ECONSTOR
Make Your Publications Visible.

A Service of

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Legge, Stefan

Conference Paper

Innovation in an Aging Population

Beiträge zur Jahrestagung des Vereins für Socialpolitik 2016: Demographischer Wandel - Session: Demographic Change: Productivity and Social Security, No. C12-V3

Provided in Cooperation with:
Verein für Socialpolitik / German Economic Association

Suggested Citation: Legge, Stefan (2016) : Innovation in an Aging Population, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2016: Demographischer Wandel - Session: Demographic Change: Productivity and Social Security, No. C12-V3, ZBW - Deutsche Zentralbibliothek für Wirtschaftswissenschaften, Leibniz-Informationszentrum Wirtschaft, Kiel und Hamburg

This Version is available at:
https://hdl.handle.net/10419/145590

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

WWW.ECONSTOR.EU

Mitglied der Leibniz-Gemeinschaft

Innovation in an Aging Population

[-Author Name-]*

Preliminary Version – Please Do Not Cite

as of February 25, 2016

Abstract

What is the effect of population aging on the rate of innovation? In this paper, I examine a new channel and argue that demographic shifts affect the demand for innovative goods. In an overlapping-generations model, it is assumed that individuals must spend time on learning how to use new technology. This creates age-dependent demand structures because older individuals have limited time windows for investments to pay off. The result is that in an aging population a larger fraction of the population does not invest in acquiring new skills. The amount of R&D is reduced as demand for innovative goods falls. Using data from all OECD countries for the period 1978–2010, I find support for these theoretical predictions. Those countries that faced the largest demographic shifts experienced the sharpest growth reduction in patent applications.

JEL Classification: J11, J31, O40

Keywords: Fertility, Demographics, Innovation

* For helpful comments, I am grateful to Timo Boppart, Carl-Johan Dalgaard, Reto Föllmi, Oded Galor, Emmanuel Saez, Uwe Sunde, Joachim Voth, as well as seminar participants at Feusisberg, the University of St.Gallen, and the 2013 Summer School in Economic Growth at Warwick. Part of this paper was written while visiting UC Berkeley and Princeton University whose hospitality is gratefully acknowledged.

1 Introduction

> *"Anything that is in the world when you are born is normal and ordinary and is just part of the way the world works. Anything that is invented between when you are fifteen and thirty-five is new and exciting and revolutionary and you can probably get a career in it. Anything that is invented after you are thirty-five is against the natural order of things."*
>
> — Douglas Adams, The Salmon of Doubt (2002)

What is the impact of population aging on an economy's rate of innovation? In the coming decades virtually all Western countries face significant demographic changes. This is the result of the baby boom in the 1950s and early 1960s, followed by historically low fertility rates afterwards. Tempo-adjusted total fertility rates (TFR), which account for the postponement of childbearing, are way below the replacement level in most of the OECD and EU countries.[1] Irrespective of whether past fertility trends continue, there will be tremendous changes in the age structure of most rich countries. While the first major economies already face a decline in population size the various repercussions of demographic trends have received new attention (Last, 2013).[2] A central question in this regard is what are the implications of this demographic shift for the economic development of affected countries. Whereas some studies suggest that low fertility rates favor the standard of living (Lee and Mason, 2014), others provide a more ambiguous outlook (Bloom, Canning and Fink, 2010; Prettner, 2013).

This paper investigates how population dynamics affect an economy's rate of innovation. In a first step, I show that in the past three decades the share of the working-age population has not changed substantially but hovered around 65 percent in OECD countries. However, while this group was dominated by young workers in 1980, the demographic structure of 2010 looks remarkably different. The baby-boom cohort entered the labor market in the 1970s or 1980s and is now about to leave. Computing the ratio of senior (aged 45 to 64 years) to young (15 to 34 years) workers, I document a tremendous increase after 1980. To study how this affects the economy, my theoretical model assumes that individuals live for

[1] For Japan (1.47) or the EU-27 (1.77), the adjusted TFR is already way below replacement level. The United States (2.14) is exactly at the threshold. More detailed statistics are provided by Bongaarts (1999) and in Table A.1 in the appendix.

[2] To illustrate the magnitude of demographic trends, in an article entitled 'The incredible shrinking country' (published on March 23, 2014), *The Economist* finds that Japan lost roughly the population of Jersey City (or 244,000 people) in 2013.

two periods and have to invest in knowledge in order to possess the necessary skills for using innovative goods. For young and old individuals in the model there are different, limited time windows for such skill investments to pay off. As a result, people of different age have different preferences with respect to innovative products. While young individuals demand innovative goods, the old cohort abstains from learning how to use the latest technology. It follows that in an aging population, aggregate demand for innovative goods declines. As a result, the economy's rate of innovation slows down.

While these predictions arise from a theoretical model, I examine them using a novel data set that contains information about patent applications for all OECD countries for the years 1978 to 2010. The empirical results show that growth in patent applications per capita is lower in countries with an older workforce. For almost all countries, an aging population has been associated with less innovative activity. In line with the idea of the theoretical model, the decline in patent applications appears to be driven by patents on information and communications technology (ICT). In order to test the robustness of the negative effect of population aging on innovation, I apply an instrumental variables approach using demographic information from earlier periods as instrument. The results confirm the finding that population aging has a negative impact on the growth rate of patent applications. Finally, I show that those countries that experienced the largest demographic shifts between 2000 and 2010 are the ones with the most negative trend in patent growth.

