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Contribution of demography to economic growth from 1870 to 2100: A cross-country comparison of Austria, Spain, and Sweden using NTA/NTTA data

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Contents

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Abstract

This paper has a twofold objective. First, we assess quantitatively the contribution of changes in the age structure of the population and in the stock of human capital to the growth rate of output per capita over the period 1870–2100. Second, we analyze the impact of changes in the population structure on the accumulation of wealth from 1870 to 2100. To do so, we use a general equilibrium model populated by overlapping generations, in which individuals may live up to a maximum of 105 years and make optimal decisions on their consumption of market- and home-produced goods, and on the supply of labor to the market and at home. The model uses NTA and NTTA data and is calibrated to match historical macroeconomic data on income, consumption, and labor supply from 1870 to 2014 in Austria, Spain, and Sweden.

We find that the overall contribution of the change in the population structure —age and education structure— to per capita income growth from 1870 to 2014 was around twenty five percent. The change in the age structure of the population explains over thirty percent of the observed per-capita income growth from 1870 to 1950. The contribution to income per-capita of the change in the education structure of the population was becoming increasingly important from 1950 to 2014 and will become, after the exogenous technological progress, the main driver of per-capita income growth in the future.

Given the current per-capita pension benefit profiles and assuming that future contribution rates cannot exceed thirty five percent, we also find that the aging of the population in Austria, Spain, and Sweden will prevent future increases in the stock of physical capital per worker.

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1 Introduction

Past changes in the population structure —age structure and educational structure— are related to many of the economic outcomes that we currently observe.[1] Already during the 18th century Malthus (1798) argued that population change and economic development are closely linked. While Malthus postulated a negative link between increasing population levels and economic growth given a finite resource, the relation changed during the industrial revolution when economic growth and population growth were positively related. However, economists did not account for population change in their models until the late 1960s (Samuelson, 1958; Coale and Hoover, 1958; Tobin, 1967) and more recently by Galor and Weil (2000) and Bommier and Lee (2003), to cite a few examples.

Many of the recent economic-demographic studies focus on the role of population aging for economic development, e.g. Cutler, Poterba, Sheiner, Summers (1990), Bloom and Williamson (1998), Kelley and Schmidt (2005), Acemoglu and Johnson (2007), Ashraf, Weil, and Wilde (2013) Cervellati and Sunde (2015), and Mason, Lee and Jiang (2016) among others. This literature has shown that future economic outcomes will be partially determined by current demographic processes. This is so even if fertility patterns sharply increase to replacement levels, which is known as "population momentum" in the field of demography. For instance, the generations born after World War II (WWII), known as baby-boomers, already had a strong influence on the rapid economic growth observed after the WWII, an effect known as first demographic dividend. These generations are expected to have a sizable impact on the sustainability of public transfer systems, such as the health system, the pension system, and on the accumulation of savings, seven to nine decades later.

Understanding how demographic processes impact the economy requires information that it is frequently not available. It needs, among others, long time series of national accounts, life cycle profiles of relevant economic variables, the evolution of the age composition of households over time, the evolution of the educational attainment across cohorts, and the change in the population structure. The goal of the National Transfer Accounts (NTA) project, and specifically the AGENTA project, is to understand how population growth and the change in the population structure have, and will, influence the macroeconomy around the World, and in Europe, respectively. To this end, several country teams are constructing a database about how people at each age consume, produce, and finance their future consumption either through public transfers, private transfers, or assets. In this paper we make use of this database and complement the data with historical information. However, due to limitations in historical data, it is necessary to implement and develop theoretical models that, together with the existing information, will allow us to backcast and forecast economic outcomes. This task will help us to better understand the relationship between demographic change and economic growth. Moreover, it will give us more reliable projections of the future accumulation of wealth.

[1] According to the Population Reference Bureau, demography is "the scientific study of human populations, including their sizes, compositions, distributions, densities, growth, and other characteristics, as well as the causes and consequences of changes in these factors". See http://www.prb.org/Publications/Lesson-Plans/Glossary.aspx.

Our goal in this paper is to quantitatively analyze the economic effects of changes in the age structure and the educational structure of the population in three European countries that are representative of Central, South, and North of Europe: Austria, Spain, and Sweden. In particular, by starting in 1870 and going up to 2100, we focus our analysis on two relevant topics in economic demography. First, we ask how economic measures such as output per capita would compare in the case that no change in fertility, mortality, and the educational structure take place. Second, we study the impact of changes in the population structure and the introduction of the welfare state on the accumulation of wealth. Specifically, we analyze the evolution of the wealth-to-output ratio over time and determine whether the implemented public education system and public pension system allow past, present, and future generations to consume more than they produce.

In order to study these two research questions we have constructed a computable general equilibrium (CGE) model with overlapping generations in which fertility, mortality, and the educational structure can be varied exogenously. Given that we aim at studying the impact of changes in the population structure, we have realistically reconstructed all the relevant demographic information for the three countries from year 1800 onwards.[2] Although a historical economic analysis has already been conducted for Spain and Sweden using a CGE model (de la Croix, Lindh, and Malmberg, 2008; Sánchez-Romero, Abio, Patxot, and Souto, 2016), up to our knowledge this is the first time in case of Austria.[3] Our model differs from Ashraf, Weil, and Wilde (2013) and more recently from Mason, Lee and Jiang (2016) in that our economic agents optimally respond to the new demographic circumstances. Thus, our model can better account for the growth rate of output per worker (also known as productivity component), which is frequently biased in models whose parameters are based on growth regression estimates due to endogeneity problems (Feyrer, 2007).

Our results suggest that demography accounts for around one-fourth of the total per capita income growth during the period 1870–2015. The contribution of demography to income growth was significantly higher during the period 1870–1950 (over thirty percent) and was dominated by the change in the age structure of the population, while the contribution of demography during the period 1950–2015 was smaller (over twenty percent) and driven by an educational dividend. We also find that the observed increase in the per capita income during the last hundred and fifty years was also accompanied by an increase in the aggregate wealth-to-output ratio. The evolution of this ratio was driven by two factors: the increasing life expectancy and the older age structure of the population. An important finding from our baseline simulation is that there is no further capital deepening, or increasing capital per worker, from year 2000 onwards. Our simulations suggest that this is mainly caused by the crowding-out effect of the pension system. This is true even when we restrict the social security contribution rate to thirty five percent, which implies a future replacement rate close to fifty percent. As a consequence, Austria, Spain, and Sweden will not benefit from a permanent second demographic dividend, which is consistent with previous

[2] The set of reconstructed demographic information contains data on age-specific mortality rates, age-specific fertility rates, net migration rates, and population distributions for both sexes combined. In the case of Sweden, the main task has been to correct for data inconsistencies and age-heaping problems observed in the historical data. These problems are discussed in the documentation of the Human Mortality Database (2016).

[3] The analysis has been done under the current border of the three countries.

findings by Prskawetz and Sambt (2014), for Austria and Sweden, and by Sánchez-Romero, Patxot, Renteria, and Souto (2013) for Spain.

The paper is organized as follows. Section 2 details the theoretical model, its implementation, and the exogenous economic and demographic information collected. Section 3 explains in detail the evolution of vital rates and the educational system in Austria, Spain, and Sweden. Section 4 presents the contribution of the demographic transition on the per-capita income growth rate in each country. The impact of the demographic transition on the evolution of the wealth-to-output ratio is discussed in Section 5. Section 6 concludes. We complement the paper with a detailed appendix with information on the reconstruction of each economic variables for the three countries and the CGE model implemented.

2 Implementation of the model

The results of the paper are obtained by simulating the development of three European economies from 1870 to 2100 that differ in the onset of their demographic transition, from high fertility and high mortality to low fertility and low mortality, and also in the introduction of the modern educational system, which complements the classical reading and writing with knowledge of algebra and calculus. The three countries analyzed are Austria, Spain, and Sweden. We choose these three countries since they represent well the typical economic and demographic pattern as observed in Central, South, and Northern Europe, respectively.

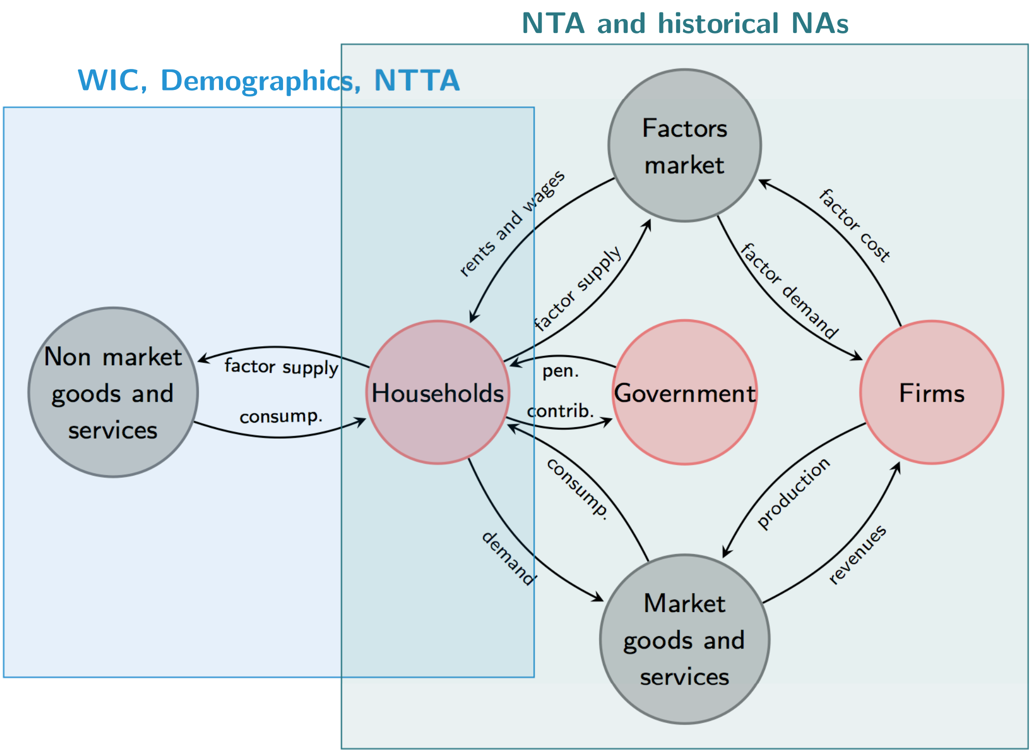


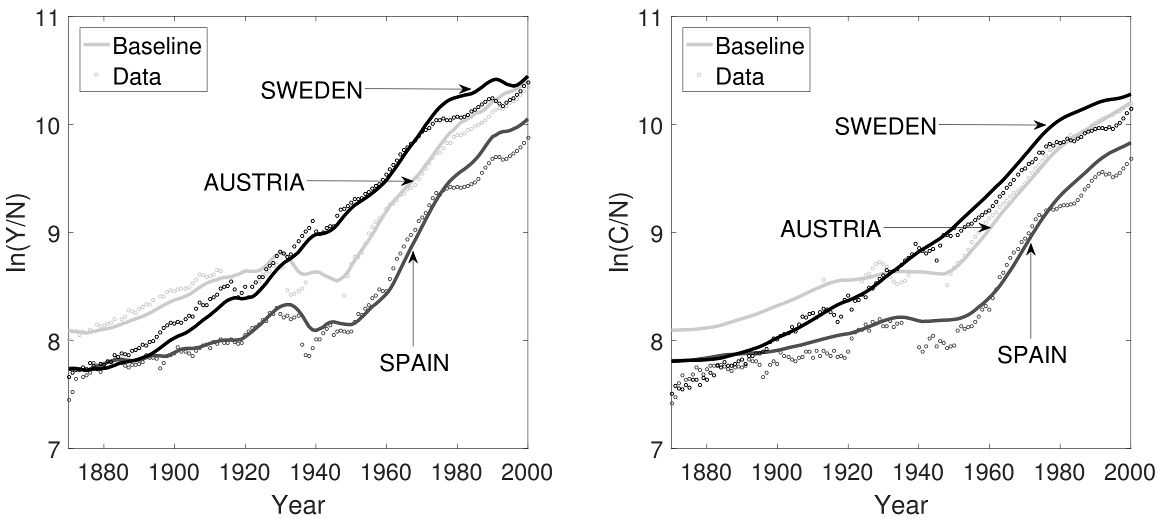
Figure 1: Model framework

The economic model, summarized in Figure 1, constitutes a large-scale OLG model à la Auerbach and Kotlikoff (1987) comprised of three types of agents (see red circles): households, firms, and a government. For a detailed explanation of the model see Sánchez-Romero, Abio, Patxot, and Souto (2016). Individuals face mortality risk and may live up to a maximum age of 105 years. Households are formed by an adult, or household head, and a number of dependent children. We set adulthood at age 16, rather than age 18, since the economic model starts from the 19th century and goes up to the 21st century. This implies that when children become 16 years old, they leave their parent's home and form a new household. The number of dependent children raised varies by age and across cohorts according to the observed and projected fertility and mortality patterns. Household heads are assumed to be heterogeneous by their level of education. We do so by randomly assigning each individual at birth to one of the following three ISCED levels developed by UNESCO: ISCED 0-2 (lower secondary education or less), ISCED 3-4 (upper secondary), and ISCED 5+ (tertiary). The evolution of education by birth cohort is based on a combination of data taken from the Wittgenstein Centre Data explorer (Wittgenstein Centre Database, 2015; Goujon et al., 2016) and historical enrollment rates in each ISCED group for Austria and Spain (Nuñez, 2005). Household heads endogenously choose the demand for consumption goods, both purchased in the market and produced at home, and the supply of labor to the market and to the production of home-goods. Total consumption of market-goods and home-produced goods is distributed among the surviving household members according to their age through the adult equivalent consumption function used in the National Transfer Accounts (NTA) and the AGENTA project (Istenič, Šeme, Hammer, Lotrič Dolinar and Sambt, 2016). Home-goods are produced combining time and intermediate goods purchased in the market. Moreover, household heads devote time to rear their children, which reduces the available time for work. A similar assumption can be found in Galor and Weil (2000). We consider childrearing time to be proportional to the time devoted to household chores and inversely related to the age of children based on National Time Transfer Accounts (NTTA) data (Vargha, Šeme, Gál, Hammer and Sambt, 2016). Thus, the total available time of each adult, which is limited by an exogenous time devoted to education while in school, is assumed to be optimally distributed among leisure, market work, household chores, and childrearing time.

Firms produce, combining capital and labor under a constant-returns to scale technology, a single good that can be either consumed, or used as an intermediate good for home-production, or saved as a store of value by individuals. We use the same standard capital share of 1/3 and capital depreciation rate of 5 percent in the three countries. This assumption makes the comparison across countries easier and allows us to focus on the relationship between demography, economic growth, and the accumulation of wealth. Firms operate in competitive markets paying for the stock of capital and labor supply demanded their marginal productivities.

The government provides public education to individuals attending school and pension benefits to retirees. Both public expenditures are financed through a balanced PAYG system via consumption taxes and social contributions, respectively. The cost of education and the pension system is considered by taking cross-sectional age profiles of educational benefits and pension benefits by educational attainment from the AGENTA database in year 2010. Before year 2010 the level of these profiles are adjusted so as to match historical macroeconomic data, while from year 2010 onwards the level of these profiles are assumed to increase at the same rate as productivity. In order to prevent the cost of pension benefits to cause an excessive burden on future workers, we set the maximum Social Security contribution rate to 35 percent. Thus, If the maximum social security contribution rate is reached, pension benefits will be adjusted downwards in order to balance the budget.

Besides the supply of labor to the market and for home production, the demand for market goods, intermediate goods, home-produced goods, and leisure, the economic model is complemented with exogenous historical information on demographics, time series on educational attainment, and technological progress. Based on historical censuses, by single years of age using generalized inverse population projections techniques, we reconstruct the demographic development for each country from 1800 onwards (Lee, 1985; Oeppen, 1993). The projection of the three populations from 2010 onwards is based on Eurostat's assumptions on fertility, mortality, and migration rates. The evolution of the educational attainment for the household heads born after 1870 is based on information from the Wittgenstein Centre Data explorer (Wittgenstein Centre Database, 2015; Goujon et al., 2016) and completed with historical data from Völlmecke (1979) for Austria and from Nuñez (2005) for Spain. The educational attainment for cohorts born before 1870 and after 2100 are held constant at the levels of 1870 and 2100, respectively. Labor productivity has also been calculated for the three countries from 1870 to 2014 by dividing the output, taken from historical national accounts data, by our own reconstruction of the stock of human capital (see Appendix A.1). Following the European Commission (2015), we set the future labor-augmenting technological progress at 1.5 percent per year. For further details see Appendix A.2.



