coefficients convey the effect of a unit change on aggregate savings rate in percent. The negative coefficients on the young dependency ratio show that savings decrease when families have more kids. The effect of a rising old dependency ratio is stronger, but not always statistically significant. This may suggest that retired households do not dissave to the extent implied by the life-cycle model (Url – Wüger, 2005), as is shown by Börsch-Suppan et al. (2001) for Germany. The output gap has a positive effect, showing that saving tends to be procyclical overall. The effects of the retirement replacement rate and the real interest rate are negative but often not statistically significant. The BIC select the PW specification as the optimal one, but the two candidate models have comparable fits.

A1.2.4 The relation between saving, investment and the current account

In a closed economy aggregate saving must equal aggregate investment. Both variables are endogenous variables in macroeconomic models, and they will usually depend on the interest rate, current income, expected future income, expected net profitability and other variables. In general, economies are open to trade in goods and services, and they allow free movement of capital. In this case, the residents in one country can borrow and lend across borders either directly or more likely through financial intermediaries, and the relation between domestic savings and investment must be extended by international flows of financial assets. The associated stock variable to the current account balance is the net international investment position of a country. If a country is a net creditor, like Germany, the net international investment position is positive, which implies that this coun-try has a claim on foreign output, i.e. it owns assets issued by a foreign institution providing an interest or a dividend stream. If a country is a debtor country, like the USA, the net in-ternational investment position is negative, which implies that this country owes part of domestic output to foreign creditors, i.e. this country issues securities to foreigners and pays interest or dividends to foreigners.

The current account balance of a single year corresponds to the change in the net international investment position (given no change in the value of international assets). If we allow for changes in valuation, e.g. due to exchange rate movements, price changes or a depreciation of non-performing assets, the change in the net international investment position would include an extra position showing changes in valuation.

Because the current account, CA_t, of an open economy reflects the imbalance between domestic savings, S_t, and investment, I_t, we can use the following identity:

$$CA_t = S_t - I_t = Y_t + r_t\, NIIP_t - C_t - I_t. \qquad (A11)$$

Next, we can substitute savings by the difference between aggregate income and consumption, C_t. The aggregate income of an open economy comprises domestic output, Y_t, and the net inflow of capital income from the rest of the world $NIIP_t$, where r_t denotes the return on net foreign assets.

A1.2.5 Inflation

The central bank can affect nominal GDP in the short run by increasing or decreasing the money supply or its target interest rate. Raising or lowering the target interest rate constitutes a classic transient shock to an economy. The stance of monetary policy is defined with respect to the natural rate of interest. The natural rate of interest is a short-term interest rate that is compatible with potential output and stable inflation. Setting the policy rate equal to the natural rate would happen if the output gap is closed and the inflation rate is within the desired range (Taylor, 1993). Monetary policy is said to be restrictive if the target rate is greater than the natural rate. The

TABLE A1.3 **Aggregate saving**

	F.E.[1]	F.E.[1]	FGLS	FGLS	PW	PW
Ageing indicators						
Young dependency ratio	−0.407 *** (−7.09)	−0.323 *** (−6.61)	−0.232 *** (−3.77)	−0.161 ** (−2.76)	−0.245 (−1.55)	−0.204 ** (−2.61)
Old dependency ratio	−0.883 *** (−12.53)	−0.807 *** (−10.37)	−0.520 *** (−4.72)	−0.282 ** (−2.80)	−0.489 (−1.83)	−0.344 * (−2.44)
Macroeconomic indicators						
Output gap		0.466 *** (9.10)		0.481 *** (24.58)		0.491 *** (16.63)
Retirement replacement rate (single)		−5.974 *** (−3.79)		−1.404 * (−2.15)		−1.377 (−1.20)
Real interest rate		−0.130 * (−2.19)		-0.0161 (−0.78)		-0.0132 (−0.43)
Country dummies	yes	yes	yes	yes	yes	yes
Time dummies	no	no	no	no	no	no
H0: Cross-sectional independence	7.1 ***	1.2				
H0: Absence of serial correlation	332.2 ***	132.4 ***				
H0: Groupwise hemogeneity	777.5 ***	896.2 ***				
BIC				5168		**5086**
Years	36	36	36	36	36	36
Countries	13	13	13	13	13	13

[1] Driscoll-Kraay standard errors.
Numbers in parenthesis are t-statistics; *** 1 percent; ** 5 percent; * 10 percent level of significance.