My research is related to different strands of the literature. First, a couple of studies have investigated how demographic trends affect the economy in general and innovation in particular. The work by Acemoglu and Linn (2004) is most closely related to my paper. The authors show that due to demographic trends the size of various age groups changes over time. Since most pharmaceutical drugs are mainly used by a specific age group, demographics affect the market size for each drug. Acemoglu and Linn use this mechanism to establish empirically a positive market size effect on innovation. A related paper by DellaVigna and Pollet (2007) finds that demographic trends can be used to predict changes in demand for age-sensitive sectors. Linking consumer preferences and product demand to innovation, Föllmi and Zweimüller (2006) as well as Föllmi, Würgler and Zweimüller (2014) provide theoretical models which explain firms' decision to undertake either product or process innovations. The idea that demand affects the rate of innovation is also supported empirically by Miao and Popp (2013). In particular, the authors show that natural disasters lead to an increase in

risk-mitigating innovations.

A large body of literature has established that innovation is key for economic growth (e.g., Aghion and Howitt, 1992). Although economic growth is not a primary concern of this paper, I show how the incentives to innovate are affected by an aging population. A negative effect of demographics on growth, however, is not clear (Becker, Glaeser and Murphy, 1999). An empirical study by Ahituv (2001) finds that a decrease in population growth is associated with higher GDP per capita growth. In general, demographic trends can affect the economy through its implications on, for example, social security, savings rates and capital accumulation, the business cycle, or education (Cutler et al., 1990; Jaimovich and Siu, 2009; De La Croix and Licandro, 2013). In this regard, Krueger and Ludwig (2007) show that the demographic transition towards an older population reduces return to capital while having a positive effect on wages.

My paper adds to the literature by suggesting a new mechanism which links population aging to innovation. Notably, this mechanism as well as my theoretical model addresses the *demand* side of innovation and remains silent about the *supply* side. Following Acemoglu (2002), I argue that in an aging population the demand for certain innovative goods declines. The reduced market size for such goods then leads to a reduction in the respective R&D efforts. While I also find some empirical evidence for supply side effects in the data, I do not address this in my theoretical model as it is not the focus of this paper.

The paper proceeds as follows. In Section 2, I illustrate demographic trends in the past decades. Section 3 provides a simple theoretical model which illustrates the mechanism through which population aging affects the rate of innovation. In Section 4, I test the model's predictions empirically. Finally, Section 5 concludes.

2 Demographic Trends

In this section, I document several demographic trends which occurred in major economies over the past couple of decades. Particular emphasis is put on changes in the age composition of the workforce. For this I define a new measure to capture population aging: the senior-to-young worker ratio.

2.1 Fertility Rate

Most Western countries experienced substantial fertility shocks in the past and have had very low levels of fertility since the 1970s. In Figure 1, the fertility rates of six selected countries since 1960 are shown.[3] It was during the 1970s when the fertility rate fell below 2.1 (i.e., the replacement level) in several countries. And despite some variation afterwards, most countries countries kept a sub-replacement rate of fertility. Even France and the United States have a fertility rate that is barely at the replacement level.

— Figure 1 about here —

Historical data on fertility rates reveals substantial shocks over time. Figure A.1 in the appendix indicates that the fertility rate in Germany declined sharply after 1910, experienced a boom between 1950 and 1965, and has been below the replacement level since 1970. The baby boom is clearly visible and can be observed for many countries. For the empirical analysis in Section 4, I exploit this boom as exogenous variation. Jones and Tertilt (2008) document similar demographic trends for the United States: The total fertility rate (TFT) fell steeply from about 5.5 in 1850 to 2.4 in 1940, reaching a temporary high of 3.5 during the baby boom period around 1960, but fell afterwards to about 2.0 in 1990. Since then, the TFR has remained roughly stable although this is largely driven by the relatively high fertility rate of Hispanics (2.4) and Blacks (2.0). For white non-Hispanic Americans, the TFR is about 1.8 and thus below the replacement level.

Both observed trends in fertility —temporary shocks as well as the fall below replacement levels— caused substantial changes in the composition of the population. Today almost all of the world's population lives in countries with declining fertility rates. This finding does not change when taking into account the postponement of childbearing. The so-called tempo-adjusted total fertility rates are also found to be substantially below replacement levels. While this adjustment usually raises the fertility rate by about 0.2, for Japan (1.47), Switzerland (1.69), as well as the EU-27 (1.77), the adjusted TFR is already very low. And the United States (2.14) is about to pass the threshold to sub-replacement levels.