(a) Income per capita (in logs) (b) Consumption per capita (in logs)

Figure 2: Per capita income and consumption measured in EUR 2010 in natural log, 1870–2000.

Source: Historical national accounts and authors' estimations.

We calibrate for each country preferences between market-produced goods, home-produced goods, leisure, and the risk aversion on leisure by minimizing a penalty function that contains information of three time series from 1870 to 2000: per capita income, per capita consumption, and average hours worked by the population between age 16 and 65, as well as the average per capita hours worked by educational attainment between 1998 and 2003. Moreover, for comparative purposes, we assumed the same subsistence level of market- and home-produced goods, and the same share of intermediate goods in home-production across the three countries. Figure 2 shows the fit of our baseline simulations to actual data on per capita income and per capita consumption from 1870 to 2000 for Austria (light gray), Spain (dark gray), and Sweden (black).

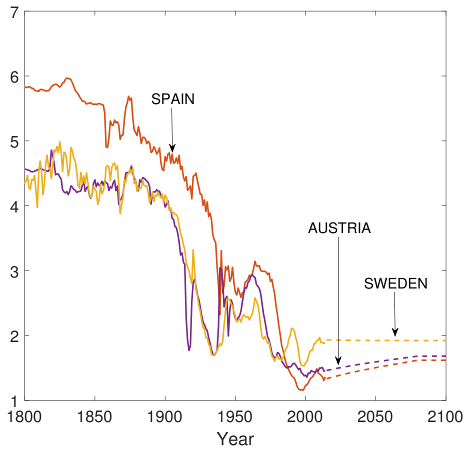
3 Demography of Austria, Spain, and Sweden

3.1 Vital rates

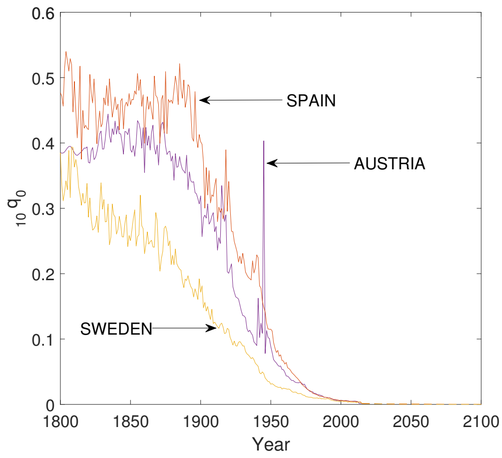
Figures 3(a)-3(d) plot the evolution of fertility and mortality rates for Austria, Spain and Sweden from 1800 to 2100. As evident by the TFR development in all three countries fertility declined during the second half of the 19th century and first half of the 20th century. Fertility levels decreased from values of about 6 to 3 in Spain, and from around 4.5 to a TFR of around 2 in Austria and Sweden. The pronounced drop of fertility in the 1914–1918 for Austria coincides with World War I. During the late 1950s and early 1960s, the baby boom induced an increase of the TFR to values of around 2.5 (in case of Sweden) and about 3 children per woman (in case of Austria and Spain). Thereafter fertility declined to values below 2 children per woman in the 1970s until the 1990s when fertility started to stabilize. Note that the fall in fertility was more pronounced in Spain while in Sweden and partly in Austria an echo effect of the baby boom becomes visible. The projections until 2100 assume a partial convergence across all three countries to a value of about 1.68, 1.62, and 1.92 children per woman in Austria, Spain, and Sweden, respectively, based on Eurostat's assumptions.

Infant mortality started to decline as early as in the beginning of the 19th century in Sweden. In Austria and Spain infant mortality did not decline before the last quarter of the 19th century in case of Austria and even not before the turn of the 20th century for Spain. During the 20th century infant mortality decline continued approaching values of about 1 per thousand in all three countries by the end of the 20th century. Note, that for Spain and Austria infant mortality continued to be much higher —compared to Sweden— during most of the 20th century. The huge peak in infant mortality for Austria around 1940s is explained by World War II.

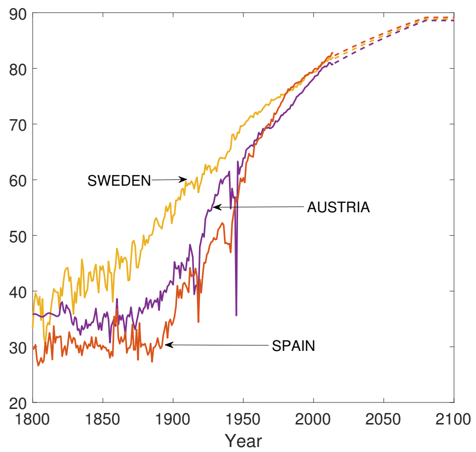
During the time span from 1800 to 2100 life expectancy increases in all countries from a value of around 30 years in Spain in 1800 and around 38/40 years in Austria/Sweden to values around 80 years at the beginning of the 21st century and is expected to approach 90 years in the convergence scenario in 2100. While Sweden was always leading in terms of gains in survival, the life expectancy in Austria and Sweden remained rather constant until the mid-19th century and started to increase in the late 19th and early 20th century. The pronounced drops in life expectancy in Spain and Austria during the 20th century are due to the Spanish flu in 1918 and the first and second World War in case of Austria. Note that life expectancy at age 15 (Figure 3(d)) did not change much in all three countries before



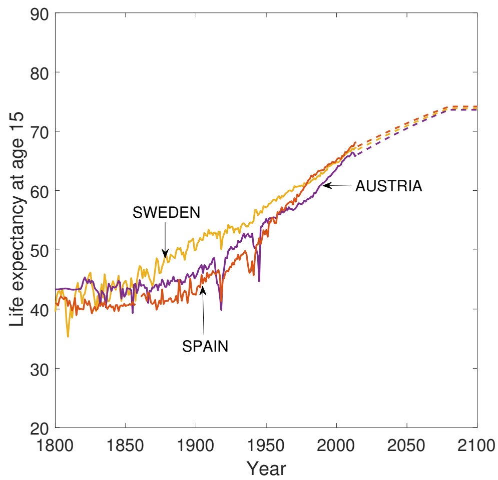
(a) Total fertility rate



(b) Infant mortality rate



(c) Life expectancy at birth



(d) Life expectancy at age 15

Figure 3: Historical and projected demographic information for Austria, Spain, and Sweden, 1800-2100

Source: Authors' estimations from 1800 to 2010 (solid lines) and Eurostat data from 2010 to 2100 (dotted lines).

the second half of the 19th century. During this time period improvements in mortality occurred mainly at infant ages. The increase in life expectancy at age 15 during the 20th century indicates improvement in mortality in adult and later on older ages.

Overall, though the trends in fertility and survival are similar across all three countries, the level and rate of change of fertility and mortality are quite distinct across the three countries. Obviously these heterogeneous demographic developments will also be related to the economic developments in these three countries.

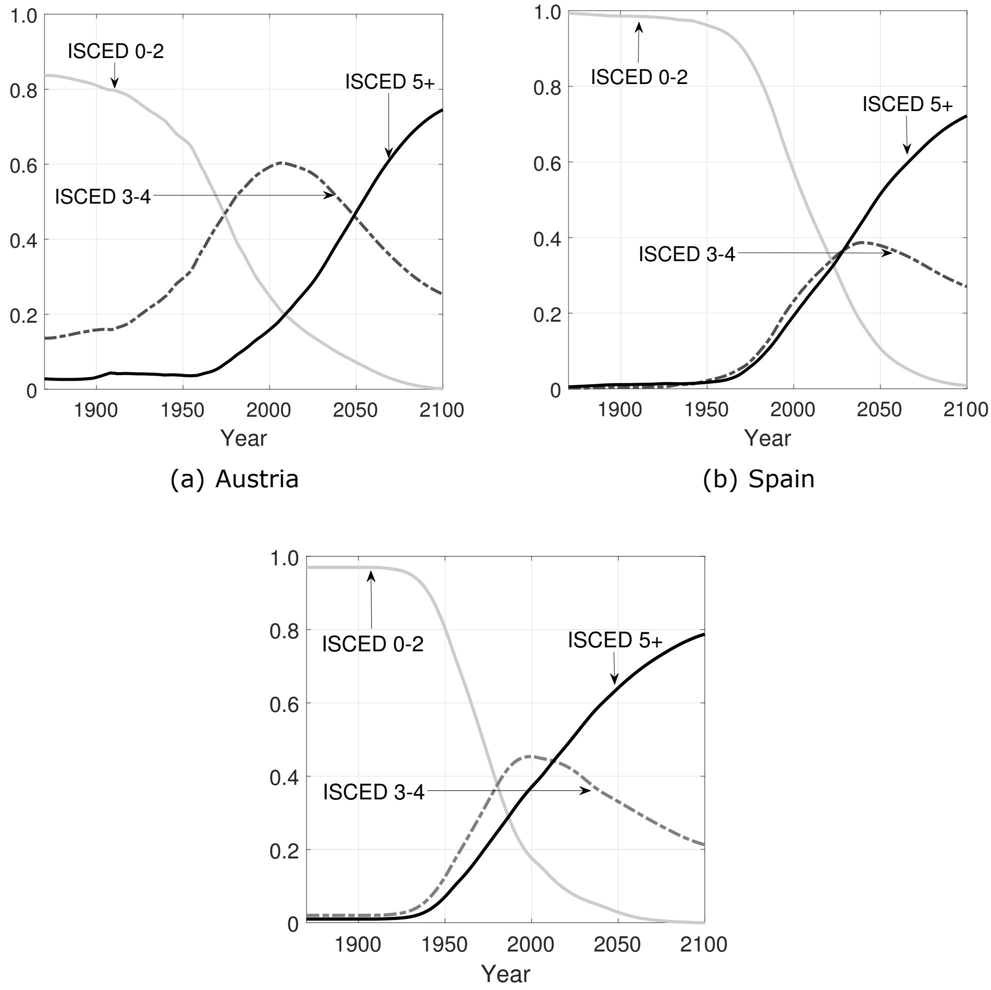
3.2 Education

Figure 4 plots the shares of the population between age 16 and 65 by educational attainment for Austria, Spain and Sweden from 1870 to 2010 and its projection to 2100. In order to improve the estimations for Austria and Spain, we combined historical records on enrollment rates in each educational group from Völlmecke (1979) for Austria and from Nuñez (2005) for Spain with data from the Wittgenstein Centre Database (2015).

The educational attainment by birth cohort has been reconstructed based on the assumption that education is acquired before age 30. Thus, we proceeded in the following way with data from the WIC human capital database. From the educational attainment by five-year age groups for the period 1970 to 2100 we constructed a new dataset by birth-cohort, age-group and educational attainment. We then calculated by birth cohort the fraction of people from age 30 until 60 in each ISCED level. When there is no information before age 60, which occurs for the earliest cohorts, we use the average of the value until the last age group available. Thus, for the cohort born in 1870 the educational attainment is based on one data point, for the cohort born in 1880 there are at least two data points, and so on. We continue these steps until we can observe the same cohorts from age 30 to 60.

For all three countries we observe that during the early 20th century a decrease in the share of lower secondary or less education was accompanied by a rise in the share of upper and post secondary education as well as an increase in the tertiary education. The level and onset of this change was however different in the three countries. Austria, which was a forerunner of the expansion of education with other countries like France and England, introduced eight years of compulsory education in 1870 (Flora, 1983). Sweden introduced a six-year compulsory educational system in 1878, extended it to seven years in 1936 and to nine in 1950 (Flora, 1983; de la Croix, Lindh, and Malmberg, 2008). In contrast to the experience of Austria and Sweden, the first Spanish generation that obtained eight years of education was born in the 1970s (Nuñez, 2005). As a result the educational distribution of the population is markedly different in the three countries between 1870 and 2100 (see Figure 4(a)). In Austria the share of upper and post secondary as well as tertiary eduction started to increase already around 1920. It was not before the 1940s (in Sweden) and the 1970s (in Spain) that a similar change in the educational composition took place. While the share of the working-age population with lower secondary and less education declined to less than 20 percent for Sweden by 2000, the corresponding share is about 60 percent for Spain and slightly more than 20 percent for Austria. Similarly striking is the difference in the share of the working-age population with tertiary educational level that reached almost 40 percent by 2000 for Sweden and is only slightly above 20 percent in Austria and Spain. Austria is the country with the highest share of the working-age population with upper and post secondary education in 2000 (about 60 percent) compared to 25 percent in Spain and 45 percent in Sweden. The shares are projected to progressively converge by year 2100 to 30 percent in the ISCED level 3–4 and 70 percent in the ISCED level 5+.

Since education is related to economic behavior these differences in the educational composition across Austria, Spain and Sweden will also induce different economic developments in these countries. We analyze these effects in the next section.



(a) Austria (b) Spain

(c) Sweden

Figure 4: Educational distribution of the population between 16 and 65 years old, 1870–2100.

Source: see the text. Note: The acronym ISCED stands for the International Standard Classification of Education developed by UNESCO. ISCED 0-2 corresponds to individuals with completed lower secondary or less, ISCED 3-4 corresponds to upper secondary and post-secondary non-tertiary, and ISCED 5+ represents those individuals with tertiary education.

4 Impact of demography on income growth

In the last three decades the literature has shown that the change in both the age structure of the population and the educational structure of the population had a significant impact on per capita income growth after World War II in many countries (Kelley and Schmidt, 1995, 2005; Bloom and Williamson, 1997, 1998). However, assessing the contribution of demography to per capita income growth is difficult, because demographic changes are related to the supply of capital and labor, not only directly through the change in the structure of the population, but also indirectly through the change in the behavior of individuals.

We can clearly distinguish four direct effects of the change in the structure of the population on per capita income growth. First, the population negatively affects per capita income growth when the number of dependent children grows faster than the working age population, in which case we may speak of a "youth burden". Second, the change in the age structure of the population positively affects per capita income growth when the working-age population grows faster than the dependent population, known as first demographic dividend. Third, the population may have a positive (negative) effect on per capita income growth when the elderly population, who mainly relies on assets (transfers) to finance their consumption, grows faster than the working age population. The positive effect is due to a capital deepening —second demographic dividend—, while the negative effect is due to a crowding-out. And fourth, the change in the educational structure of the population has a positive effect on per capita income growth when the working-age population also benefits from an increase in the average number of years of schooling. In addition to these direct effects, per capita income also changes due to a behavioral reaction to the new demographic setting. For instance, lower fertility promotes investment in human capital per child (Becker and Lewis, 1973), increases per capita consumption and savings, while lower mortality at old age boosts savings and labor supply (Sánchez-Romero, d'Albis, and Prskawetz, 2016). Therefore, looking exclusively at the contribution of the structural change of the population on the economy is insufficient for assessing the impact of demography on per capita income growth.

In this section, we aim at measuring the contribution of demography on per capita income growth. To do so, we follow Sánchez-Romero (2013) by comparing the baseline economy to three hypothetical economies. First, an economy, named H1, in which the age structure of the population as observed in 1800 continues until nowadays. The comparison of the baseline to H1 will inform us about the contribution of the change in the age structure and its behavioral reaction to economic outcomes. Second, an economy, named H2, in which the educational structure as observed in 1800 persist until now. That is, an economy formed by a working-age population mostly with less than lower secondary education and a small elite with tertiary education. Comparing the baseline economy to H2 shows the contribution of the increase in human capital and its behavioral reaction to economic growth. Last, since in reality there exists a correlation between education, fertility, and mortality, we consider a third economy, named H3, in which we assume that neither the population age structure nor the educational structure have changed since 1800. The difference between the growth rate of per capita income in the baseline economy and that in H3 takes into account the combined effect of the change in the age structure of the population, the change in human capital, and the behavioral reaction to both changes.