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monetary policy should be accommodative if the policy rate is lower than the natural rate. A central bank will raise the target rate if the inflation rate is above the desired level and lower the target rate if inflation is too low. Alternatively, the central bank can base its stabilization policy on the unemployment rate. If the unemployment rate is above the natural level (NAWRU), this signals the need for a more accommodative monetary policy.

Like potential output and the NAWRU, the natural rate of interest cannot be observed and must be estimated indirectly. Capturing the effect of financial factors, productivity or risk preferences of households pose additional empirical challenges. Estimates show that the natural rates of interest in the USA and the euro area have been decreasing. The natural rates have declined sharply in the wake of the global financial and economic crisis of 2008 and even became negative in the euro area (Brand et al., 2018).

Conventional economic wisdom holds that, in the long run, inflation is a purely monetary phenomenon. Nevertheless, the empirical literature has identified population ageing as one of the few structural determinants whose relationship to inflation appears to be robust (Juselius – Takáts, 2018). This empirical evidence claims to account for exceptionally low inflation rates experienced by advanced economies in the past decades, and a sluggish reaction of inflation to monetary policy.

The study by Juselius – Takáts (2018) uses a particularly long set of data from 22 advanced economies from 1870 to 2016 to demonstrate that the increase in the dependent population ratio (children, adolescents, young adults and retirees) tends to positively correlate with higher inflation rates, but also that the effect becomes negative when the share of the oldest cohorts (80+) in the total population increases. These findings are consistent with the life-cycle hypothesis mentioned in the previous section. We therefore use the same set of demographic indicators as in the previous section where we discuss the modelling of the aggregate savings rate.

Turning to the other control variables, we include the previous year's output gap as a measure of inflationary pressure due to cyclical fluctuations in aggregate demand. The second control variable is an estimate of the natural rate of interest. The natural rate of interest is the rate that is compatible with the normal degree of aggregate capacity utilization, i.e. when actual output equals potential output (zero output gap). The rate of interest is thus neutral with respect to inflation. We use the aggregate of the monthly estimates for the USA, the Euro area and the UK published by the Federal Reserve Bank of New York, obtained using the one-sided version of the Holston et al. (2017) model. The Euro area estimate is assigned to each Euro area member state in our sample. As for Denmark, Japan and Sweden, we estimate the natural rate by applying the ubiquitous HP filter to the short-term real interest rate. The short-term rate should trace the natural rate if the central bank raises the short-term rate in response to inflationary pressures and cuts the rate once the pressure abates. The underlying assumption is, of course, that economic activity and prices react to policy changes in a timely fashion. Finally, we include trade openness. In general, the more open the economy is, the more pronounced the effect of import prices and exchange rate fluctuations on inflation will be.

The estimates are collected in Table A1.4. Each of the eight specifications return positive coefficients on demographic variables, corroborating the existing empirical evidence and the life-cycle hypothesis. The inclusion of time-fixed effects leads to smaller coefficients on demographic variables, leading to a loss of statistical significance. The lagged output gap has the expected positive sign. Higher than normal levels of aggregate capacity utilizations are indicated by a positive output gap and tend to increase inflation in the following year. The natural rate of interest has a positive and often statistically significant effect on inflation. All models show a positive effect of trade openness on inflation. The BIC model selection criterion suggests that the FGLS regression with the time-fixed effects offers the best trade-off between the size of the errors and the model complexity. We pick this specification as our final model.

A1.3 Projections

This section describes the methodology for developing long-term projections. Since our methodology takes many elements from the methodology detailed in the technical appendix of the Ageing Report (European Commission, 2017), especially with respect to the labour market, the following exposition will focus on variables used in the panel regressions presented in the previous section. The empirical models contain several exogenous variables whose future paths are required for a projection. We begin our discussion by showcasing the univariate exponential smoothing as a method of obtaining long-term forecasts of exogenous variables (Hyndman et al., 2008).