These low fertility rates already caused significant demographic shifts and if trends of the past continue, larger compositional changes will occur. This in turn will have implications

[3]Note that the depicted fertility rates are not tempo-adjusted. However, such adjustments increase the fertility rate by about 0.2 and do not alter the trend. Fertility data for a larger set of countries is provided by Table A.1 in the appendix.

that have been described as the root cause of many economic and social problems (Last, 2013). Most notably, with a continuous sub-replacement level of fertility, the population will shrink in size and become older. Both developments can affect the rates of innovation and investment as I argue in this paper. However, at least since the Industrial Revolution there has not been any country experiencing sustained, structural population decline. Today, only Russia and Japan with their already shrinking populations may indicate the impact of sustained below-replacement levels of fertility.[4]

2.2 Compositional Changes

Fertility rates of the past decades altered the composition of the population in all countries. Due to the baby boom cohort, now in their 50s and 60s, the demographic shifts are particularly sizable.

Shares of Young, Adults, Retirees — The most straightforward way of illustrating compositional changes in the population is to define three age groups: children aged 0-19, adults aged 20-64, and retirees aged 65 or more. Figure A.2 in the appendix shows how the share of each group changed after 1950. In addition, projections for the future are shown assuming a constant fertility rate. The plots illustrate the tremendous demographic shifts. Most important is the impact of the baby boom period from 1950 to the early 1960s. First it increased the share of 0-19 year olds. Then, between 1970 and 2020, the share of working-age people is extraordinarily high. Starting around 2020, however, the share of retirees will increase sharply. This share has always increased due to rising life expectancy but the positive trend will increase once the baby boom cohort enters retirement age. Much of the economic research on population aging has focused on the implications of this latter group. In particular, financing retirement schemes has been subject to intensive research. However, for this paper I focus on the working-age population and how it changed due to demographic trends in the past.

[4]There are two major historical incidents of shrinking populations. The first occurred in the Roman Empire between A.D. 200 and 600 and marked the descent into the Dark Ages. The second incident was caused by the Black Death between 1340 and 1400 with world population shrinking from 443 to about 374 million.

Shares of Young and Senior Workers — Splitting the population into children, adults, and retirees shrouds a remarkable shift among the adult group: The shares of senior (45-64 year old) and young (15-34) workers have changed substantially in OECD countries. In order to document this, I define senior-to-young worker ratio (henceforth *S2YWR*) as

$$S2YWR = \frac{\text{share } (45-64 \text{ year old})}{\text{share } (15-34 \text{ year old})} \tag{1}$$

This ratio is motivated in two ways: First, in most countries people usually work when their age is somewhere between 15 and 65. While careers differ greatly across individuals, it is possible to argue that people outside this age bracket account for a tiny fraction of the total labor force. With this information, we can state that the age group of 15–34 year olds broadly covers the youngest people in the labor market. Conversely, the 45–64 year olds mark the most senior group. Using the ratio defined above is interesting for another reason. In the United States, the baby boom period lasted from 1946 to 1964. Thus in the year 1980, the baby boom cohort fell exactly in the group of "young workers". Thirty years later in 2010, the baby boomers are "senior workers". As a result, the senior-to-young worker ratio was very low in 1980 and has increased ever since. This is shown in Figure 2, not only for the United States but also for China, Germany, and Japan.

— Figure 2 about here —

Since the baby boom was a phenomenon observed in many countries, there are similar trends in the *S2YWR* for all four of the world's largest economies. Together these four countries account for roughly half of the world GDP. For the set of OECD countries we observe very similar trends. There is not a single country in which the ratio did not increase.[5] Between 1980 and 2010, the overall mean of the *S2YWR* changed from 0.63 to 0.96, a 52 percent increase in thirty years.

— Figure 3 about here —

The remarkable shift in the demographics of the working-age population is illustrated by Figure 3. The entire distribution of the *S2YWR* shifted to the right. Most notably, there was no OECD country with a *S2YWR* exceeding unity in 1980. In contrast, today

[5]Figure A.3 in the appendix shows the trends in the *S2YWR* for every OECD country between 1980 and 2010.

the majority of countries has a larger share of senior workers than young workers. The next section presents a theoretical model which describes a particular mechanism how the shift in the *S2YWR* affects innovation.

3 Theory

This section describes the setup and steady state equilibrium of an overlapping-generations model that features age-dependent preferences arising from necessary investments in skills for consumption. The model builds upon prior work by Acemoglu and Linn (2004) but adds a novel mechanism linking population aging to an economy's rate of innovation. Furthermore, in my model individuals choose a preferred level of product innovation and quality.[6]

3.1 Setup

Population and Demography — The economy is populated by a discrete number of generations denoted by $t \in \mathbb{N}^+$. All individuals live for two periods: young and senior adulthood. For simplicity, I assume away childhood and retirement. Population growth is determined by the exogenous fertility rate n_t. In particular, young adults L_t^Y of period t have $(1+n_t)L_t^Y$ children. These will then become young adults at date $t+1$ and senior adults in period $t+2$. By assumption, raising children comes at no cost. All decisions are made at the beginning of adulthood when individuals decide about how much to consume and how much to invest in skills.