Table 1 reports the growth rate of per capita income in Austria, Spain, and Sweden from 1870 to 2015 and the contribution of demography to its growth. The third block of rows in Table 1, column IV, shows how Sweden experienced the fastest per capita income growth during the period 1870-2015, with an average annual growth of 2.05 percent, followed by Austria (1.81 percent) and Spain (1.73 percent). The annual growth rate of total income, reported in column II, was higher in Spain (2.45 percent) than in Austria (2.25 percent), but the faster population growth in Spain (0.72 percent) relative to that in Austria (0.45 percent) offset this increase. By splitting the per capita income growth rate from 1870 to

2015 into two periods, we obtain that the average economic growth was 1.84 percentage points higher in the period 1950–2015 than in the period 1870–1950 in the three countries.[4] The difference in the growth rate between both periods was quite significant in Austria and Spain due to the fall in production during the World Wars and the inter-war period in the case of Austria and the Civil War in the case of Spain (see Figure 2). Indeed, we can observe in column IV how Spain experienced both the slowest growth among the three countries during the period 1870–1950, and the fastest growth during the period 1950–2015. In Sweden, on the contrary, the difference in economic growth between both periods is small due to the neutral position during both World Wars.

Table 1: Contribution of demography to per capita income growth from 1870 to 2015

	Annual growth rates (in %)			Contribution (in %)		
	Income	Population	Per capita income	Age structure H1	Educational structure H2	Demography H3
	II	III	IV=II-III	V	VI	VII
1870–1950						
Austria	1.29	0.54	0.74	32.9	8.9	41.4
Spain	1.17	0.66	0.51	31.5	2.0	32.0
Sweden	2.49	0.63	1.86	18.7	0.0	18.3
1950–2015						
Austria	3.45	0.33	3.12	6.8	17.0	20.6
Spain	4.02	0.80	3.23	15.3	10.6	24.6
Sweden	2.79	0.50	2.29	3.2	6.8	8.0
1870–2015						
Austria	**2.25**	**0.45**	**1.81**	**12.7**	**15.2**	**25.3**
Spain	**2.45**	**0.72**	**1.73**	**17.9**	**9.2**	**25.8**
Sweden	**2.62**	**0.57**	**2.05**	**11.0**	**3.4**	**13.2**

Source: Authors' calculations.

The last three columns of Table 1 show the contribution of demography to per capita income growth in each country. We do so by comparing for each country the per capita income growth rate in the baseline economy to the per capita income growth rate in our three hypothetical economies (H1, H2, and H3). Therefore, we take into account the combined effect of changes in the age structure of the population, changes in human capital, and changes in behavior. Column V in Table 1 shows the contribution of the change in the age structure of the population to per capita income growth. From year 1870 to 2015, the observed fall in fertility and mortality explains 12.7 percent and 11 percent of the observed per capita income growth in Austria and Sweden, respectively, and 17.9 percent in Spain. The greater contribution of the change in the age structure in Spain is due to the faster change in its population during the period analyzed (see Section 3.1 above for more details). The analysis between the two periods also shows some interesting facts. For instance, the contribution of the change in the age structure is more pronounced during the first period (1870–1950) than during the second period (1950–2015) in the three countries.

[4]Using column IV in Table 1, we obtain 1.843=(3.12-0.74)/3+(3.23-0.51)/3+(2.29-1.86)/3.

Over 30 percent of per capita income growth during the period 1870–1950 is explained by the change in the age structure in Austria and Spain, while only 18.7 percent in Sweden. During the period 1950–2015 the contribution of the change in the age structure to per capita income growth only accounts for 6.8 percent in Austria, 15.3 percent in Spain, and 3.2 percent in Sweden.

We complement the previous results with the contribution of education to per capita income growth. Table 1, column VI, reports the contribution of changes in the educational structure of the working age population to income growth and its behavioral reaction through labor supply and savings. Unfortunately, given the lack of labor income data for workers with less than lower secondary education, the numbers shown in Table 1, column VI, only reflect the productivity gains of workers with more than lower secondary education.[5] Hence, our results do not account for the complete expansion from no education (ISCED 0) to lower secondary education (ISCED 2). This implies that our baseline simulation gives a smaller contribution of the change in the educational structure to per capita income than the change in the age structure from 1870 to 2015.

Austria, as one of the forerunners of the expansion of education in the 20th century, already benefitted from the introduction of public upper secondary education to its per capita income growth by 8.9 percent during the period 1870–1950 and by 17 percent during the period 1950–2015. In Spain and in Sweden, in contrast, the expansion from lower secondary to upper secondary education contributed to per capita income growth only by 10.6 percent and 6.8 percent, respectively, during the period 1950–2015. The smaller contribution of education to per capita income growth in Sweden, for the overall period 1870–2015, relative to that in Austria and Spain is due to the non significant wage differential across the three educational groups in Sweden (see Figure 14 in Appendix A.1). This circumstance probably reflects the existence of strong unions and higher public education expenditures during working ages on the ISCED level 0-2 in Sweden (see Figure 19 in Appendix A.3), which does not occur in Austria and Spain.

The combined contribution of the educational expansion and the fall in fertility and mortality to per capita income growth during the period 1870–2015 is summarized in column VII, Table 1. The numbers presented in this column are obtained by comparing the average annual per capita income growth rate in the baseline to that derived in our hypothetical economy H3. We find that the total effect of the change in the population structure (labeled as demography) during the period 1870–2015 accounts for around one-fourth of the total per capita income growth in Austria and Spain, respectively, and for 13.2 percent in Sweden.[6] Comparing the contribution of demography to per capita income growth in the period 1870–1950 to that in 1950–2015, we have a significantly higher contribution in the first period (41.4 in Austria, 32 in Spain, and 18.3 percent in Sweden) than in the second period (20.6 in Austria, 24.6 in Spain, and 8 percent in Sweden). Moreover, comparing columns V and

[5]Wage rates per hour worked by educational attainment in Austria, Spain, and Sweden are only available for recent years in the EU-SILC database (see Figure 14 in Appendix A.1). Therefore, our wage rate profiles are representative of individuals with at least lower secondary education, which reflects the current educational system with a compulsory education between 8 and 9 years and not the wage rate profiles in the 19th century.

[6]Note that the numbers in column VII do not exactly coincide with the sum of columns V and VI due to the non-linear nature of the model.

VI, we have that the contribution of demography to income growth is mainly explained by changes in the age structure of the population from 1870 to 1950, while the contribution of demography to per capita income growth during the period 1950–2015 is mainly an educational dividend. This result was already found by Crespo Cuaresma, Lutz, and Sanderson (2014).

An important remark should be given about the results already presented in this section. In particular, since we do not account for the complete expansion of the educational system, there are good reasons to believe that the impact of demography to income growth was much higher in the past. By not fully capturing the educational transition, we have in principle overestimated the contribution of the exogenous productivity growth to per capita income growth.[7] As a consequence, it is likely that not only the contribution of education, but also the contribution of the fall in fertility and mortality, to per capita income growth is underestimated due to the significant correlation between the age structure and total factor productivity (Feyrer, 2007, 2008). Indeed, Kelley and Schmidt (2005) find by applying econometric methods to a cross-country panel of countries that demography might account up to 39% of per capita income growth in Europe during the period 1960-1995.[8]

Table 2: Contribution of demography to per capita income growth from 2015 to 2100

	Annual growth rates (in %)			Contribution (in %)		
	Income	Population	Per capita income	Age structure H1	Educational structure H2	Demography H3
Austria	1.58	0.01	**1.57**	-2.7	9.9	9.6
Spain	1.47	-0.17	**1.64**	-3.2	21.9	13.5
Sweden	1.97	0.48	**1.48**	-3.3	3.0	0.4

Source: Authors' calculations.

To complete our analysis, Table 2 reports the expected contribution of demography on per capita income growth during the period 2015-2100. Assuming a future labor-augmenting technological progress of 1.5% (or equivalently an annual total factor productivity growth of 1%), which corresponds to the average technological growth assumed by the European Commission up to 2100, we derive that the change in the age structure of the population will have a minor, and even negative, contribution on per capita income growth. This is equivalent to say that the expected evolution of longevity and fertility (based on Eurostat's assumption) will not have a significant impact on per capita income. In contrast, education will have a greater contribution on per capita income growth from 2015-2100. Therefore, if the age structure and the educational structure of the population follows the pattern described in figures 3 and 4, the future demographic dividend will be an educational dividend.

[7] Recall that total productivity growth is calculated as a residual with respect to other explanatory variables like the change in the age structure or the educational structure.

[8] We obtain these numbers from Table 3 in Kelley and Schmidt (2005) by adding to the demographic translations component, the demographic core variables, and the log of the life expectancy at birth.

5 The demand for life cycle wealth

In the previous section we studied the contribution of the change in the population structure on per capita income growth. National Transfer Accounts (NTA) can also be applied for understanding how demographic changes affect life cycle wealth. The key concept for analyzing wealth using NTA is the demand for life cycle wealth. This concept was first introduced by Tobin (1967), as an extension of the life cycle theory of saving proposed by Modigliani and Brumberg (1954). The demand for life cycle wealth is a generalization of the individual life cycle saving behavior that allows for the introduction of the family structure, childhood, and old age. Therefore, it is a better framework than the simple life cycle model for analyzing the aggregate saving in a real economy. The life cycle demand for wealth will inform us whether a generation allocates part of her lifetime labor income to finance the consumption of other generations or, instead, whether part of their lifetime consumption is financed by other generations.

In this section we will start analyzing the demand for life cycle wealth at the individual level, which better accounts for the behavioral change, and we will end up studying the macro level effects by multiplying the profiles by the population size at each age.

5.1 Individual demand for life cycle wealth

The life cycle wealth of an individual of age x born at time t, denoted by $w(x,t)$, is the amount of wealth needed at age x to finance her remaining lifetime consumption, given the expected remaining lifetime labor income:

$$w(x,t) = \int_x^\omega e^{-\int_x^s r(t+p)+\mu(p,t)dp} \left[c(s,t) - y_l(s,t)\right] ds. \tag{1}$$

ω is the maximum age of the population, $r(t)$ is the market interest rate at time t, $\mu(x,t)$ is the mortality hazard rate at age x of an individual born at time t, c is the individual consumption, and y_l is labor income. A positive (negative) $w(x,t)$ value means that a person of age x born in year t expects to consume more (less) than she expects to earn from her work over her remaining lifetime. The gap between lifetime consumption and lifetime labor income at each age x is met by relying not only on assets, denoted by $a(x,t)$, but also on transfers from other generations, $\tau(x,t)$. Thus, the life cycle wealth comprises assets and transfer wealth; i.e., $w(x,t) = a(x,t) + \tau(x,t)$.

Transfer wealth is the present value of expected transfers to be received minus the expected value of transfers to be given. Thereby, transfer wealth includes the net worth of expected public transfers as well as the net worth of the expected private transfers. An example of public transfer wealth is the social security wealth in a PAYG system; i.e., the present value of the expected future benefits received minus the present value of social contributions to be paid. While an example of private transfer wealth is the in-kind transfers received from parents minus those that individuals are expecting to give to their offspring. Nonetheless, since in reality individuals give and receive many transfers along their lifespan, for simplicity, in this paper we focus our attention on two public transfers —education and social security pension benefits— and three private transfers —capital wealth transfers (bequest), goods purchased in the market or produced at home, which are targeted to satisfy the consumption needs of children, and the time spent caring for children.

Under this setting, we analyze the evolution of the life cycle wealth at birth for the generations born between 1870 and 2050. Provided that individuals are born with zero assets in their balance accounts, their life cycle wealth at age 0 is equal to their transfer wealth at age 0. In the next subsection we study the evolution of the public transfer wealth, and we continue with the evolution of the private transfer wealth.

5.2 Net present value of public education and public benefits: Birth cohorts 1870–2050

The net present value of public transfers at birth for an individual born in year t, denoted by $\tau_p(0,t)$, depends on the market discount factor r, the mortality hazard rate of the cohort $\mu(\cdot,t)$, and the difference between benefits received and taxes paid

$$\tau_p(0,t) = \int_0^{\omega} e^{-\int_0^x r(t+s)+\mu(s,t)ds} \left[\tau_p^+(x,t) - \tau_p^-(x,t)\right] dx, \tag{2}$$

where τ_p^+ denotes public transfers received and τ_p^- are the public transfers paid. Hence, according to Eq. (2) transfers received early in life become bigger (smaller) than those received late in life when the market discount rate is high (low) as well as when the life expectancy is low (high). In a balanced budget, this implies that when the average age at receiving benefits is younger (older) than the average age at paying taxes, the sign of $\tau_p(0,t)$ becomes positive (negative). Therefore, given that we assume public education is financed through consumption taxes and pension benefits through social security contributions on labor income, we have that public education creates a positive transfer wealth, since education is received early in life, while Social Security creates a negative transfer wealth given that pension benefits are received upon retirement.

Figure 5 shows the evolution of the net present value at birth of education benefits (dotted line) and taxes paid (solid line) for education as a percent of lifetime labor income for cohorts born between 1870 and 2050. The introduction of the modern educational system, which set up compulsory primary education, differs in the three countries as we have already discussed in section 3.2.[9] In particular, during the second half of the 20th century the expansion of the educational system to secondary and tertiary education, and the increasing number of students of the baby boom generation, make the net present value of taxes paid higher than the present value of education benefits received for those cohorts born during the period 1920–1945 in Austria, 1930–1970 in Spain, and 1900–1945 in Sweden. Figure 5 also shows that the net present value of education relative to the lifetime labor income, or the difference between benefits and taxes, will become increasingly positive for future cohorts in the three countries. Thus, provided the projected vital rates and the educational expansion (see Section 3), the net present value of education will reach a

[9] In Austria, the first law introducing compulsory primary education was passed in 1869 (Flora, 1983). In Spain, the first law that introduced compulsory and free primary education was passed during the Second Republic in 1931, but it was sharply interrupted by the Civil War (1936–1939). It was not until 1970 that a universal and compulsory education from age 6 to 14 years was established (Nuñez, 2005). In Sweden, six years of compulsory education was introduced in 1878, extended to seven years in 1936, and expanded to nine in 1950 (Flora, 1983).

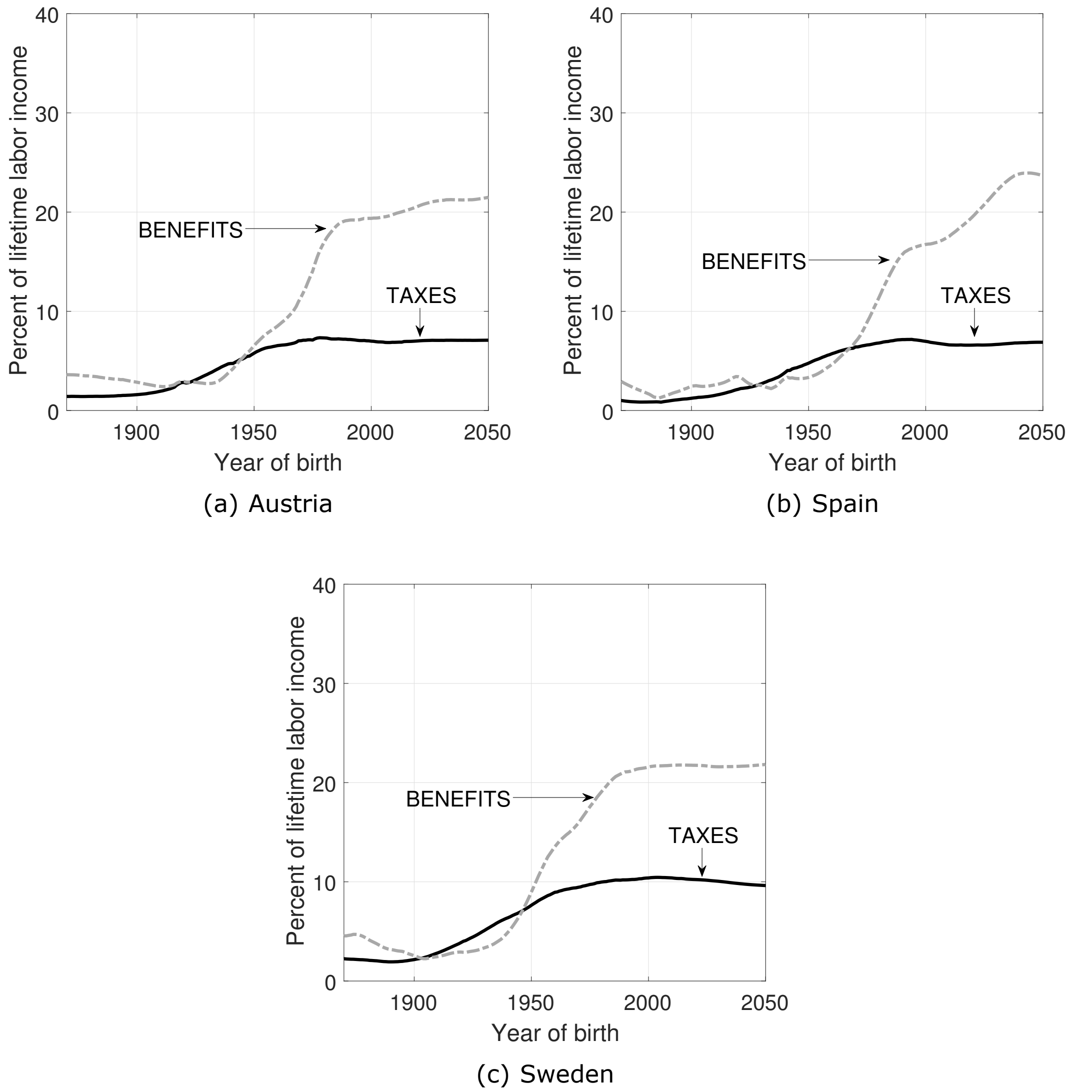


Figure 5: Present value at birth of education benefits and taxes paid for education as a percent of lifetime labor income: Cohorts 1870-2050

Source: Authors' calculations based on the baseline simulation.

plateau of 12 percent and 15 percent for the cohorts born after the 1990s in Sweden and Austria, respectively, and close to 16 percent for the cohorts born in the 2050s in Spain. As a consequence, the projected public transfers on education will allow future generations in Austria, Spain, and Sweden to consume 15, 12, and 16 percent more than they expect to earn, respectively.