A1.3.1 Univariate Forecasting using Exponential Smoothing

Some exogenous input variables, such as the degree of openness or the price of ICT capital, are projected univariately using exponential smoothing state space models. The inclusion of a damping trend in the smoothing model ensures that projections stabilize in the future rather than increase or decrease indefinitely. This levelling off is desirable given that steep trends observed in the past – for example, the steep fall in the price of ICT equipment – are unlikely to persist over the long term. We therefore should expect more moderate price dynamics in the long run. The open question is at what level and how soon a series will level off. The following specification ensures convergence, such that the level and the rate of convergence are determined endogenously by the estimated model parameters. The exponential smoothing state space model can be used for smoothing historical data and for forecasting. We will use this model for forecasting only and rely on the HP filter for extracting past trends, as this is the current practice in the EC modelling approach.

The exponential smoothing state space model for a time series X_t with additive errors generated by a single disturbance term $\epsilon_t \sim N(0,\sigma^2)$ can be written as:

TABLE A1.4 **Inflation**

	F.E.[1]	F.E.[1]	FGLS	FGLS	**FGLS**	PW	PW	PW
Ageing indicators								
Young dependency ratio	0.706 ***	0.751 ***	0.676 ***	0.771 ***	0.173 *	0.856 ***	0.906 ***	0.204
	(5.04)	(5.17)	(9.30)	(10.43)	(2.07)	(5.33)	(6.88)	(1.78)
Old dependency ratio	0.354 ***	0.409 ***	0.361 ***	0.252 ***	0.121	0.475 **	0.347 *	0.148
	(3.62)	(4.53)	(6.79)	(4.22)	(1.74)	(2.60)	(2.31)	(1.16)
Macroeconomic indicators								
Previous year's output gap		0.141 *		0.145 ***	0.221 ***		0.118 *	0.197 ***
		(2.30)		(5.90)	(8.03)		(2.10)	(4.33)
Natural rate of interest		0.320 **		0.404 ***	0.155 *		0.495 ***	0.121
		(3.30)		(6.34)	(2.39)		(3.66)	(1.28)
Trade openness		0.0353 **		0.0722 ***	0.0488 ***		0.0944 ***	0.0502 **
		(2.74)		(8.61)	(4.85)		(5.98)	(3.08)
Country dummies	yes	yes	yes	yes	yes	yes	yes	yes
Time dummies	no	no	no	no	yes	no	no	yes
H0: Cross-sectional independence	18.3 ***	14.6 ***						
H0: Absence of serial correlation	48.4 ***	51.1 ***						
H0: Groupwise hemogeneity	124.7 ***	178.9 ***						
BIC				4259	**4231**		4534	4523
Years	35	35	35	35	35	35	35	35
Countries	13	13	13	13	13	13	13	13

[1] Driscoll-Kraay standard errors.
Numbers in parenthesis are t-statistics; *** 1 percent; ** 5 percent; * 10 percent level of significance.

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$$X_t = l_{t-1} + \phi b_{t-1} + \epsilon_t, \qquad (A12a)$$

$$l_t = \alpha l_{t-1} + \alpha\phi b_{t-1} + \alpha\epsilon_t, \qquad (A12b)$$

$$b_t = \phi b_{t-1} + \alpha\beta\epsilon_t. \qquad (A12c)$$

Here $\alpha \epsilon (0,1)$ and $\beta \epsilon (0,1)$ are the smoothing parameters. The damping parameter $\phi \epsilon (0,1)$ controls the rate of change of the trend. Equation (A12b) describes the level and equation (A12c) the change in the level. This interpretation of the two equations follows from the fact that an h-step ahead forecast of X_t tends to l_t in the absence of damping ($\phi = 0$). In the presence of damping ($\phi > 0$) this limit equals $l_t + {}^{\phi}/_{(1-\phi)}\ b_t$. To see this, observe that an h-step ahead forecast of X_t at time t is given by

$$\hat{X}_{t+h|t} = l_t + b_t \sum_{i=1}^{h} \phi^i \qquad (A13a)$$

$$l_t = \alpha Y_t + \alpha(1-\alpha)(l_{t-1} + \phi b_{t-1}), \qquad (A13b)$$

$$b_t = \beta \Delta l_t + (1-\beta)\ \phi b_{t-1}. \qquad (A13c)$$

The forecast converges to $l_t + {}^{\phi}/_{(1-\phi)}\ b_t$ for $h \to \infty$. The output of such a model comprises the estimates of α, β, ϕ and σ, as well as the paths of the unobserved components l_t and b_t and the forecast of the variable itself.