In any period t, there are L_t^Y young adults as well as L_t^S senior workers. It holds that $L_{t+1}^Y = (1+n_t)L_t^Y$ and $L_{t+1}^S = L_t^Y$. This results from the fact that all individuals live for exactly two periods. The total population grows for $n_t > 0$, shrinks for $n_t < 0$, and remains constant for $n_t = 0$. The ratio of senior to young workers ($S2YWR$) is given by

$$\frac{L_t^S}{L_t^Y} = \frac{1}{1+n_{t-1}} := S2YWR_t. \tag{2}$$

A baby boom period can be illustrated by an increase in n_t. First, this leads to a decline

[6] In the model by Acemoglu and Linn, individuals do not choose a specific quality but are indifferent between the best and second-best quality level while spending a constant share of their income on the innovation-related good. The rate of innovation is determined by the market size for each drug which in turn affects firm competition and R&D efforts to be the firm with the highest quality.

in $S2YWR_{t+1}$ when the large cohort enters the labor market. Subsequently, however, there is an increase in $S2YWR_{t+2}$ when the baby boom cohort turns into senior workers.

Utility and Types of Goods — The economy features two different types of goods. First, a basic good denoted by y. This can be consumed, used for production or for research expenditures. Second, there is a sophisticated good x which can be produced at different quality levels q and requires skills for consumption. Each individual has an exogenously given endowment y_t in both life periods.[7] Preferences are given by

$$U_t = u_t + r^{-1}u_{t+1} \tag{3}$$

$$\text{with} \quad u_t = c_t^{1-\gamma}(q_t x_t)^{\gamma} \quad \text{and} \quad u_{t+1} = c_{t+1}^{1-\gamma}(q_{t+1}x_{t+1})^{\gamma} \tag{4}$$

where r is the discount rate of consumers (and the economy's interest rate) and $\gamma \in (0,1)$. Consumption of the basic good (y) is denoted by c_t while x_t is the amount of the sophisticated good consumed in period t. In order to simplify the analysis, it is assumed that $x_t \in \{0,1\}\ \forall t$. Given the utility function, this implies that individuals always consume one unit of the sophisticated good and only choose the quality thereof. This assumption as well as the Cobb-Douglas functional form are for simplicity.

The price of the basic good is normalized to 1 in all periods (numeraire) while p_t denotes the (relative) price of the sophisticated good. In the absence of bequests, savings, or borrowing, the budget constraints for the two periods read

$$y_t \geq c_t + p_t(q) + e_t \quad \text{and} \quad y_{t+1} \geq c_{t+1} + p_{t+1}(q) + e_{t+1} \tag{5}$$

where $p_t(q)$ and $p_{t+1}(q)$ are the price of the chosen quality q, and e_t as well as e_{t+1} reflect investments in skills in the two periods. These are necessary for the consumption of higher quality versions of the sophisticated good.

Investments for Innovative Goods — Each individual in the economy can only consume higher qualities of the sophisticated good if she has the necessary skills. While it takes no learning to consume quality q_{t-1} for someone born at time $t-1$, it requires an invest-

[7] An alternative is to assume inelastic supply of one unit of labor each period at wage rate y_t. Note that for simplicity I abstract from modeling senior workers to earn more than young workers.

ment of $e_t = \phi(q_t - q_{t-1})$ with $\phi > 0$ to be able to use the state-of-the-art quality q_t.[8] This assumption can be motivated by an example. For every innovative good (e.g., computers) adults have to spend time learning how to use it. This investment is not necessary for more established goods (e.g., telephone) if individuals grew up at a time when these were already available. An individual born in 1960, for instance, grew up in a world with widespread use of telephones but no computers. When the latter were introduced during the 1990s, this person was in his thirties and had to spend a considerable amount of time on learning how to use computers.[9] This kind of investment is crucial for the model's dynamics. Note that it is possible to extend the model to allow skills to deteriorate over time:

$$E_t = e_t \quad \text{and} \quad E_{t+1} = E_t(1-\xi) + e_{t+1} \quad \text{with } \xi \geq 0 \tag{6}$$

However, for the baseline model, I assume that skills, once obtained, are neither lost nor unlearned. This appears to be the more relevant case. Thus I assume $\xi = 0$ throughout the model. Moreover, the cost of learning how to use new technology is assumed to be the same for an individual in her young and senior period.

R&D and Production — At any time t there is one firm with the technology to produce the best quality q_t of the sophisticated good. This firm can produce one unit of x_t at quality q_t using one unit of the basic good y_t. The marginal cost of producing x are one irrespective of the quality level. In order to achieve one unit increase in quality, a firm has to spend $\delta > 0$ units of the basic good. If a firm develops a new quality, it receives a patent for one period. The total R&D spending for the quality improvements demanded by consumers in period t is given by $z_t = \delta(q_t - q_{t-1})$. By assumption there is free entry into R&D and each (potential) firm has access to the same research technology.[10]

Given that the marginal costs of production for all quality levels is equal to one, the firm with the best quality level at time t faces a competitive fringe by competitors. Hence it will only be able to charge $p_t(q_t) = 1 + \delta(q_t - q_{t-1})$ for its quality. This results from the fact that

[8]The way I model the acquisition of knowledge is similar to Garicano and Rossi-Hansberg (2015) who assume a fixed cost of learning a unit length of solving problems.