To complement the public education expenditures, Figure 6 shows the evolution of the net present value at birth of Social Security pension benefits and contributions, known as Social Security pension wealth, as a percent of lifetime labor income for cohorts born between 1870 and 2050. Similarly to the education system, the Social Security system was established in remarkably different years in the three countries analyzed. In Austria, the first pension law was implemented in 1909 (International Social Security Association,

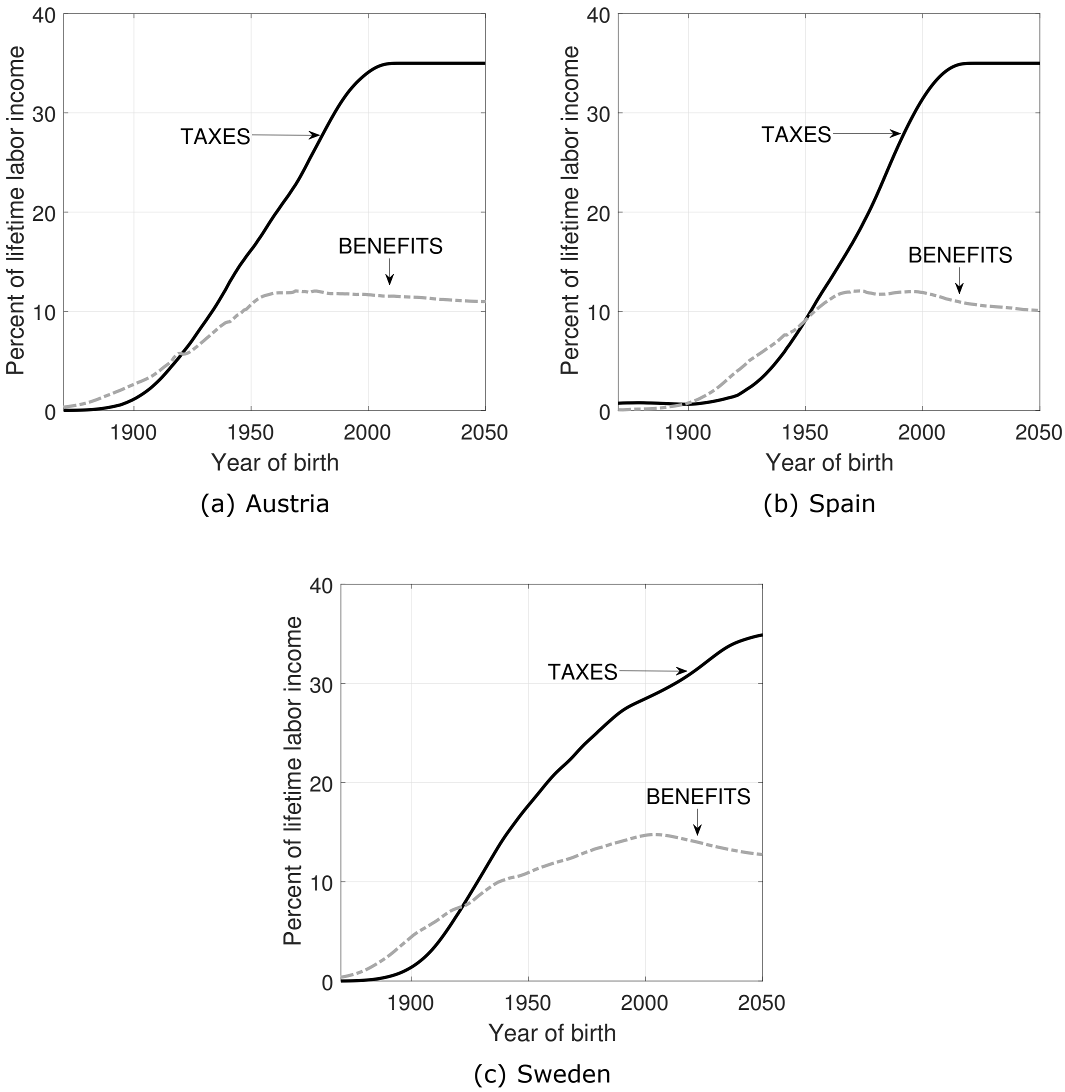


Figure 6: Present value at birth of pension benefits and Social Security contributions paid as a percent of lifetime labor income: Cohorts 1870-2050

Source: Authors' calculations based on the baseline simulation.

2016), although many of the current principles were set up in 1956 (OECD, 2005). In Spain, the first pension law is that of 1919, however it is not until the 1970s that a more modern old-age pension system started to be implemented.[10] In Sweden, the first pension law was set in 1913, whereas the current universal social insurance program was developed in the laws of 1962 and 1998 (International Social Security Association, 2016). Figure 6 shows how the first generations benefitting from the introduction of the old-age pension system received a windfall. However, as we have explained, a mature pension system leads to a negative transfer wealth. Thus, for the generation born after 1920 in Austria, 1925 in Sweden, and 1950 in Spain taxes paid relative to lifetime labor income become

[10] The "General Law of Social Security", which sets the pillars of the modern Social Security in Spain, was passed in 1967.

higher than benefits received. The results we obtain from the baseline scenario suggest that the difference between taxes and benefits over the lifetime will range between 22–23 percent for the cohort born in 2050 in all three countries. In other words, future generations will end up allocating between 22–23 percent of their lifetime labor income to finance the consumption of other generations.

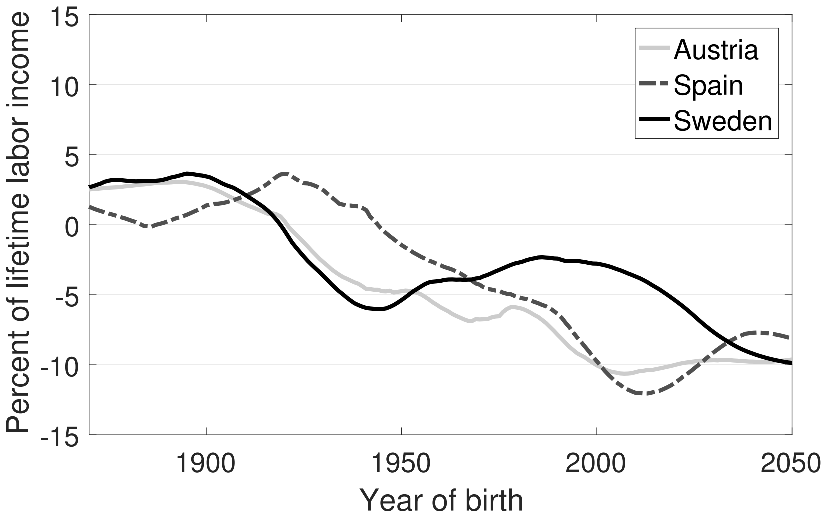


Figure 7: Present value at birth of expected lifetime education and Social Security pension wealth as a percent of lifetime labor income: Cohorts 1870–2050

Source: Authors' calculations based on the baseline simulation.

Figure 7 shows the net wealth from adding the transfer wealth of the public education expenditures to the transfer wealth of the Social Security for cohorts born between 1870 and 2050. According to our results, cohorts born between 1850 and WWI experienced a positive transfer wealth from the public sector in Austria and Sweden. In Spain, this positive transfer wealth is extended until those born in 1950 due to the late implementation of the modern education system. In contrast, the cohorts born in the 21st century will experience an overall negative transfer wealth from the public sector that ranges between 7 and 12 percent of their lifetime labor income.

The negative public net transfer wealth for the cohorts born in the 21st century, shown in Figure 7, does not mean, however, that the society will be worse off as we will explain in Section 5.4. Before we proceed to explain the overall macroeconomic consequences, we complete the picture by studying the net private transfer wealth at age zero in the following subsection.

5.3 Net private transfer wealth: Birth cohorts 1870–2050

The net present value of private transfers at birth for an individual born in year t, denoted by $\tau_f(0, t)$, depends on the market discount factor, the survival probability of the cohort, and the difference between monetary inflows and outflows, and the wealth privately received and transferred from and to other generations

$$\tau_f(0,t) = \int_0^{\omega} e^{-\int_0^x r(t+s)+\mu(s,t)ds} \left[\tau_f^+(x,t) - \tau_f^-(x,t)\right] dx, \tag{3}$$

where τ_f^+ denotes private inflows and wealth received from other generations and τ_f^- are the private outflows and wealth transferred to other generations. Recall in section 2 we have assumed that private transfers received, $\tau_f^+(x,t)$, at age a in year t only includes in-kind goods and services received at age x from parents in order to finance the consumption needs and the accidental bequest received at age x. Whereas private transfers given are comprised of the total consumption of children living at home when the individual is the household head at age x and the average bequest left by cohort t at age x.

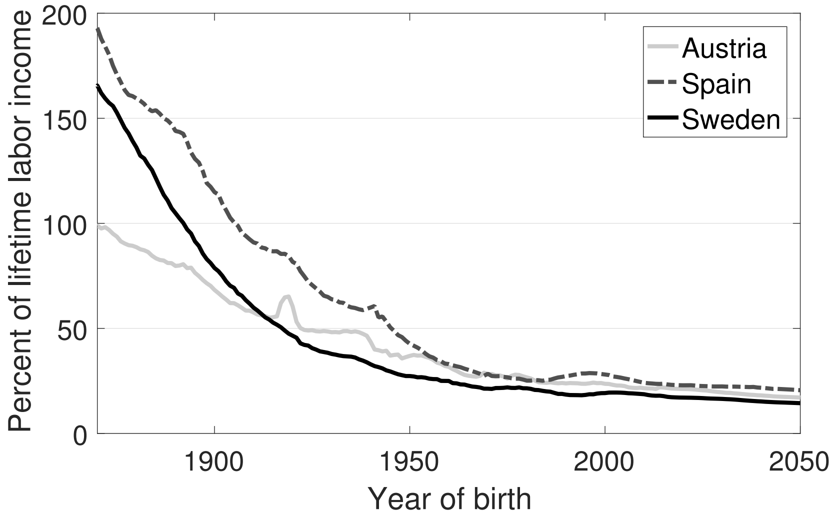


Figure 8: Present value at birth of expected net private transfers as a percent of lifetime labor income: Cohorts 1870–2050

Source: Authors' calculations based on the baseline simulations.

Figure 8 shows the present value at birth of net private transfers as a percent of lifetime labor income for the cohorts born between 1870 and 2050. According to our baseline simulations, the net private transfer wealth exceeds 100 percent when the life expectancy is low, and progressively declines to less than 20 percent of lifetime labor income as the life expectancy increases. This is equivalent to say that an individual born in year 1870 consumed over her lifespan more than twice their expected lifetime labor income. The high infant mortality during the nineteenth century and its decline during the twentieth century explains the initial high value and its subsequent fall (see Figure 3(b)). On the one hand, net private transfer wealth is initially high because the expected cost of raising children and leaving bequest is very low, due to the high infant mortality. On the other hand, the net private transfer wealth also increases relative to the lifetime labor income because it was very likely that an infant will not survive to the working age. Consequently, our results imply that the market cost of raising children was in the past extremely high.

Adding up the net private transfer wealth to the net public transfer wealth Figure 9 shows

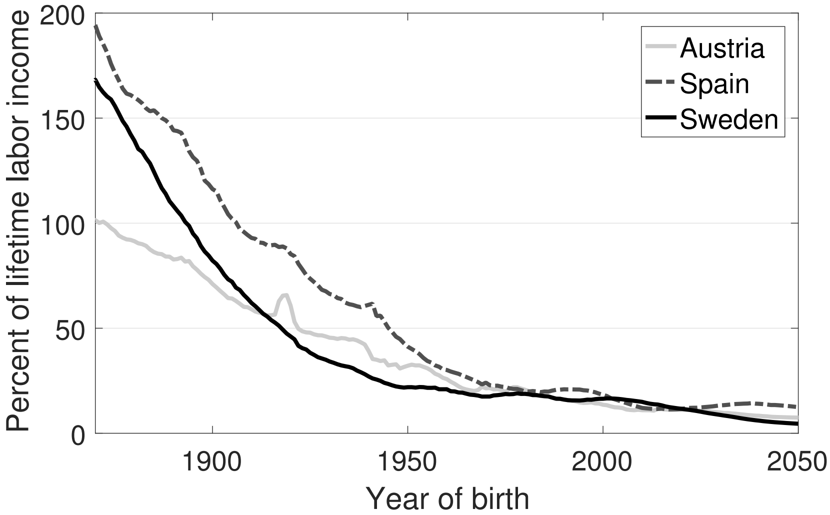


Figure 9: Life cycle wealth at birth as a percent of lifetime labor income: Cohorts 1870–2050

Source: Authors' calculations based on the baseline simulations.

that the demand for life cycle wealth at birth is highly positive for those born in year 1870 and it will get close to zero, although still positive, for younger cohorts.

5.4 Aggregate demand for life cycle wealth: Period 1870–2100

In the previous subsection we have shown that future cohorts will continue consuming more than they expect to earn from labor, though to a lower extent than previous generations. Now, we use the same NTA framework for studying whether the implemented system of public and private transfers allow the population of each country to consume more than they expect to earn from labor. To perform this analysis, we calculate the aggregate demand for life cycle wealth at each year t, denoted by $W(t)$. This measure is expressed as the sum across age of per capita demand for life cycle wealth (see subsection 5.1) weighted by the population age distribution

$$W(t) = \int_0^\omega Pop(x, t-x) w(x, t-x) dx, \qquad (4)$$

where $Pop(x, t-x)$ is the population size at age x of the cohort born in year $t-x$. In a closed-economy, it is shown that the aggregate wealth, $W(t)$, is the sum of capital, $K(t)$, and aggregate transfer wealth, denoted by $T(t)$ (Willis, 1988; Bommier and Lee, 2003; Lee and Mason, 2011; Lee, 2016). As a consequence, a positive (negative) aggregate transfer wealth, i.e. $T(t) = W(t) - K(t) > (<) 0$, means that the population consumes in year t more (less) than would earn over their remaining lifetime. While $T(t) = 0$, for all t, corresponds to an economy in which individuals' consumption follows a pure life cycle saving, either because the economy is a pure market economy, or because all transfers are set so as to cancel each other.