A1.3.2 Projecting Gross Domestic Product (GDP)

Obtaining a long-term path of real GDP requires projecting the three inputs of the production function (A1). When combined, these three inputs yield a projection of potential output, which conceptually represents real GDP in the long-run, i.e. when cyclical fluctuations first abate and then disappear, and the output gap closes.

Labour input

Our projections of the labour input as defined by equation (A2) update the projections published by the EC in the Ageing Report 2018 (European Commission, 2018) by incorporating the latest main population scenario of 2019 by Eurostat and the current forecast by the European Commission from spring 2019. The labour input in persons is based on three age cohorts: 15–24, 25–54, 55–65 and two sexes. The Ageing Report publishes participation rates for these six cohorts in five-year intervals, cf. Table 2.2. To obtain annual time series, we fill the missing years using linear interpolation. The updated labour force projections are thus based on the participation rates assumed in the Ageing Report 2018 combined with the most recent population scenario.

The next step is to project the rate of gainful employment. For this we need to project the unemployment rate. The projections of unemployment rates combine the most recent NAWRU estimates by the EC obtained using the methodology described in Havik et al. (2014) with the long-run assumptions detailed in the technical supplement to the Ageing Report (European Commission, 2017). Since, conceptually, the NAWRU represents the rate of unemployment in the long run, the EC methodology assumes the convergence of the actual unemployment rate to the NAWRU over the medium term (t+5), which in turn converges to an anchor value in the long term. This assumption corresponds to a closing of the output gap over the five-year period. Starting from t+5, the NAWRU thus represents the actual unemployment rate.

The anchor value essentially represents those determinants of the unemployment rate that can be traced to structural determinants of unemployment and labour market institutions. Orlandi (2012) argues that empirical factors that explain actual unemployment can also explain the trends of the actual unemployment rates represented by the NAWRU. Orlandi (2012) estimates panel regression models, separately for the old and the new member states. The anchor values for each country are based on the estimated coefficients of the panel models.

The structural factors used by Orlandi (2012) concentrate on the reservation wage and other determinants of the probability of a match between a job seeker and a firm. The reservation wage is the lowest wage rate at which workers are willing to accept a job. Increases in labour taxes or unemployment benefits (replacement rates) tend to raise the reservation wage and lower labour supply. Strong trade unions tend to create the insider-outsider situation, in which the unemployed cannot underbid the current wage (Lindbeck – Snower, 2001). In this environment, external adverse shocks to employment may lead to a permanent increase in the rate of unemployment (Blanchard – Summers, 1986). These structural and institutional labour market conditions belong to the set of supply-side determinants of unemployment. On the demand side, successful active labour market policies provide training that may otherwise have to be provided by the employer. They facilitate the search, thus improving the probability of a successful match.

The non-structural factors that are likely to affect the equilibrium unemployment rate include the rate of technical progress represented by TFP growth and the real interest rate. Changes in productivity growth affect unemployment through labour demand in the short term and through the substitution between labour and capital in a long-run perspective. An increase in the real interest rate depresses investment, which in turn lowers labour demand. The relative importance of the construction sector is an example of a persistently operating cyclical factor. In several European countries, unsustainable developments in the construction sector have exacerbated the impact to the global financial and economic crisis on the economy and the labour market.

The anchor value for the NAWRU represents a country-specific estimate of the value to which the NAWRU should converge in the long run. However, the EC methodology imposes additional convergence criteria for the member states' NAWRU to avoid „extrapolating into the far future very high unemployment rate values." (European Commission, 2017, p. 58). We adopt this assumption by using the long-term unemployment rates as published in the Ageing Report 2018. A smooth transition between the updated NAWRU projections in the medium-term and the long-term values in the Report is achieved by using a linear interpolation between the corresponding starting and end points.

The final step in projecting labour input involves average working hours. The methodology of the Ageing Report assumes constant average working hours for the age-sex cohorts in each country. Unfortunately, the Report does not publish the actual paths of the working hours or the total labour input. We therefore sourced the OECD data for the average working hours in 2017. The projection assumes constant working hours for three age-cohorts: 15–24, 25–54, 55–65 and two sexes. This assumption implies that future changes in total working hours emanate solely from shifting shares among age groups and both sexes.