[9]Sometimes the terms 'digital natives' and 'digital immigrants' are used to distinguish individuals who grew up in a digital world from those growing up in an earlier time.

[10]Note that following Aghion and Howitt (1992) it is assumed that the firm with the best quality does not invest in R&D itself.

in period t the price of the quality level q_{t-1} drops to one as the patent expires. Any better quality, first available in period t, is offered at price $p_t(q_t)$ which increases in q_t.

Choosing Quality and Utility Maximization — In order to illustrate how individuals optimize their lifetime utility, consider the cohort of individuals born in period $t-1$. Upon entering adult life, this group chooses an optimal strategy for both periods t and $t+1$. They determine the consumption of the basic good in both periods, c_t and c_{t+1}. Moreover, they choose how much to invest in skills: e_t and e_{t+1}. When deciding whether to purchase a quality higher than q_{t-1} —which can be purchased at a price of one and consumed without skill investments— the gain in utility must outweigh the costs. In particular, individuals can choose between $\{c_t, q_t\}$ and $\{c_t + (\delta+\phi)\Delta q_t, q_{t-1}\}$, where $\Delta q_t = q_t - q_{t-1}$ and $\delta(q_t - q_{t-1})$ as well as $\phi(q_t - q_{t-1})$ indicate the higher price and the necessary skill investments, respectively. If the first combination, $\{c_t, q_t\}$, is strictly superior, individuals will invest $e_t > 0$ in skills. In the second period $t+1$ the cohort is in senior age. For them to abstain from further skill investments ($e_{t+1} = 0$) and continue consuming q_t it must hold that $\{c_{t+1} + (\delta+\phi)\Delta q_{t+1}, q_t\}$ is preferred over $\{c_{t+1}, q_{t+1}\}$. To satisfy both conditions, I impose the following assumption.

Assumption 1. *It is assumed that*

$$c_{t+1}\left(q_{t+1}^{\gamma/(1-\gamma)} q_t^{-\gamma/(1-\gamma)} - 1\right)/\Delta q_{t+1} < \delta + \phi < c_t\left(q_t^{\gamma/(1-\gamma)} q_{t-1}^{-\gamma/(1-\gamma)} - 1\right)/\Delta q_t.$$

where I use the fact that that $p_{t+1}(q_t) = 1$. The assumption implies that the cost of innovating (δ) and learning (ϕ) are not too large to prevent individuals from choosing q_{t-1} over q_t but large enough to not invest in skills as senior adults. The optimality of investing in skills only when young (i.e., $e_t > 0$ and $e_{t+1} = 0$) requires that

$$\left(c_t^{1-\gamma} q_t^{\gamma}\right) + \frac{1}{r}\left(c_{t+1}^{1-\gamma} q_t^{\gamma}\right) \geq \left(\tilde{c}_t^{1-\gamma} q_t^{\gamma}\right) + \frac{1}{r}\left(\tilde{c}_{t+1}^{1-\gamma} q_{t+1}^{\gamma}\right) \tag{7}$$

with $c_t = \tilde{c}_t = y_t - 1 - (\delta+\phi)\Delta q_t$, $c_{t+1} = y_{t+1} - 1$ and $\tilde{c}_{t+1} = y_{t+1} - 1 - (\delta+\phi)\Delta q_{t+1}$. For condition (7) to hold, I impose the following assumption.

Assumption 2. *It is assumed that* $\delta + \phi \leq \Delta q_{t+1}^{1/1-\gamma}/(\Delta q_{t+1}^{\gamma/1-\gamma} - y - 1)$.

This implies that, in general, a cohort born at $t-1$ lives and consumes quality q_t in periods t and $t+1$. It follows that only the young generation invests in skills and demands a

higher quality level. In order to maximize lifetime utility, individuals choose a quality level given by

$$q_t^* = \frac{\gamma}{\delta + \phi} y_t + \gamma q_{t-1}. \tag{8}$$

It is straightforward to see that the preferred quality is increasing in γ and y_t but decreasing in the cost of innovating (δ) and learning (ϕ). Using equation (8) and the fact that a firm has to invest $z_t = \delta(q_t - q_{t-1})$ for the quality improvement, we get that

$$z_t^* = \delta\left(\frac{\gamma}{\delta + \phi} y_t - (1 - \gamma) q_{t-1}\right) \tag{9}$$

which shows that total R&D spending is increasing in y_t. Profits of the firm with the best technology in period t are given by

$$\pi_t(q_t) = \delta(q_t - q_{t-1}) L_t^Y = \delta\left[\frac{\gamma}{\delta + \phi} y_t - (1 - \gamma) q_{t-1}\right] L_t^Y. \tag{10}$$

Note that patent protection expires after one period. Thus the firm with the best quality in one period receives no profits in subsequent periods: $\pi_{t+1}(q_t) = 0$. This is because both the price and the marginal cost of quality q_t are one in period $t + 1$.