To illustrate the evolution of Eq. (4), Figure 10 shows the per capita demand for life cycle

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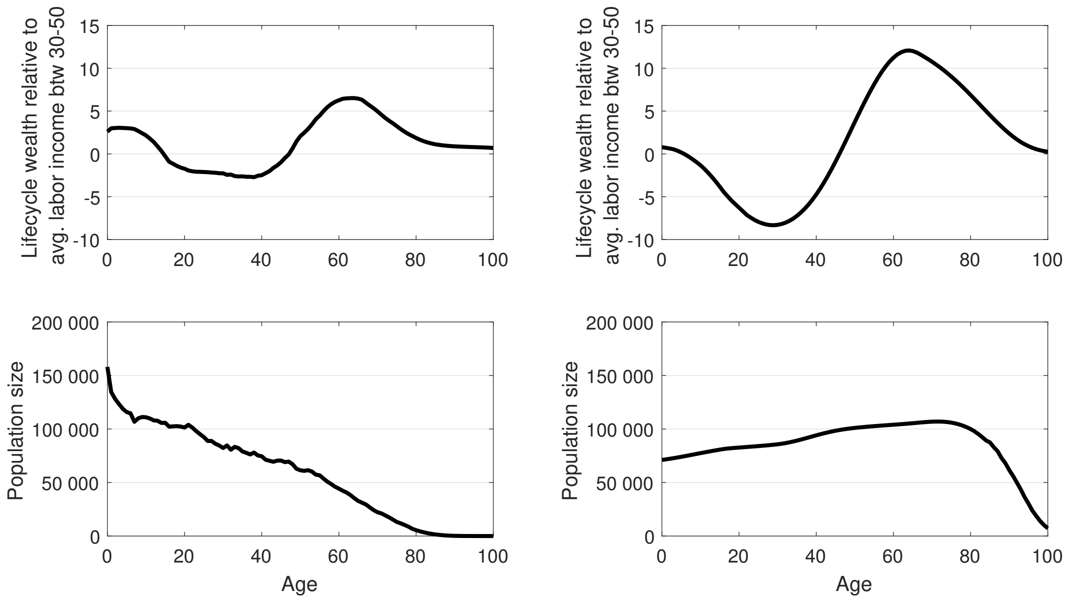
wealth profile and the population age structure of Austria in 1900, when the population was young, and in 2100, when the population is expected to be old. Panel 10(a) clearly shows that a young population puts more weight on the life stage in which the demand for life cycle wealth is negative, while Panel 10(b) shows that an older population puts more weight on the life stage in which the demand for life cycle is positive. Thus, during the demographic transition we might expect that the economy moves from a low, or even negative, aggregate life cycle wealth value to a positive and high life cycle wealth. The aggregate demand for life cycle wealth also changes due to the change in the per capita life cycle wealth profile. The main effect explaining the change in the profile is due to the fall in mortality. Indeed, mortality affects the life cycle wealth through two channels. First, comparing the top panels in Figure 10, we can observe how the longer life expectancy leads individuals to demand more wealth at the end of life in order to finance the increasing number of years in retirement. Second, since mortality impacts on the value of future consumption and labor income, we can also observe in the top panels of Figure 10 an increase in the magnitude of both the negative and the positive stages of the demand for life cycle wealth. This is because the fall in mortality raises the probability of giving to the children when young and receiving when old. The same effect occurs when the interest rate decreases.



(a) Year 1900 (young) (b) Year 2100 (old)

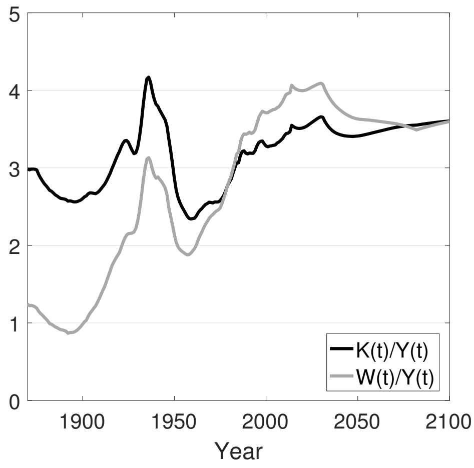
Figure 10: life cycle wealth profile and population age distribution in Austria

Source: Authors' calculations based on the baseline simulation for Austria.

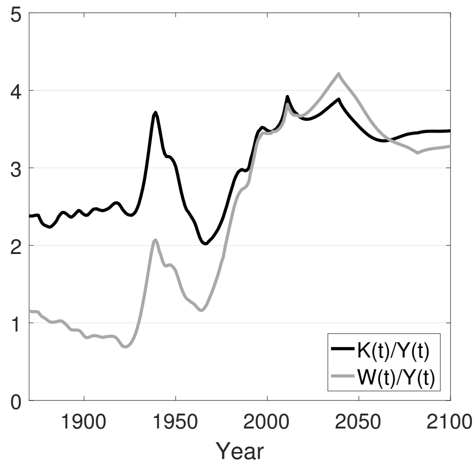
The evolution of the aggregate demand for life cycle wealth relative to the output from 1870 to 2100 is shown in Figure 11 for Austria, Spain, and Sweden (gray line). We also include in this figure the evolution of the capital to output ratio (black line) in order to have a complete picture of the evolution of the aggregate transfer wealth, since $T(t) = W(t) - K(t)$. Figure 11 depicts, based on our baseline simulations, how the ratio between the aggregate demand for life cycle wealth to output increased from 1, in 1900, to 4, in 2000, in Austria and Sweden. In Spain, the increase in the aggregate demand for life cycle wealth to output ratio occurred with a delay of 30 years —period 1930 to 2030— from less than 1 to 4. Moreover, Figure 11 shows how the stock of capital to output ratio increased in the three countries during the 20th century. According to our results, the increase was from 2.5 to around 3.5 in Austria and Spain, and from slightly more than 2 to almost 4 in Sweden. The two humps observed in Austria and Spain before the mid-20th century are caused by the fall in production during the WWI and WWII in the case of Austria and the Civil War (1936–1939) in the case of Spain, rather than to an increase in aggregate wealth. The difference between $W(t)$ and $K(t)$ gives the aggregate transfer wealth. In particular, $T(t)$ has changed from -1.5 at the beginning of the past century to almost zero in the last decades. This is consistent with the illustration in Figure 10. These numbers imply that at the beginning of the 20th century the population used on average 1.5 years of work to finance the consumption of younger generations, while at the end of the 20th century the population consumes what is produced. Note, however, that the first half of the 21st century is characterized by a positive aggregate transfer wealth.

An important result from the baseline simulation is that there is no further capital deepening from year 2000 onwards. In principle, the population aging process is expected to yield an increase in the capital per worker due to the slower growth rate of the working age population and the increase in savings due to the longer retirement period. Hence, the fact that we do not observe a future capital deepening is equivalent to say that Austria, Spain, and Sweden will not benefit from a permanent second demographic dividend. This is consistent with previous findings by Prskawetz and Sambt (2014), for Austria and Sweden, and by Sánchez-Romero, Patxot, Renteria, and Souto (2013) for Spain. There are two main reasons for this finding. First, the assumed annual productivity growth rate of 1.5% makes output to increase faster during the first half of the 20th century than the capital stock. Thus, when a lower productivity growth is assumed, the model gives a further increase in the capital-output ratio. A second explanation, which was already suggested by Feldstein (1974), is that the generosity of the pension system crowds the future capital stock out.

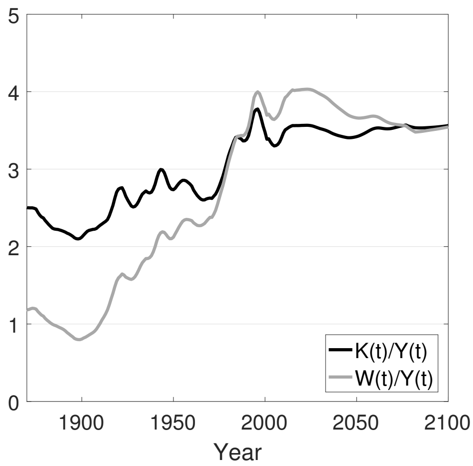
To check the validity of the crowding-out hypothesis in our model, we plot in Figure 12 the final steady-state equilibrium in the capital market that results from the baseline simulation and that from a hypothetical economy in which there is no pension system. The country used for this analysis is Austria. The black solid line represents the producers' demand for capital relative to output under a standard Cobb-Douglas production function with $\alpha = 1/3$ and $\delta = 0.05$. The dark gray lines represent the supply of capital by household, given by K/Y, with the pension system (solid) and without the pension system (dashed). Where supply intersects the demand, we have the capital market equilibrium A (with pensions) or B (without pensions). The light gray lines correspond to the aggregate demand for life cycle wealth with the pension system (solid) and without the pension system (dashed). Thus, given the identity $T = W - K$, we have that $T = 0$ in case of A, but $T < 0$ in case of B. Figure 12 shows that removing the pension system increases future savings; in other words, the pension system creates a crowding-out effect, as for any given interest rate r the new capital-to-output ratio is shifted to the right (compare the solid curves to the dotted curves). Figure 12 also gives an additional interesting insight. In particular, note that if



(a) Austria (AUT)



(b) Spain (ESP)



(c) Sweden (SWE)

Figure 11: Aggregate demand for life cycle wealth to output ratio, 1870-2100

Note: $K(t)$ is the aggregate supply of capital. $W(t)$ includes, besides the capital stock $K(t)$, publicly provided education, retirement pensions, consumption taxes, social contributions, goods and services purchased in the market not consumed by household heads, and accidental bequest.

pension benefits are removed, the new market equilibrium will be represented by point B rather than by point A. At the new market interest rate, which is below 3%, the wealth-to-output ratio (gray dotted curve) will be lower than that in point A, which implies that the population will consume less than would earn over their remaining lifetime (or $T < 0$).

In sum, by analyzing the demand for life cycle wealth, we have obtained that the lifetime consumption of future cohorts will be greater than their lifetime income. This occurs because although the public transfer wealth becomes negative for future births, the transfers from parents to children create a positive transfer wealth that still dominates over public transfers. In contrast, at the aggregate level, the population aging process will lead the three economies to allocate part of their work to finance the consumption of the elderly,

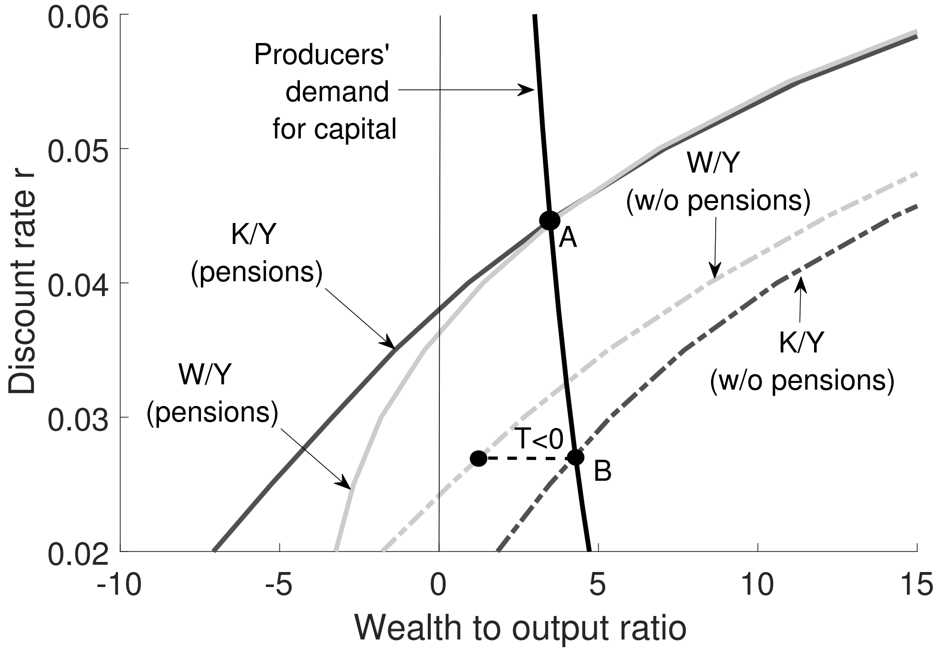


Figure 12: Equilibrium in the capital market and the role of aggregate transfers

Source: Authors' calculations based on the baseline simulations.

allowing the population to have a greater wealth-to-output ratio.

6 Conclusion

In this paper we study the contribution of changes in the demographic structure —age and educational structure— on per-capita income growth and the evolution of savings through the aggregate wealth-to-output ratio. The study is conducted for three European countries from year 1870 to 2100 that represent Central, South, and North of Europe: Austria, Spain, and Sweden. We focus on the wealth-to-output ratio, rather than on savings, since the former measure gives us information about the number of years of work necessary to maintain the level of consumption. Moreover, it informs us about whether a society transfers resources towards the youth or the elderly over time. We deal with these two topics, by implementing a CGE model with overlapping generations and realistic demography in which household heads, who are heterogeneous by level of education, optimally choose the consumption of market- and home-produced goods, and the time spent working in the market and in home production.

The main results suggest that population matters for explaining the evolution of per capita income growth and savings for the last hundred and fifty years in the three countries. Specifically, we find that demography accounts for around one-fourth of the total per capita income growth during the period 1870–2015. The contribution of demography to income growth, mainly explained by the change in the age structure of the population, was significantly higher (over thirty percent) during the period 1870–1950 than during the last sixty five years (around twenty percent). From 1950 to 2015, the demographic dividend was mainly an educational dividend. During the 21st century our baseline economy suggests a small negative effect of the change in the age structure of the population to per-capita income and a positive effect of education, especially in countries like Spain with a late introduction of public upper secondary and tertiary education.

We also find that the observed increase in per capita income during the last one-and-a-half centuries was also accompanied by an increase in the aggregate wealth-to-output ratio during the 20th century. The evolution of this ratio was driven by two factors: the increasing life expectancy and the older age structure of the population. Looking at the stock of capital-to-output ratio, an important result from the baseline simulation is that there is no further capital deepening, or increase in the capital per worker, from year 2000 onwards, which is mainly caused by the crowding-out effect from the pension system. This result implies that Austria, Spain, and Sweden will not benefit from a permanent second demographic dividend. Moreover, following Lee (2016) the difference between the wealth-to-output ratio and the capital-to-output ratio shows how the three countries are progressively moving resources from the youth to the elderly as the age structure of the population turns from young to old.

Acknowledgements

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A Data

This section explains how we have constructed the general equilibrium model for Austria, Spain, and Sweden in which fertility, mortality, the educational distribution by birth cohort, the labor-augmenting technological progress, publicly provided education, and pension benefits are exogenous. Sections 3.1 and 3.2 explained in detail the evolution of fertility, mortality and the educational distribution for the three countries analyzed. In the appendix we focus on explaining how the labor-augmenting technological progress, publicly provided education, and pension benefits have been calculated based on the existing historical data. It should be kept in mind that many of the data presented in the appendix is only used for the reconstruction of the exogenous variables. Thus, we use italics to distinguish the data used in the CGE model from the data used exclusively for the reconstruction.

A.1 Stock of human capital

We assume output is produced using a neoclassical production function that takes physical capital $K(t)$ and human capital $H(t)$ as input factors, where human capital embodies education and the age-specific productivity associated to each level of education.

The effective labor supply of an individual is assumed to be a function of her education, age- and education-specific labor force participation rate, age- and education-specific productivity, and her intensive labor supply or hours worked. Moreover, we assume that individuals with different educational attainment are perfectly substitutable. Thus, the stock of human capital at time t is given by

$$\mathsf{H}(t) = \int_0^\omega Pop(x,t) \left(\int_{\mathsf{E}} WP(x,e)\mathsf{HW}(t)\mathsf{LFPR}(x,e) f(t-x,e)de \right) dx, \tag{5}$$

where $Pop(x,t)$ is the population size at age x in year t, $WP(x,e)$ is the efficient labor units at age x with education e, $\mathsf{HW}(t)$ is the annual hours worked per employee, $\mathsf{LFPR}(x,e)$ is the labor force participation rate at age x with education e, and $f(t-x,e)$ is the fraction of people born in year $t-x$ with educational attainment e.[11] Notice that Eq. (5) implies that the stock of human capital will change over time because of the change in the annual number of hours worked and because of changes in the age and educational structure of the population.