Capital Input

The evolution of the capital stock is computed by applying the perpetual inventory method. Let I_t be the investment at time t and $\rho \in (0,1)$ is a constant rate of depreciation, then the perpetual inventory method defines the law of motion for the net capital stock K_t as

$$K_t = I_t + (1-\rho)K_{t-1}. \qquad (A14)$$

The second term says that a certain constant fraction of the previous year's capital stock is lost due to economic obsolescence of physical wear and tear. To project the capital stock, we thus only need to project investment. The EC methodology uses an estimate of the ratio of investment to potential output, which is assumed to follow a univariate autoregressive process, as detailed in (Havik et al. (2014), p. 76 and 77)[5]. When combined with the estimates of potential output, univariate forecasts for the investment ratio produce a path for investment, which in turn delivers the path of capital stock when substituted into equation (A14).

The above procedure is used to develop projections till t+10. Projections beyond this horizon make use of the idea that capital accumulation in the long run must be balanced against the growth of labour input and productivity growth. To achieve a balanced growth path, the ratio of capital to

5 There are exceptions to this rule, notably Germany, where a different adjustment procedure is used. Investment paths for the new member states are also obtained using more ad hoc procedures.

labour expressed in efficiency units must converge to a constant. This balancing ensures that an economy will follow a steady state path eventually. However, imposing a constant ratio may cause an implausibly sharp jump in investment. To avoid this, the EC methodology moves the point of convergence further out and assumes a gradual (linear) adjustment until convergence is achieved. Specifically, the 2018 Ageing Report assumes the equality of capital and labour (in efficiency units) from 2034 onwards. The above two-step procedure defines the future evolution of the capital stock.

Productivity Input (TFP)

The methodology used to project the TFP growth in this study fundamentally differs from the way the EC projects productivity trends. The EC defines a scenario in which the group of countries whose current GDP per capita is above the average GDP per capita of all member states converges to 1 percent TFP growth in the long run (0.8 percent by 2045). The rates of convergence for the other countries inversely depend on their current relative GDP per capita. The further they are from the average, the faster their productivity will grow. In our sample, only Italy and Spain are currently below the EU28 average, so they should experience slightly faster rates of productivity growth than, say, Germany, France or Austria. Nevertheless, this effect is negligibly small, since these countries are only slightly below the current average. The convergence-based boost to economic growth is markedly stronger for the new member states, whose per capita incomes are well below the average. In the very long term, however, the TFP trend should settle to an annual rate of 1 percent in all member states. In view of the labour share of 0.65, this TFP growth implies a growth of labour productivity of 1.5 percent per year.

The aim of this study is to account for the effect of an ageing population on productivity growth. We therefore use the empirical models for the TFP trend, ICT intensity (including software) and the savings rate estimated in Section A1.2 to simultaneously determine the future TFP path. Simultaneity is inevitable since the TFP trend depends on the ICT intensity as our simple proxy for investment in automation and digitisation of the economy. The future paths of openness and the price of ICT are obtained using the exponential smoothing state space model described in A 1.3.1. For simplicity, both the real rate of interest and the natural rate of interest have been set at 1 percent for all countries. The replacement rate of the pension system has been kept constant for the whole projection period, as this quantity is an institutional variable. The output gap is assumed to halve every year and thus to converge to zero rather quickly.

To achieve a smooth transition from the current value to the first projection value, the country-specific residuals of the panel regression models have been kept constant rather than set to zero. Doing so is particularly important for models that contain time effects reflecting past trends, since they cannot be meaningfully extrapolated in the future. Working with end-of-estimation sample residuals helps to achieve a smooth transition between the observed data and their projections, while also allowing demographic projections to play a role in shaping the future paths. In a final step, all trending series, such as the TFP trend, ICT intensity and potential output, have been subsequently smoothed using an HP filter with the smoothing parameter $\lambda=100$. This last step ensures a smooth transition. The effect of smoothing is negligible beyond the first year of the projection, because the trending series are already quite smooth by construction.

Our closing remark pertains to the estimates for Japan and the USA. Both countries are not included in the Ageing Report 2018. Nevertheless, projections for participation rates and the current average hours worked are available for both countries from other sources. The NAWRU estimate is available for the USA but not for Japan. For Japan, we estimate the NAWRU by applying the HP filter to the time series for unemployment. The remaining estimates all follow our extension of the EC methodology of the recent Ageing Report.