3.2 Equilibrium

In equilibrium, aggregate demand for both vintage (q_{t-1}) and innovative goods (q_t) depends on the composition of the population. While young adults of period t purchase the latest quality (q_t), senior adults only demand the basic good as well as last-period's best quality of the innovative good (q_{t-1}). When the share of senior relative to young adults increases, aggregate demand shifts in favor of vintage goods. This is summarized in the following proposition.

Proposition 1. *Controlling for population size, if the population share of senior individuals increases, the demand for innovation declines.*

Proof. Total demand for the innovative quality q_t in period t is given by the number of young adults L_t^Y as every young individual consumes one unit of x_t at quality q_t. □

As a result of the change in demand, total R&D spending as well as the economy's rate of innovation decreases in an aging population.

Proposition 2. *If the senior-to-young worker ratio is higher, per capita total spending on R&D as well as the number of patent applications per capita decreases. Formally, if the* $S2YWR_t$ *is higher both* z_t/L_t *and* $\Delta q_t/L_t$ *are reduced.*

Proof. Total spending on R&D is given equation (9). Dividing both sides by L_t and replacing population size on the right-hand side by the $S2YWR$ from equation (2) shows that $\partial z_t^*/\partial S2YWR_t < 0$. □

Concerning the dynamics of the model, an increase in the fertility rate n_t of period t causes population aging in $t+2$. During this process, the rate of innovation decreases. While the model abstracts from several potentially important factors, it illustrates the main mechanism through which population aging can affect the rate of innovation. Extensions of the model could include international demand for innovative goods. However, in the empirical part, I already control for trade openness and find that it does not affect my findings. Another potential issue with the model is that it contains only one sector with R&D. In a multi-sector model, however, innovation could shift from one sector with declining demand to other sectors like health care in which demand might increase if the population becomes older. In the empirical analysis, I discuss this idea in more detail.

4 Empirical Evidence

This section puts the predictions of my theoretical model to the data. The idea of is to investigate whether the remarkable demographic shift in the composition of the labor force —documented in Chapter 2— is associated with economic outcomes of the kind suggested by the model. In particular, the theory suggests that with an aging population (or labor force), there should be a decline in the demand for innovative goods (Proposition 1) as well as a reduced number of patents (Proposition 2).

Concerning the first proposition, the lack of detailed data on product demand by age group obstructs a direct test. However, survey data from the Pew Research Center shows that, for example, smartphone ownership is highest among younger Americans. While 85% of 18–29 year olds use a smartphone, only about half of the 50–64 year olds do so. Similarly, data from Statistica indicates that more than half of iPhone users in the United States are aged 13-34 while only 21% are aged 45-64. Furthermore, among smartphone owners it is the

younger age group which uses the most sophisticated services like online banking or turn-by-turn navigation. However, it remains to be shown that —beyond this anecdotal evidence— population aging generally affects a country's rate of innovation.

4.1 Data

For the empirical analysis, I use a novel data set that contains country-level statistics on both demographics as well as innovative activities. I compile the data set by drawing on three sources. First, for demographic information the UN Population Division provides data from 1950 to 2010 for a large set of countries. This not only includes fertility rates and age group shares for the past but also projections for the future based on different assumptions with respect to the fertility rate. Second, in order measure innovative activity I follow the recent literature (e.g. Aghion et al., 2014 and 2015) and use the number of patent applications per capita.[11] The OECD publishes information on such applications for each country and year. This data is publicly available for the years 1978–2012 and covers mostly OECD countries but has information for a selected group of non-OECD members as well. Field-specific information on patent applications (e.g., in ICT) is available for the same set of countries and the period 1999-2012. In the empirical analysis, I use this information to measure innovative activity in each country. Finally, the Penn World Table (PWT, Mark 8.1) provides detailed data on economic indicators for 167 countries between 1950 and 2011. Throughout my analysis on innovative activities, I use data from 1978 to 2010 unless otherwise indicated. The focus is on OECD countries.[12] In order to illustrate the data set, Table 1 provides summary statistics on the main variables employed in the regressions.

— Table 1 about here —

The data set includes all 34 OECD countries for the period 1978-2010. Hence, the number of observations is 34×33 years = 1,112. The number of patent applications, however, takes

[11] An alternative measure for a country's innovative activity is given by its R&D expenditures as a share of GDP. While such expenditures can be considered a proxy variable for R&D efforts, patent applications closer resemble the quality improvements that I discuss in the model.

[12] As of 2015, there are twenty founding member countries and fourteen that joined later. The former group joined in 1961 and consists of Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States. Subsequently, the following countries joined: Japan (1964), Australia (1971), New Zealand (1973), Finland (1969), Mexico (1994), the Czech Republic (1995), Hungary (1996), Poland (1996) and Korea (1996).

the value zero in some years and countries. Thus the growth rate in patent applications is missing in a few cases. The senior-to-young worker ratio (henceforth *S2YWR*) in this data set ranges from 0.31 to 1.21, reflecting the large variation across countries and time. Innovative activity is measured as the total number of patent applications per one million people which ranges from zero to 345.

4.2 Descriptive Evidence

The main prediction of the model is that the rate of innovation declines in an aging population. In order to examine this effect in the data, I first plot the time trend in the senior-to-young worker ratio for all OECD countries. In Figure 4, it is apparent that there was not much of a trend prior to the late 1990s. However, afterwards there was a steep increase.