Figure 13 shows the annual hours worked per worker from year 1870 to 2014 used in our reconstruction. Hours worked in Austria have been calculated using data from Maddison (2007) for the period 1870–1995 and from OECD (2016) for the period 1995–2014. For Spain, we combine data from Prados de la Escosura and Rosés (2010b), for the period 1870–2000, and OECD (2016) from 2000 to 2014. For Sweden, where values of annual hours worked differ substantially among the alternative sources, we calculate the average among the values reported in Maddison (1995), OECD (2016), and Edvinsson (2005) for those years in which the available time series overlap.

Figure 14 shows the endowment of efficient labor units, or age-productivity index, by edu-

[11] Note that $f(t-x,e)$ is non differentiable. In order to be mathematically correct, we would need a Stieltjes integral.

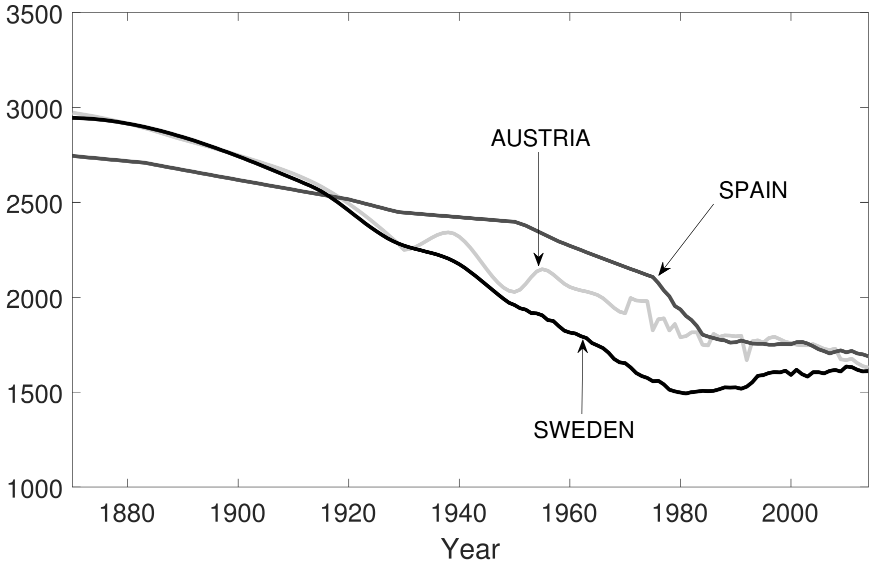


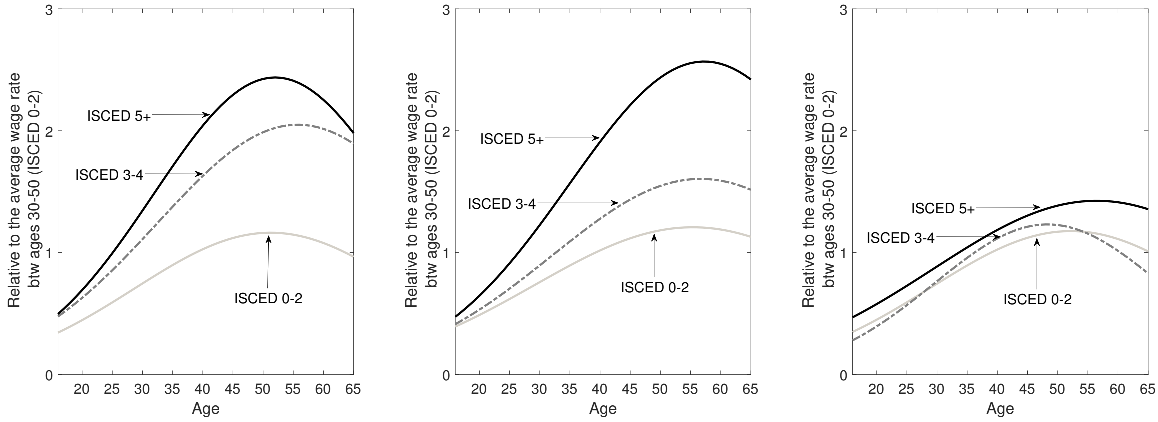
Figure 13: Annual hours worked per worker, 1870–2014.

Note: Authors' calculations based on different sources (see text).

cational attainment that we use for Austria, Spain, and Sweden. The age-productivity index by educational attainment captures at each age the productivity differential per hour worked across education groups. Our productivity index takes into consideration both the returns to education and experience. In principle, this index should not reflect productivity changes due to gender, type of contract (part-time vs. full-time), location (rural vs urban), and working place, among other characteristics, since they are not being modeled. Moreover, it is important to realize that if the quality of education does not differ across the three countries, the same age-productivity index can be used for all the countries analyzed. However, due to data limitations, our productivity indices reflect many non-modeled compositional changes as well as the fact that the educational system differs across the three countries. In order to partly avoid some of the biases that the compositional changes may cause for the measure of our productivity index, we use in our estimations the wage rate per hour worked of males with full-time contracts working in the private sector. These profiles are based on data from EU-SILC (2011). In the case of Sweden this strategy seems to be crucial in order to obtain some differences across the three educational groups, although as Figure 14 shows the labor income profile by educational attainment does still not differ much across educational groups in case of Sweden.

Age- and education-specific labor force participation rates by educational attainment are taken from the EU Labor Force Survey (LFS) from 1998 to 2003/2004 for all the countries. Figure 15 shows the labor force participation rates by educational attainment used in the reconstruction of the stock of human capital in each country. Each profile has been calculated as the average labor force participation rate by educational attainment over the period 1998–2003/2004.

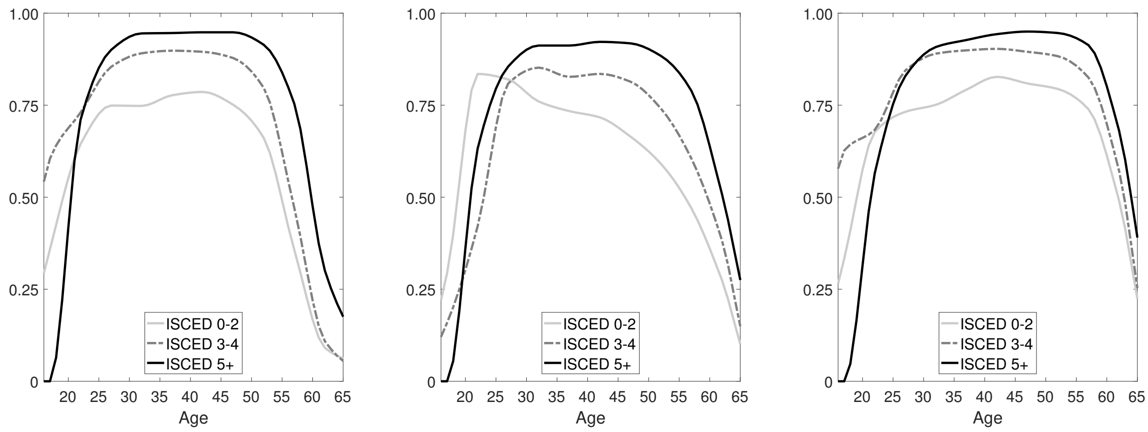
Figure 16 shows the educational distribution for those cohorts born between 1800 and 1990. The information reported for Austria has been calculated combining historical records



(a) Austria (b) Spain (c) Sweden

Figure 14: Average (gross) wage rate per hour worked by educational attainment

Source: EU-SILC (2011).



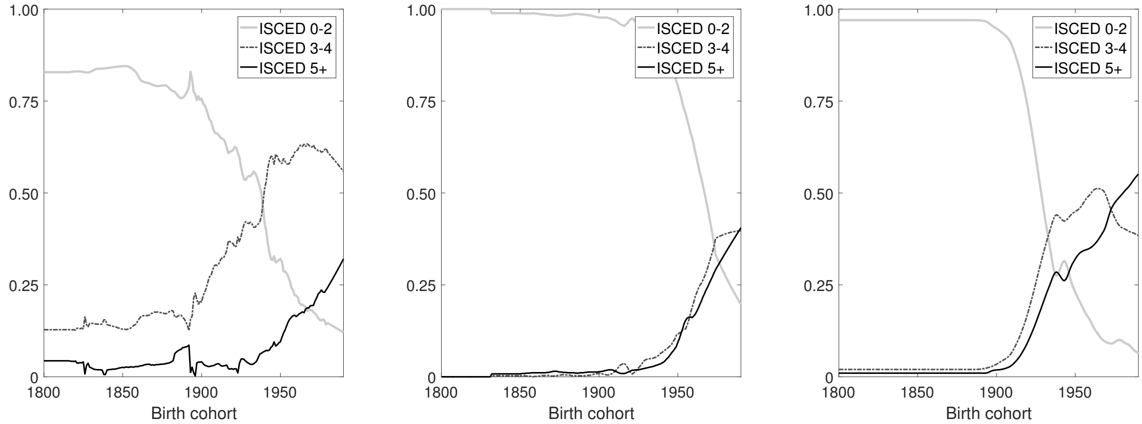
(a) Austria (b) Spain (c) Sweden

Figure 15: Labor force participation rates by educational attainment

Source: EU Labor Force Survey (LFS).

on enrollment rates by educational group from Völlmecke (1979) with data from IPUMS-I (2015) and from the Wittgenstein Centre Database (2015). For Spain, we combined the educational attainment for the cohorts born between 1832 and 1979 from Nuñez (2005) with data from the Wittgenstein Centre Database (2015). Swedish data completely relies on the information reported by the Wittgenstein Centre Database (2015).

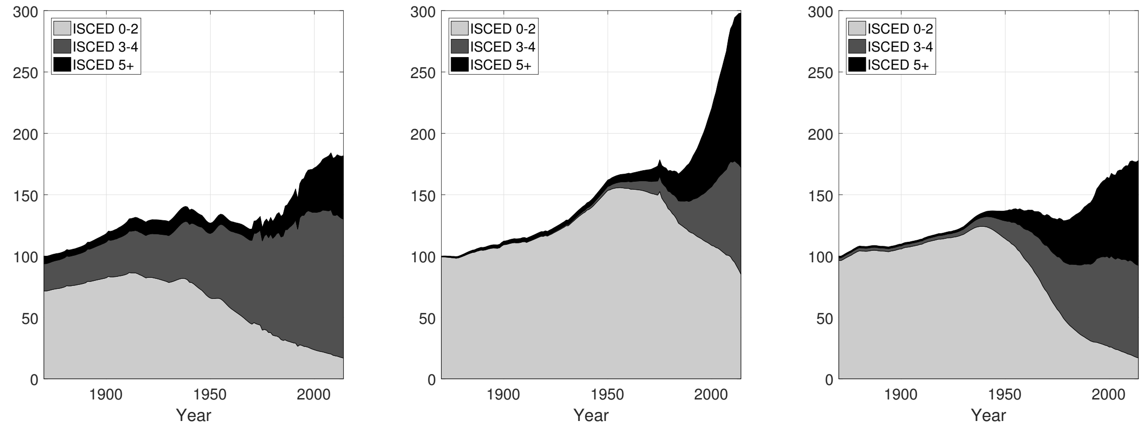
Figure 17 shows the evolution of the stock of human capital and its decomposition by educational attainment from 1870 to 2014 that results from our reconstruction. Thus, figure 17 has been calculated combining the information shown in figures 13-16 with our population estimates. It clearly shows that throughout the last hundred and fifty years the



(a) Austria (b) Spain (c) Sweden

Figure 16: Fraction of people by level of education, 1800–1990

Note: Authors' calculations based on different sources (see text).



(a) Austria (b) Spain (c) Sweden

Figure 17: Stock of human capital by educational attainment, 1870–2014 (1870=100)

Note: Authors' calculations based on different sources (see text).

stock of human capital tripled in Spain, while it only increased by eighty percent in Austria and Sweden. There are two effects that explain the faster growth in the case of Spain. First, the more rapid annual population growth experienced by the Spanish population from 1870 to 2015, which was close to 0.7 percent, versus the case of Austria (0.45 percent) and Sweden (0.57 percent). And second, the higher differential in the age-productivity index by educational attainment in case of Spain.

A.2 Productivity growth

Since the three countries analyzed are small-open economies, we use labor productivity as a proxy for the labor-augmenting technological progress. This is because labor productivity coincides in a neoclassical production function with the labor-augmenting technological progress when the wage rate per efficiency unit of labor is constant over time. Indeed, given that $wA(t)H(t) = (1-\alpha)Y(t)$, where A is the labor-augmenting technological progress, α is the capital share, w is the wage rate per efficient unit of labor, Y is output, and H is the human capital stock, we have

$$\frac{d}{dt}\log A(t) = \frac{d}{dt}\log \frac{\mathrm{Y}(t)}{\mathrm{H}(t)}. \tag{6}$$

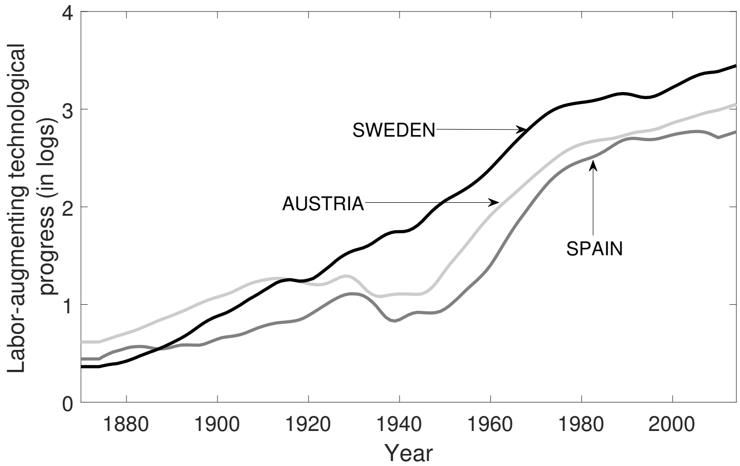


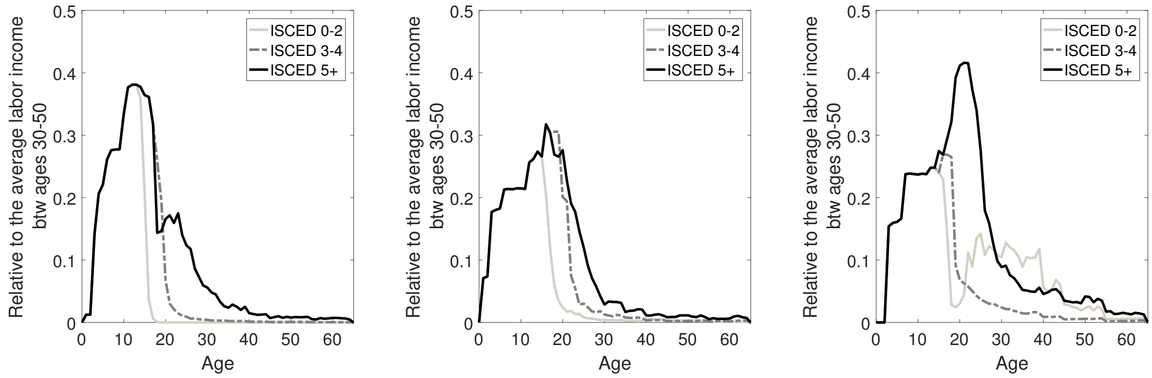
Figure 18: Labor-augmenting technological progress: Period 1870–2014.

Source: Authors' calculations.

Figure 18 shows the evolution of the labor-augmenting technological progress from 1870 to 2014 calculated for Austria, Spain, and Sweden. Before year 1870 we assume no productivity growth, while after year 2014 we assume that labor-augmenting technological progress increase annually by 1.5 percent in the three countries.

A.3 Public education expenditures

In our model public educational expenditures vary over time, by age, and educational attainment. We assume that all public educational expenditure profiles can be decomposed into a temporal component $\phi(t)$ and an age- and education-specific component, which we denote by $g(x, e)$. We rely on the recently estimated profiles of consumption of public education for year 2010 by Istenič, Šeme, Hammer, Lotrič Dolinar and Sambt (2016) done for the AGENTA project. Figure 19 shows the age- and education-specific cost of education relative to the average labor income between ages 30 and 50 for Austria, Spain, and Sweden for year 2010.



(a) Austria (b) Spain (c) Sweden

Figure 19: Public education expenditures by educational attainment

Source: Istenič, Šeme, Hammer, Lotrič Dolinar and Sambt (2016).