A1.4 Data Sources

Growth of working-age population	wpg	Eurostat, Population on 1st January by age and sex; Population projections at national level (2018–2100), June 2019; United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition.
ICT intensity	ict	OECD, National Accounts Statistics; Kirsten Jäger (The Conference Board), EU KLEMS Growth and Productivity Accounts 2017 release – Description of Methodology and General Notes, Revised July 2018.
Natural rate of interest	nr	Natural Rate of Interest, Holston-Laubach-Williams (One-Sided), Federal Reserve Bank of New York; European Commission, AMECO, Spring 2019.
Old dependency ratio	owr	Eurostat, Population on 1st January by age and sex; Population projections at national level (2018–2100), June 2019; United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition.
Output gap	ygap	European Commission, CIRCABC, Output gaps.
Ratio of old to middle-aged workers	omr	Eurostat, Population on 1st January by age and sex; Population projections at national level (2018–2100), June 2019; United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition.
Real interest rate	rr	European Commission, AMECO, Spring 2019.
Retirement replacement rate (single)	penrr	Égert, Gal and Wanner (2017), "Structural policy indicators database for economic research (SPIDER)", OECD Economics Department Working Paper No. 1429.
Savings rate	sr	European Commission, AMECO, Spring 2019.
Trade openness	openness	European Commission, AMECO, Spring 2019.
US deflator of ICT capital	uspict	OECD, National Accounts Statistics.
Young dependency ratio	ywr	Eurostat database, Population on 1st January by age and sex; Population projections at national level (2018–2100), June 2019; United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition.

TABLE A1.5 **Decomposition of direct and indirect effects from demographics on TFP Trend – Potential Output –** Average annual percentage changes

	Szenario: TFP-growth at …	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	0.27	0.00	–0.16
	projected population without automation	0.13	–0.12	–0.29
	projected population including automation	0.13	–0.12	–0.29
France	constant population	0.04	–0.11	–0.11
	projected population without automation	–0.04	–0.16	–0.10
	projected population including automation	–0.03	–0.17	–0.10
Germany	constant population	–0.11	–0.42	–0.41
	projected population without automation	–0.22	–0.44	–0.44
	projected population including automation	–0.23	–0.44	–0.44
Italy	constant population	–0.24	–0.66	–0.97
	projected population without automation	–0.50	–1.02	–1.18
	projected population including automation	–0.49	–1.02	–1.19
Spain	constant population	0.23	–0.19	–0.47
	projected population without automation	0.00	–0.61	–0.76
	projected population including automation	0.01	–0.61	–0.77
Japan	constant population	–0.76	–0.84	–1.22
	projected population without automation	–0.94	–1.26	–1.58
	projected population including automation	–0.93	–1.26	–1.59
USA	constant population	0.28	0.19	0.33
	projected population without automation	0.33	0.30	0.38
	projected population including automation	0.33	0.30	0.38

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.6 **Decomposition of direct and indirect effects from demographics on TFP Trend – Potential output per capita in 2010 Euro**

	Szenario: TFP-growth at …	2030	2040	2050
		Deviation from baseline in percentage points		
Austria	constant population	–1,099	–2,848	–5,044
	projected population without automation	–1,820	–4,223	–7,234
	projected population including automation	–1,821	–4,230	–7,219
France	constant population	–1,004	–2,780	–4,149
	projected population without automation	–1,340	–3,368	–4,759
	projected population including automation	–1,332	–3,374	–4,785
Germany	constant population	–1,002	–2,948	–5,029
	projected population without automation	–1,612	–3,716	–6,054
	projected population including automation	–1,612	–3,732	–6,053
Italy	constant population	–117	–1,514	–3,567
	projected population without automation	–1,006	–3,442	–6,072
	projected population including automation	–968	–3,420	–6,077
Spain	constant population	15	–1,342	–3,525
	projected population without automation	–750	–3,409	–6,548
	projected population including automation	–723	–3,387	–6,565
Japan	constant population	–1,937	–3,333	–7,037
	projected population without automation	–2,838	–6,467	–12,469
	projected population including automation	–2,759	–6,377	–12,423
USA	constant population	–1,381	–3,024	–3,525
	projected population without automation	–1,124	–2,196	–2,310
	projected population including automation	–1,146	–2,222	–2,314

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.7 **Decomposition of direct and indirect effects from demographics on TFP Trend – Productivity (Production per hour worked) –** Average annual percentage changes