— Figure 4 about here —

Similarly, there was not much of a trend in the average growth rate in patent applications per capita prior to 2000. In contrast, in the period between 2000 and 2010, there was a notable decline in R&D-related activity. In the econometric analysis of Section 4.4, I will thus concentrate on this period.[13] This descriptive evidence suggests that population aging has rather a contemporaneous effect on innovation with little indication of anticipation.[14] In Figure 5, I plot the annual growth rate in patent applications per capita against the senior to young worker ratio. The graph is based on data from all current OECD countries and the time period 1978 to 2012.

— Figure 5 about here —

The growth rate of patent applications is significantly lower in those country-year observations with a larger senior-to-young worker ratio. As a notable finding, the plot suggests that there is a large variation in patent growth rates at S2YWR below one. Once the share of senior workers dominates, however, the mean growth rate in patent applications converges to zero. On average the growth rate drops from 0.26 to 0.01 when moving from a S2YWR of 0.75 or lower to a ratio above 1.10. A similar pattern is also found for most OECD countries when they are analyzed separately. Figure 6 provides two examples.

[13] Another benefit of focusing on the time after 1999 is that I have data on field-specific patent applications.

[14] The missing anticipation effect is discussed by DellaVigna and Pollet (2007). To explain this phenomenon, the authors suggest a model of inattention to available information about the future.

— Figure 6 about here —

In both the United States and Germany, the rate of innovative activity declined after 1978 along with a large increase in the *S2YWR*. Whether this observation just illustrates a correlation between two variables that follow a time trend or whether there is in fact a causal relationships requires further investigation.

4.3 Empirical Specification

In the first step of the econometric analysis, I run a regression of patents per capita on the senior-to-young worker ratio. This uses data from all 34 OECD countries and control variables for the GDP per capita, population size, trade openness and the share of 65+ year olds. Moreover, I control for the initial level of total patent applications per capita to take into account convergence effects (Barro and Sala-i Martin, 1992). Finally, I add country- and year-fixed effects to the regressions. The baseline specification is given by

$$\text{PAT}_{c,t} = \gamma_c + \delta_t + \tau \text{S2YWR}_{c,t} + \mathbf{X}_{c,t}\beta + \varepsilon_{c,t} \tag{11}$$

where $\text{PAT}_{c,t}$ is the growth in patent applications per capita, γ_c as well as δ_t are country- and year-fixed effects, $\mathbf{X}_{c,t}$ is a vector of control variables, and $\varepsilon_{c,t}$ denotes the time-varying country-specific idiosyncratic standard error which is clustered at the country level. The coefficient of interest is given by τ and indicates the impact of the senior-to-young worker ratio on the rate of innovation. Following the theoretical model of Section 3, I expect τ to be negative. This would indicate that population aging negatively affects R&D-related activities.

Identifying the causal effect of population aging on the rate of innovation remains a challenging task even though trends in demography can be considered exogenous. The primary source of concern is that some unobserved factor reduces R&D-related activities. The simultaneous trend in demography could then be spuriously correlated with trends in innovation. In order to mitigate this concern, I add country- and year-fixed effects to the regression. They pick up two disturbing factors. First, time-fixed country-specific factors which are not explicitly included on the right-hand side of equation (11). This is crucial as the literature points out the role of long-run, persistent determinants of innovation which differ across countries. These include, for example, political institutions, property rights, or cultural traits.

All these factors vary across countries and affect the rate of innovation. However, in my empirical model, such determinants are absorbed by the time-invariant country-fixed effect. Second, the inclusion of year-fixed effects controls for common shocks such as the economic slowdown caused by the financial crisis in 2007-08. In addition, δ_t also reduces the impact of spurious time trends and panel error correlations. The downside of including fixed effects is that adding $N + T - 2$ dummy variables to the model creates a particularly demanding environment. It removes a large share of both the cross-country and within-country variation of the data. Hence, when reporting the results I show estimates of equation (11) with and without fixed effects.

4.4 Results

The results shown in Table 2 confirm the pattern found before and suggest again that a higher share of senior (45-64 year old) workers is associated with less growth in patent applications. This finding does not depend on whether control variables are added to the specification. Moreover, the addition of country- and year-fixed effects does not alter the negative coefficient on the *S2YWR* either.

— Table 2 about here —

Considering the magnitude of this effect, the estimates of Table 2 suggest that an increase of the senior-to-young worker ratio by 1% reduces the the growth rate of patents per capita by about 0.9%. In the last three columns of Table 2, patent data for specific sectors is used as the dependent variable. First, I consider the field of information and communications technology (ICT). According to my theoretical model, the negative impact of population aging is expected to be larger in this case. The estimates shown in Table 2 confirm this prediction. While the negative coefficient on $\text{S2YWR}_{c,t}$ remains highly significant its magnitude increases from about 0.9 to 1.2 when focusing on ICT patents. In contrast, no such significant negative effect is found among patents in medical or pharmaceutical technology. In line with research by Acemoglu and Linn (2004), research in an aging population might shift toward the development of new drugs and medical technology.