In order to be consistent with past data, the level of the profiles shown in Figure 19 are adjusted to match the total public education expenditures to output ratio from historical data. In particular, we derive the value of $\phi(t)$ by using the accounting identity that total consumption of public education, left-hand side of Eq. (7), equals total public educational expenditures, right-hand side of Eq. (7), or

$$\phi(t) \underbrace{\frac{(1-\alpha)\mathsf{Y}(t)}{\mathsf{L}(t)}}_{\text{Income per worker}} \int_0^\omega Pop(x,t) \left(\int_{\mathsf{E}} g(x,e) f(t-x,e) de \right) dx = \underbrace{\frac{\mathsf{G}_e(t)}{\mathsf{Y}(t)}}_{\text{Education to output}} \mathsf{Y}(t), \tag{7}$$

where $\mathsf{L}(t) = \int_0^\omega Pop(x,t) \left(\int_{\mathsf{E}} \mathsf{LFPR}(x,e) f(t-x,e) de \right) dx$ is total employment in year t and $G_e(t)$ is the total public educational expenditure in year t. Given the available information on the education to output ratio, collected from historical national accounts data, we calculate after rearranging terms $\phi(t)$ as follows

$$\phi(t) = \frac{1}{1-\alpha} \frac{\mathsf{G}_e(t)}{\mathsf{Y}(t)} \frac{\int_0^\omega Pop(x,t) \left(\int_{\mathsf{E}} \mathsf{LFPR}(x,e) f(t-x,e) de \right) dx}{\int_0^\omega Pop(x,t) \left(\int_{\mathsf{E}} g(x,e) f(t-x,e) de \right) dx}. \tag{8}$$

Figure 20 shows the evolution of the adjustment factor for education $\phi(t)$. The adjustment factor $\phi(t)$ is later on used as an exogenous factor in the CGE-OLG model. Figure 21 shows on the left panel the ratio between the total public education expenditure and output in the three countries analyzed. The dots are actual data on total public education-to-output ratio for Austria and Sweden, taken from Flora (1983), while the data for Spain is taken from Comín and Díaz (2005). The panel on the right-hand side in Figure 21 shows the consumption tax rate that is necessary in each country to pay for the public education in the baseline simulation.

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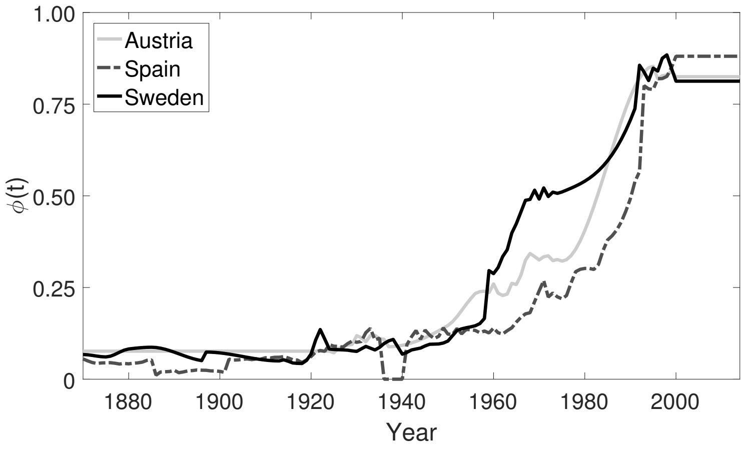

Figure 20: Evolution of the adjustment factor for education $\phi(t)$: Period 1870–2014.

Source: Authors' calculations (see text).

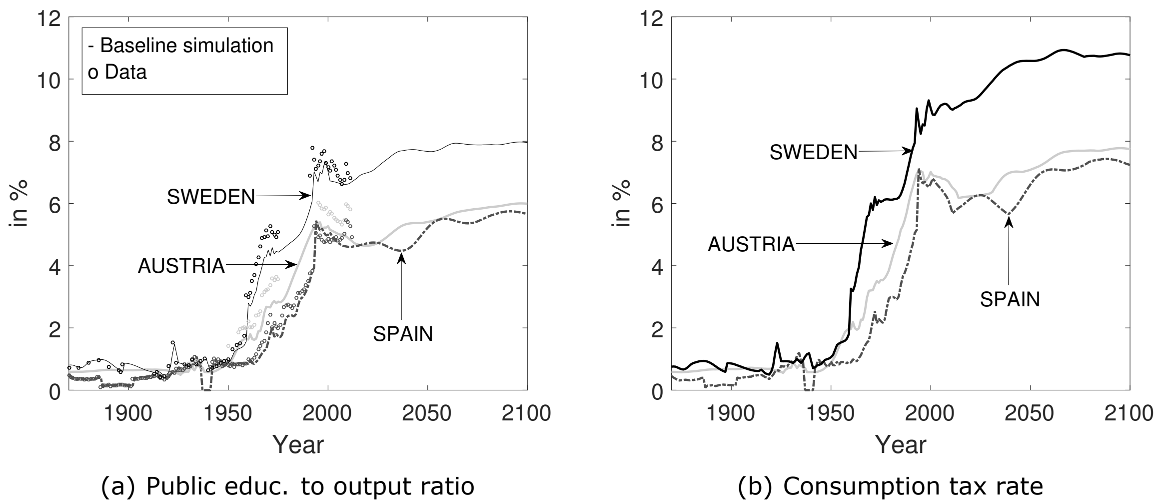

Figure 21: Total public education expenditures to output ratio and consumption taxes (Baseline simulation)

Source: Authors' calculations.

A.4 Public pension expenditures

Our model also takes into consideration the economic consequences of running a PAYG pension system. Since pensions have an effect on the decision of saving for retirement motive, this component is crucial for analyzing the evolution of the stock of capital during the last hundred and fifty years and it is likely to become even more important in the future due to the longer life expectancy.

We follow a similar strategy with the pension benefits as with public educational expenditures. Thus, we consider that public pension benefits vary over time, by age, and by educa-

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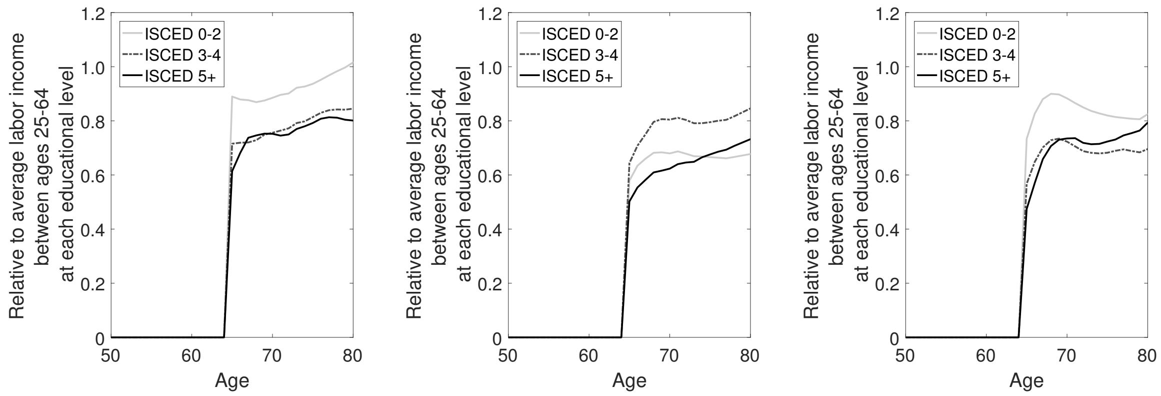
tional attainment. Also, we consider that pension benefits can be decomposed in a temporal component, denoted by $\psi(t)$, and an age- and education-specific component, that we denote by $\gamma(x, e)$. Public pension benefit profiles by level of education are taken from Istenič, Šeme, Hammer, Lotrič Dolinar and Sambt (2016). Figure 22 shows per-capita pension benefit profiles as a percentage to the average labor income of workers between age 25 and 64 by level of education in Austria, Spain, and Sweden.



(a) Austria (b) Spain (c) Sweden

Figure 22: Per capita pension benefits relative to the average labor income between age 25 and 64 by level of education: Austria, Spain, and Sweden

Source: Istenič, Šeme, Hammer, Lotrič Dolinar and Sambt (2016).
Notes: All values are extracted for year 2010. Each panel provides information about the generosity of the pension system, or replacement level, and how progressive is the pension system by level of education. We observe that the average replacement level is above sixty percent in the three countries and that the highest education group has the lowest value for most of the ages, which implies some degree of progressivity.

To calculate the value $\psi(t)$, we use the identity that total pension benefit expenditures, left-hand side of Eq. (9), equals aggregate pension benefit received, right-hand side of Eq. (9). Thus,

$$\text{Pen}(t) = \int_{65}^{\omega} Pop(x,t) \int_{\mathsf{E}} \underbrace{\left[\int_{65-\rho}^{65} \rho A(t) WP(s,e) \text{HW}(t) \text{LFPR}(s,e) ds\right]}_{\text{Avg. labor income between age } [65-\rho, 65] \text{ with education level } e} \psi(t)\gamma(x,e) f(t-x,e) dedx, \quad (9)$$

where $\mathsf{Pen}(t)$ denotes the total pension benefits paid in year t and ρ is the number of pensionable years used for the calculation of pension benefits. We set ρ at 40 years since all three educational groups supply their labor at age 25. After rearranging terms, we have

$$\psi(t) = \frac{\mathsf{Pen}(t)}{\mathsf{Y}(t)} \frac{\mathsf{Y}(t)}{\int_{65}^{\omega} Pop(x,t) \int_{\mathsf{E}} \left[\int_{65-\rho}^{65} \rho A(t) WP(s,e) \mathsf{HW}(t) \mathsf{LFPR}(s,e) ds \right] \gamma(x,e) f(t-x,e) dedx}$$
$$= \frac{\mathsf{Pen}(t)}{\mathsf{Y}(t)} \frac{\mathsf{H}(t) \left(\frac{\mathsf{K}(t)}{\mathsf{Y}(t)} \right)^{\frac{\alpha}{1-\alpha}}}{\int_{65}^{\omega} Pop(x,t) \int_{\mathsf{E}} \left[\int_{65-\rho}^{65} \rho WP(s,e) \mathsf{HW}(t) \mathsf{LFPR}(s,e) ds \right] \gamma(x,e) f(t-x,e) dedx}. \quad (10)$$

Figure 23 shows the exogenous evolution of the adjustment factor $\psi(t)$ from 1870 to 2014 used in the CGE model. The information on the total pension cost to output ratio is taken from Flora (1983) for Austria and Sweden and from Comín and Díaz (2005) for Spain. Time series on capital-to-output ratio are taken from Prados de la Escosura and Rosés (2010a) for Spain and from Edvinsson (2005) for Sweden. In Austria, in order to construct a long time series of capital stock using the perpetual inventory approach method we combine data from Schulze (2005, 2007), Zentralamt and Zentralkommission (1966, 1991), and Statistik Austria (2014).

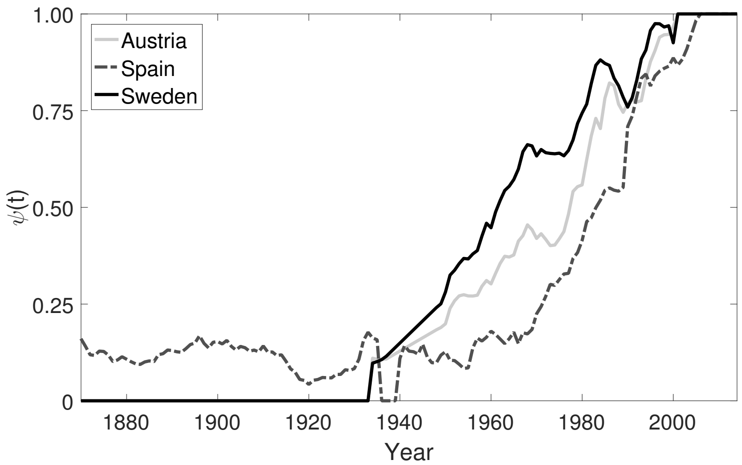
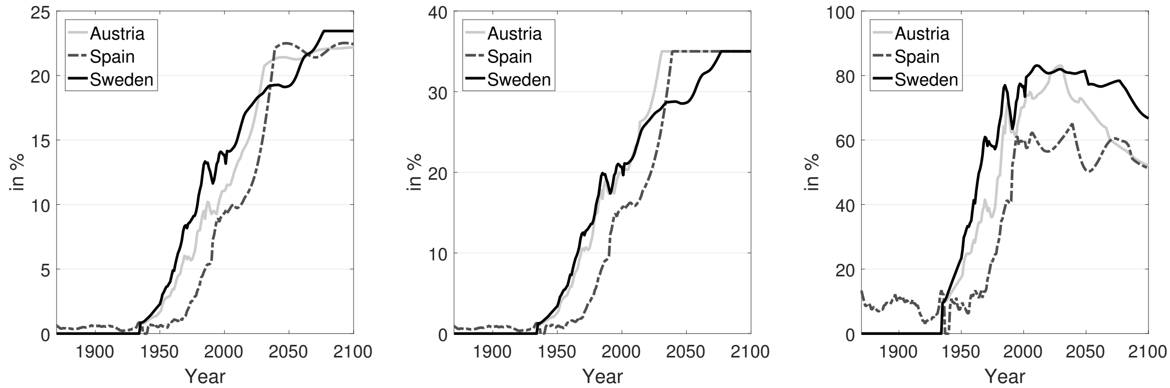


Figure 23: Evolution of the adjustment factor for pension benefits $\psi(t)$: Period 1870–2014.

Source: Authors' calculations (see text).

Figure 24 shows for each country three macroeconomic indicators of the pension system obtained in our baseline simulation. Panel 24(a) shows total pension expenditures to output ratio during the period 1870 to 2100 in Austria, Spain, and Sweden. Panel 24(b) reports the social security tax rate from 1870 to 2100. Notice that the social security tax rate will reach the limit of 35% before year 2050 in Austria and Spain and three decades later in Sweden. As a consequence, as panel 24(c) reports, in order to keep the pension system balanced, the evolution of the average pension to average salary ratio increases during the 20th century and it starts to decrease from the beginning of the 21st century.



(a) Total pension expenditures to output ratio (b) Social security contribution rate (pensions) (c) Average pension to average salary

Figure 24: Performace of pension system in Austria, Spain, and Sweden (baseline simulations): Period 1870–2100.

Source: Authors' calculations. Note: The social security contribution rate is limited to values below thirty five percent.

A.5 Childcare consumption

Our model also takes into account the necessary time that parents devotes per child over the period analyzed. To do so, we implicitly assume that childcare time received at age x from parents of age $x + 29$ is positively related with the time parents devote to household chores, or home production. Using data from Vargha, Šeme, Gál, Hammer and Sambt (2016), which contains information from HETUS and MTUS data, we calculate the average childcare time received from parents between age 0 and 16 relative to the parents' time spend at household chores as follows

$$\theta(x) = \mathbb{E}\left[\frac{\text{Total time consumed at age } x}{\text{Total time home production at } x + 29}\right]. \tag{11}$$

Figure 25 plots the decreasing role by age of child-care time given by parents relative to their time spend on household chores.

Given the age-specific fertility and mortality rates and the profile of θ, we calculate the aggregate time devoted to childcare by a household head at age x in year t relative to the household chores with the following formula

$$N(x,t) = \int_0^x e^{-\int_0^{x-a} \mu(s,t-x+s)ds}\theta(x-a)m(a,t-x+a)da, \tag{12}$$

where $\mu(a,t)$ is the mortality rate at age a in year t and $m(a,t)$ is the fertility rate at age a in year t.