	Szenario: TFP-growth at …	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	–0.05	0.01	–0.02
	projected population without automation	–0.18	–0.11	–0.15
	projected population including automation	–0.18	–0.11	–0.15
France	constant population	–0.04	0.01	–0.01
	projected population without automation	–0.11	–0.04	0.00
	projected population including automation	–0.11	–0.04	–0.01
Germany	constant population	0.00	–0.01	–0.04
	projected population without automation	–0.11	–0.03	–0.08
	projected population including automation	–0.12	–0.03	–0.07
Italy	constant population	0.01	0.01	0.00
	projected population without automation	–0.25	–0.35	–0.22
	projected population including automation	–0.24	–0.36	–0.23
Spain	constant population	–0.06	0.01	0.02
	projected population without automation	–0.29	–0.41	–0.27
	projected population including automation	–0.28	–0.41	–0.28
Japan	constant population	0.12	–0.04	0.09
	projected population without automation	–0.06	–0.46	–0.27
	projected population including automation	–0.05	–0.46	–0.28
USA	constant population	–0.08	0.03	–0.03
	projected population without automation	–0.04	0.13	0.02
	projected population including automation	–0.04	0.13	0.03

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.8 **Decomposition of direct and indirect effects from demographics on TFP Trend– Gross domestic saving –** As a percentage of GDP

	Szenario: TFP-growth at …	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	–0.64	–2.16	–2.74
	projected population without automation	–0.64	–2.16	–2.74
	projected population including automation	–0.64	–2.16	–2.74
France	constant population	–0.80	–1.94	–2.35
	projected population without automation	–0.80	–1.94	–2.35
	projected population including automation	–0.80	–1.94	–2.35
Germany	constant population	–0.65	–2.09	–2.32
	projected population without automation	–0.65	–2.09	–2.32
	projected population including automation	–0.65	–2.09	–2.32
Italy	constant population	–0.81	–2.76	–4.03
	projected population without automation	–0.81	–2.76	–4.03
	projected population including automation	–0.81	–2.76	–4.03
Spain	constant population	–0.80	–2.69	–4.24
	projected population without automation	–0.80	–2.69	–4.24
	projected population including automation	–0.80	–2.69	–4.24
Japan	constant population	–0.66	–1.83	–3.14
	projected population without automation	–0.66	–1.83	–3.14
	projected population including automation	–0.66	–1.83	–3.14
USA	constant population	–0.88	–1.84	–2.12
	projected population without automation	–0.88	–1.84	–2.12
	projected population including automation	–0.88	–1.84	–2.12

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.9 **Decomposition of direct and indirect effects from demographics on TFP Trend – Gross fixed capital formation –** As a percentage of potential GDP

	Szenario: TFP-growth at …	2030	2040	2050
		Deviation from baseline in percentage points		
Austria	constant population	0.76	–0.74	–0.03
	projected population without automation	0.27	–1.03	–0.53
	projected population including automation	0.26	–1.02	–0.51
France	constant population	–0.20	–0.50	–0.08
	projected population without automation	–0.45	–0.53	0.02
	projected population including automation	–0.45	–0.54	0.01
Germany	constant population	–0.53	–1.51	0.08
	projected population without automation	–0.74	–1.43	–0.07
	projected population including automation	–0.76	–1.44	–0.06
Italy	constant population	–1.07	–2.84	–2.90
	projected population without automation	–2.30	–3.72	–3.38
	projected population including automation	–2.30	–3.76	–3.41
Spain	constant population	0.26	–1.41	–1.95
	projected population without automation	–0.96	–2.66	–2.51
	projected population including automation	–0.94	–2.70	–2.56
Japan	constant population	–1.59	–2.03	–3.76
	projected population without automation	–2.52	–3.13	–4.53
	projected population including automation	–2.50	–3.16	–4.56
USA	constant population	0.22	0.34	0.65
	projected population without automation	0.42	0.54	0.66
	projected population including automation	0.41	0.55	0.68

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.10 **Decomposition of direct and indirect effects from demographics on TFP Trend– Current account balance – As a percentage of GDP**

	Szenario: TFP-growth at …	2030	2040	2050
		Deviation from baseline in percentage points		
Austria	constant population	–2.18	–1.82	–2.91
	projected population without automation	–1.70	–1.53	–2.41
	projected population including automation	–1.68	–1.53	–2.42
France	constant population	–1.24	–1.77	–2.32
	projected population without automation	–1.00	–1.74	–2.43
	projected population including automation	–0.99	–1.73	–2.42
Germany	constant population	–0.91	–0.80	–2.45
	projected population without automation	–0.70	–0.87	–2.30
	projected population including automation	–0.67	–0.87	–2.31
Italy	constant population	–0.63	–0.72	–1.30
	projected population without automation	0.60	0.16	–0.82
	projected population including automation	0.60	0.20	–0.79
Spain	constant population	–1.95	–2.09	–2.61
	projected population without automation	–0.73	–0.83	–2.05
	projected population including automation	–0.75	–0.79	–2.00
Japan	constant population	0.46	–0.58	0.28
	projected population without automation	1.39	0.51	1.05
	projected population including automation	1.37	0.54	1.08
USA	constant population	–1.75	–2.35	–2.90
	projected population without automation	–1.95	–2.55	–2.92
	projected population including automation	–1.95	–2.56	–2.93

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.11 **Decomposition of direct and indirect effects from demographics on TFP Trend – Consumer Price Index** – Average annual percentage changes

	Szenario: TFP-growth at ...	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	0.23	0.78	1.01
	projected population without automation	0.23	0.78	1.01
	projected population including automation	0.23	0.78	1.01
France	constant population	0.29	0.74	0.93
	projected population without automation	0.29	0.74	0.93
	projected population including automation	0.29	0.74	0.93
Germany	constant population	0.24	0.79	0.91
	projected population without automation	0.24	0.79	0.91
	projected population including automation	0.24	0.79	0.91
Italy	constant population	0.32	1.18	1.87
	projected population without automation	0.32	1.18	1.87
	projected population including automation	0.32	1.18	1.87
Spain	constant population	0.30	1.07	1.75
	projected population without automation	0.30	1.07	1.75
	projected population including automation	0.30	1.07	1.75
Japan	constant population	0.23	0.66	1.15
	projected population without automation	0.23	0.66	1.15
	projected population including automation	0.23	0.66	1.15
USA	constant population	0.31	0.66	0.77
	projected population without automation	0.31	0.66	0.77
	projected population including automation	0.31	0.66	0.77

Note: Baseline assumes constant population fixed at values from 2018.

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TABLE A1.12 **Decomposition of direct and indirect effects from demographics on TFP Trend – TFP growth** – Average annual percentage changes

	Szenario: TFP-growth at …	ø 2018–2030	ø 2030–2040	ø 2040–2050
		Deviation from baseline in percentage points		
Austria	constant population	0.00	0.00	0.00
	projected population without automation	–0.10	–0.07	–0.09
	projected population including automation	–0.10	–0.07	–0.09
France	constant population	0.00	0.00	0.00
	projected population without automation	–0.05	–0.03	0.01
	projected population including automation	–0.05	–0.04	0.01
Germany	constant population	0.00	0.00	0.00
	projected population without automation	–0.09	0.00	–0.03
	projected population including automation	–0.09	0.00	–0.03
Italy	constant population	0.00	0.00	0.00
	projected population without automation	–0.17	–0.24	–0.13
	projected population including automation	–0.16	–0.24	–0.13
Spain	constant population	0.00	0.00	0.00
	projected population without automation	–0.15	–0.29	–0.17
	projected population including automation	–0.14	–0.29	–0.18
Japan	constant population	0.00	0.00	0.00
	projected population without automation	–0.11	–0.29	–0.22
	projected population including automation	–0.10	–0.29	–0.23
USA	constant population	0.00	0.00	0.00
	projected population without automation	0.03	0.07	0.03
	projected population including automation	0.03	0.07	0.03

Note: Baseline assumes constant population fixed at values from 2018.

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Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256
33311 Gütersloh
Phone +49 5241 81-0
www.bertelsmann-stiftung.de

Responsible for content
Dr. Martina Lizarazo López
Dr. Thieß Petersen

Authors
Dr. Serguei Kaniovski, Dr. Thomas Url

Graficdesign
Nicole Meyerholz, Bielefeld

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Address | Contact

Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256
33311 Gütersloh
Phone +49 5241 81-0

Dr. Martina Lizarazo López
Project Manager
Programm Megatrends
Phone +49 5241 81-81576
martina.lizarazo.lopez@bertelsmann-stiftung.de

www.bertelsmann-stiftung.de

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