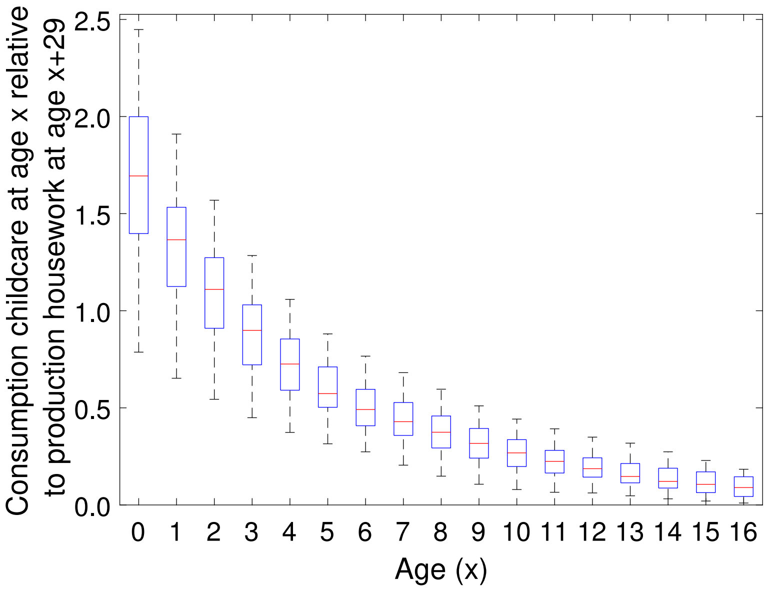


Figure 25: Per-capita childcare given to age x relative to per-capita home production at age $x + 29$

Source: Vargha, Šeme, Gál, Hammer and Sambt (2016). Notes: Boxes mark +/- one standard deviation around the mean, while whiskers mark maximum and minimum values observed in the data for each age.

B Household problem

For notational simplicity we get rid of the time component and the education component. The household head at age u is assumed to maximize the household expected utility with respect to market-produced goods c^m, home-produced goods c^h, intermediate goods c^i, time devoted to household chores h, and leisure time z

$$\max_{c^m,c^h,c^i,h,z} \int_u^\omega e^{-\int_a^x \mu(s)ds} U(c^m(x), c^h(x), z(x))dx \tag{13}$$

subject to a budget constraint,

$$\dot{a}(x) = \begin{cases} r(x)a(x) + Beq(x) & \text{for } x < A \,, \\ r(x)a(x) + Beq(x) + (1 - \tau_S(x))w(x)WP(x)\ell(x) \\ \quad +p(x)[f(c^i(x), h(x)) - c^h(x)] - (1 + \tau_C(x))(c^i(x) + c^m(x)) & \text{for } A \leq x < J \,, \\ r(x)a(x) + Beq(x) + pen(x) \\ \quad +p(x)[f(c^i(x), h(x)) - c^h(x)] - (1 + \tau_C(x))(c^i(x) + c^m(x)) & \text{for } x > J \,, \end{cases} \tag{14}$$

time constraint, a home market clearing condition

$$T(x) = z(x) + \ell(x) + h(x)N(x), \tag{15}$$
$$c^h(x) = f(c^i(x), h(x)), \tag{16}$$

and the initial and terminal boundary conditions $a(0) = 0$ and $a(\omega) = 0$.

Variable $a(x)$ stands for the financial wealth at age x, r is the interest rate, Beq is the accidental bequest received, τ_S is the social security tax rate, w is the wage rate per efficient hour of work, $\ell(x)$ is the fraction of time devoted to market work, p is the shadow price of home-produced goods, $f(\cdot,\cdot)$ is the home-production function that takes intermediate goods c^i and time h as inputs, τ_C is the consumption tax rate, $pen(x,t,e)$ is the pension benefits claimed at age x in year t by an individual with education e, which is equal to $\left[\int_{65-\rho}^{65} \rho w(t) WP(s,e)\ell(s,t,e)ds\right] \psi(t)\gamma(x,e)$, and $T(x) = 1 - t_e(x)$ is the available time after attending to education at age x.

Thus, the household head solves the following Hamiltonian

$$\begin{aligned} H =& e^{-\int_a^x \mu(s)ds} U(c^m, c^h, z) + \lambda(T - z - hN) + \gamma(f(c^i,h) - c^h) \\ &+ \mu \left(ra + Beq + p[f(c^i,h) - c^h] + (1-\tau_S) wWP(T - z - hN)\mathrm{I}_J + pen(1 - \mathrm{I}_J) - (1+\tau_C)(c^i + c^m)\right) \end{aligned}$$

where I_J denotes the indicator function that takes the value of one if $x < J$ and zero otherwise. Maximizing the Hamiltonian gives the following first-order conditions:

$$c^m: \quad e^{-\int_a^x \mu(s)ds} U_{c^m}(c^m, c^h, z) = \mu(1+\tau_C), \tag{17}$$
$$c^h: \quad e^{-\int_a^x \mu(s)ds} U_{c^h}(c^m, c^h, z) = \gamma + \mu p, \tag{18}$$
$$c^i: \quad (\gamma + \mu p) f_{c^i}(c^i, h) = \mu(1+\tau_C), \tag{19}$$
$$h: \quad (\gamma + \mu p) f_h(c^i, h) = (\mu(1-\tau_S) wWP\mathrm{I}_J + \lambda) N, \tag{20}$$
$$z: \quad e^{-\int_a^x \mu(s)ds} U_z(c^m, c^h, z) = \mu(1-\tau_S) wWP\mathrm{I}_J + \lambda, \tag{21}$$

and the dynamics of the Lagrange multiplier

$$\mu: \quad -\mu r = \dot{\mu}. \tag{22}$$

Combining (19)-(21), we have

$$e^{-\int_a^x \mu(s)ds} U_z(c^m, c^h, z) N = \frac{f_h(c^i,h)}{f_{c^i}(c^i,h)} \mu(1+\tau_C),$$

and using (17) gives

$$\frac{U_z(c^m, c^h, z)}{U_{c^m}(c^m, c^h, z)} N = \frac{f_h(c^i,h)}{f_{c^i}(c^i,h)}.$$

The above relationship is the optimal condition that needs to be satisfied both when individuals specialize in home production and when they supply their labor to firms. In this last case, the ratio between the marginal product of one hour of home production and that of one additional unit of intermediate goods satisfies

$$\frac{U_z(c^m, c^h, z)}{U_{c^m}(c^m, c^h, z)}N = \frac{f_h(c^i, h)}{f_{c^i}(c^i, h)} = \frac{1-\tau_S}{1+\tau_C}wWPN.$$

Therefore, we characterize through (17)-(22) key optimal decisions that affect both the labor supply and the accumulation of savings over the life cycle of individuals.

To solve the CGE model we use the following functional forms for the household utility function and home production:

$$U(c^m, c^h, z) = \phi_m \log\left(\frac{c^m}{\eta} - \bar{c}^m\right) + \phi_h \log\left(\frac{c^h}{\eta} - \bar{c}^h\right) + \phi_z \frac{z^{1-\sigma}-1}{1-\sigma}, \tag{23}$$

where η is a function that transforms the number of children in the household to the number of equivalent adult consumers

$$\eta(x,t) = \int_{x-16}^{x} e^{-\int_0^{x-a}\mu(s,t-x+s)ds} EAC(x-a)m(a,t-x+a)da \text{ for } x > 16,$$

where $\mu(a,t)$ is the mortality rate at age a in year t, $EAC(x)$ denotes the number of equivalent adult consumption units at age x, and $m(a,t)$ is the fertility rate at age a in year t. Thus, $\eta(\cdot)$ varies by age of the household head and over time. $\bar{c}^i > 0$ is the subsistence level of consumption of type $i \in \{m,h\}$, $\phi_i > 0$ is the relative weight of good $i \in \{m,h,z\}$ on the period utility, and $\sigma > 1$ is the inverse of the elasticity of substitution on leisure. Home production requires intermediate goods and labor

$$f(c^i, h) = \left(c^i\right)^\theta (h)^{1-\theta}, \tag{24}$$

where c^i stands for goods purchased in the market and used as intermediate goods for home production, h is the time spent on home production, θ is assumed to be positive and between zero and one.

C Market clearing conditions

Let $x \in [0,\dots,\omega]$, $t \in \mathbf{T} = \{1650,\dots,2350\}$, and $e \in \mathbf{E}$ ={lower secondary or less, upper secondary, tertiary}. Given initial values {$\bar{c}^m$, $\bar{c}^h$, ϕ_m, ϕ_h, ϕ_z, σ, θ, ρ, α, δ}, the labor augmenting-technological progress {$A(t)$}, demographic variables {$Pop(x,t)$, $\mu(x,t)$, $m(x,t)$}, the educational distribution $f(t,e)$ for cohorts born at time t, and the age-specific productivity endowment by educational attainment {$WP(x,e)$}, a recursive competitive equilibrium is a sequence of a set of household policy functions $\mathbf{c}_{e,j,t} \in \mathbf{C}$, government policy functions $\{\psi(t), \phi(t), \tau_C(t), \tau_S(t)\}$, and factor prices $\{w(t), r(t)\}$ such that

1. Factor prices equal their marginal productivities

$$w(t) = (1-\alpha)\frac{Y(t)}{H(t)}, \qquad r(t) = \alpha\frac{Y(t)}{K(t)} - \delta. \tag{25}$$

2. The government's budget constraints

$$\frac{(1-\alpha)Y(t)}{L(t)}\int_0^{\omega}Pop(x,t)\left(\int_{\mathbf{E}}\phi(t)\gamma(x,e)f(t-x,e)de\right)dx = \tau_C(t)C(t), \tag{26}$$

$$D(t)+\int_{65}^{\omega}Pop(x,t)\left(\int_{\mathbf{E}}pen(x,t,e)f(t-x,e)de\right)dx = \tau_S(t)w(t)H(t), \tag{27}$$

are satisfied, in which $\tau_S(t) = \min\{\tau_S(t), 0.35\}$, i.e. the government allows a pension tax at most of 35 percent. $D(t)$ is the aggregate debt left at death and $pen(x,t,e)$ is the pension benefits claimed at age x in year t by an individual with education e; i.e. $pen(x,t,e) = \left[\int_{65-\rho}^{65}\rho w(t)WP(s,e)\ell(s,t,e)ds\right]\psi(t)\gamma(x,e)$. Moreover, the government transfers all accidental bequests to the preceding generation, assuming a generational length of 29 years, as follows

$$\int_0^{w}\mu(x,t)Pop(x,t)\left(\int_{\mathbf{E}}a(x,t,e)f(t-x,e)de\right)dx = \int_0^{\omega-29}Pop(x,t)Beq(x,t)dx \tag{28}$$

where

$$Beq(x,t) = \max\{0, transfers(x,t)\},$$
$$D(t) = \int_0^{\omega-29}Pop(x,t)\max\{-transfers(x,t),0\}dx$$

and

$$transfers(x,t) = \frac{\mu(x+29,t)Pop(x+29,t)}{Pop(x,t)}\int_{\mathbf{E}}a(x+29,t,e)f(t-x-29,e)de + \mathbf{I}_{29}\mu(x,t)\int_{\mathbf{E}}a(x,t,e)f(t-x,e)de,$$

where $\mathbf{I}_{29}$ takes the value of one if $x < 29$ and zero otherwise.

3. Given the factor prices and government policy functions, household policy functions satisfy Eqs. (14)-(22).

4. The stock of physical capital and the human capital inputs are given by:

$$K(t) = \int_0^{\omega}Pop(x,t)\left(\int_{\mathbf{E}}a(x,t,e)f(t-x,e)de\right)dx, \tag{29}$$

$$H(t) = \int_0^{\omega}Pop(x,t)\left(\int_{\mathbf{E}}WP(x,e)\ell(x,t,e)f(t-x,e)de\right)dx. \tag{30}$$

5. The commodity market clears:

$$Y(t) = C(t) + I(t)$$

where the total consumption of market goods

$$C(t) = \int_0^{\omega}Pop(x,t)\left(\int_{\mathbf{E}}\left[c^m(x,t,e)+c^i(x,t,e)\right]f(t-x,e)de\right)dx$$

and $I(t)$ is the investment at time t.

D Model parameters

The model is comprised of a total of eleven parameters. Households are characterized by eight parameters: the utility weights of each good on the household utility $\{\phi_m, \phi_h, \phi_z\}$, the intertemporal elasticity of substitution on leisure σ, the minimum consumption level for each consumption good $\{\bar{c}^m, \bar{c}^h\}$, the home-production technology θ, and the fixed fraction of time devoted to education while the individual is in school t_e. Given that we assume a neoclassical Cobb-Douglas production function, we characterize the firms with two parameters: capital share (α) and the capital depreciation rate (δ). The government is characterized by one parameter: the number of years of work used for the calculation of the pension benefits, or pensionable years ρ.

Table 3 reports the parameter values taken from the literature as well as those structurally estimated with the model. The number of pensionable years is set at 40, since all educational groups are working at age 25. The capital share and the capital depreciation rate are set at .33 and 0.05, respectively. These two values are standard in the literature. We assume that the set of parameters $\{t_e, \theta, \bar{c}^m, \bar{c}^h\}$ coincides across the three countries analyzed. The fixed time devoted to education, while the individual is in school, is set at 0.28, which is equivalent to 4.5 hours per day for each additional year of schooling. Similar to Greenwood, Seshadri, and Yorukoglu (2005) we set the value of θ at 0.30. We set the values of $\{\bar{c}^m, \bar{c}^h\}$ at {0.25, 0.12}. These values coincide with those used in Sánchez-Romero, Abio, Patxot, and Souto (2016), once that we adjust for the initial labor-augmenting technological progress. All remaining parameters are structurally estimated with the model by minimizing a penalty function. In order to reduce the dimensionality of the problem, we impose, without loss of generality, that the sum of the utility weights equals one and that work at home upon retirement accounts for 250 minutes per day, or $h = .26$ when the total available time per week is 112 (=16×7) hours (Vargha, Šeme, Gál, Hammer and Sambt, 2016). Thus, by using the first-order conditions, we have that ϕ_z equals

$$\phi_z = \phi_h (1 - \theta) \frac{(1 - h)^\sigma}{h}.$$

Finally, we calculate for each country the values of σ and ϕ_m such that the model is capable of replicating for each country the observed income per capita, consumption per capita, average hours worked for the population between 16 and 65 years from 1870 to 2000 (see Figure 2), and the average per-capita labor supply by educational attainment between 1998 and 2003 taken from the EU Labor Force Survey (LFS).

We can highlight in Table 3 three key parameters: the subsistence level of market-produced goods $(\bar{c}^m)$, the risk aversion on leisure σ, and the weight on the utility of market-goods (ϕ_m). According to Restuccia and Vandenbroucke (2013), under low productivity a positive and high subsistence level of market-produced goods implies that the income effect dominates over the substitution effect. As a consequence, since the productivity was low during the nineteenth century, $\bar{c}^m = 0.25$ leads individuals to work long hours in order to finance their consumption. During the twentieth century, however, this parameters accounts for the fall in the number of hours worked as labor productivity increased. Parameter σ controls the response of leisure when either the wage rate per hour worked or the number of dependent children change. This parameter is, therefore, key for replicating per-capita hours worked

Table 3: Model parameters

Parameters	Symbol	Values		
Government				
Adjustment factor public education	$\phi(t)$	see Appendix A.3		
Adjustment factor public benefits	$\psi(t)$	see Appendix A.4		
Pensionable years	ρ	40 years		
Firms				
Capital share	α	0.33		
Depreciation rate	δ	0.05		
Household				
First age at adulthood	A	16		
Retirement age	J	65		
Educational distribution	$f(e,t)$	see Appendix A.1		
Relative childrearing time	$N(\cdot)$	see Appendix A.5		
Number of equiv. adult consumers	$\eta(\cdot)$	see Appendix B		
Fixed educational time	t_e	0.28		
Intermediate goods share	θ	0.30		
Subsistence level market-goods	$\bar{c}^m$	0.25		
Subsistence level home-goods	$\bar{c}^h$	0.12		
		AUT	ESP	SWE
Risk aversion on leisure	σ	2.3953	6.0580	4.5785
Weight of market-goods	ϕ_m	0.1011	0.1005	0.1485
Weight of home-goods	ϕ_h	0.6227	0.8690	0.7758
Weight of leisure	ϕ_z	0.2762	0.0304	0.0758

along the life cycle. A high value of σ implies a more inelastic labor supply, or smaller response to changes, and thus a higher per-capita labor supply at old age when the age-specific productivity falls. Parameter ϕ_m also accounts for the responsiveness of the labor supply to the market. A high value of ϕ_m reflects a higher preference for market goods, which are satisfied via an increasing market labor supply. Thus, the parameter values obtained through our model give as a result that the market labor supply of Spanish and Swedish workers is less responsive than the market labor supply of Austrians to changes in the demographic structure or in the wage rate.

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