Supply versus Demand Effect — To this point, the empirical analysis has supported the hypothesis that the growth rate in patent applications per capita decreases in an aging

population. This raises the question whether R&D-related efforts are reduced because of a supply or demand effect. The former would arise if innovative activity is mostly carried out by young workers. Hence their absence would lead to a decline in patent applications. The demand effect, in contrast, implies that due to the absence of young workers there is less demand for innovative goods. In the theoretical model of Section 3, the demand effect explains why the economy's rate of innovation is reduced if the share of senior workers increases. The data set allows to test this idea. In Column (5) of Table 2, the senior-to-young worker ratio is replaced by its two components: the population share of young (15–34 year old) and senior (45–64) workers.[15] The estimates suggest that both supply and demand factors play a role. The larger the fraction of young workers, the higher the rate of innovation. In contrast, an increase in the share of senior workers reduces patent growth.

In a second test, I examine whether there is a decline in the growth rate of patent applications *per young worker*. If this can be found in the data, it would serve as evidence of a demand effect. One problem with estimating this, however, is that any change in the number of patent applications per young or senior worker is driven largely by changes in the nominator. Demographic changes —even on a five-year basis— are minor compared to changes in R&D-related activity. Hence, it is not surprising to see that Figure A.5 in the Appendix shows results that are very similar to the ones obtained when using patent applications *per capita* as in Figure 7.

4.5 Robustness Tests

The analysis so far indicates a negative impact of population aging on the rate of innovation. In order to explore the robustness of this findings, I conduct two sets of robustness checks.

Historical Demography — To further test whether the $S2YWR$ has an effect on innovation, I suggest an instrumental variable (IV) approach using demographic information from earlier periods. In particular, I instrument, for example, the $S2YWR$ of the year 2000 by the ratio of 35–54 year olds to 5–24 year olds in 1990. The latter ratio can be referred to as medium-age worker to children ratio ($MAW2CR$). The validity of the IV approach rests

[15]Note that using the S2YWR as an explanatory variable imposes the assumption that the share of young and the share of senior workers have opposite effects on innovation. Having both shares separately in the specification allows them to have independent effects.

upon two conditions, namely that (i) demographic patterns within each country are not too distorted by immigration, and that (ii) historical population shares are uncorrelated with unobserved determinants of innovative activity. Empirically, I provide supportive evidence for the first condition.[16] Testing the second assumption, however, is not possible.

— Table 3 about here —

The use of $MAW2CR_{c,t-10}$ as an instrumental variable for $S2YWR_{c,t}$ is supported by large first stage F-tests shown in Table 3. The results with respect to how population aging affects innovative activity remain similar compared to the OLS estimation shown in Table 2. The point estimates are smaller but still highly significant. This provides further evidence that an aging population is associated with less innovation.

Time Trends — In a final test, I further explore whether changes in the senior-to-young worker ratio are not just correlated with R&D-related activities within each OECD country. If there is indeed a causal effect of workforce aging on patents, we should expect to see a sharper decline in the growth of patent applications in countries with larger increases in the *S2YWR*. Figure 7 supports this idea using data from 2000–2010.

— Figure 7 about here —

The graph plots the estimated time trends in the patent growth rate against the ten-year change in S2YWR. Countries like Korea and Greece that experienced the largest demographic shift between 2000 and 2010 are the ones that saw the largest decline in their patent growth rates over the same time period. The relationship shown in the figure can also be explored using regression analysis. Columns (4) and (5) of Table 3 provide the regression results. Notably the negative coefficient on the time trend in the *S2YWR* does not disappear when controlling for time trends in the GDP per capita, population size, trade openness and the share of 65+ year olds. Despite the small number of observations (34 OECD countries), the coefficient on the change in *S2YWR* is highly significant and negative.

[16] In the absence of migration, the $MAW2CR_{1990}$ would be identical with the $S2YWR_{2000}$. Immigration usually accounts for a tiny percent of the change in the composition of the workforce of a given age. Using data from the OECD countries, I find a correlation of about 0.9 between $S2YWR_t$ and $MAW2CR_{t-10}$.

Extending the Time Period — The results of the econometric analysis suggest a negative impact of population aging on the rate of innovation. Motivated by findings of Figures 4 and 5, I use data for the most recent period 2000-2010 in the regressions. As is visible in the figures, there is not much of a trend in either the S2YWR or innovation prior to the year 2000. Hence, when extending the sample to the period of 1980–2010 or 1990–2010, I obtain similar estimates as shown in Table 2 with reduced significance.

5 Conclusion

Given that basically all major countries experienced a substantial decline in their fertility rates, population aging will be a major trend in future decades. If present trends persist, by 2050 the median age in Europe will be significantly above fifty, up from about thirty-five today. In this paper, I explore a novel mechanism through which population aging affects innovation. Supported by the empirical analysis, my findings suggest that the rate of innovation is reduced in countries with aging workforces. Potentially the mechanism described in this paper also affects the rate of economic growth. This is because economic growth often occurs through improvements in quality as new models of consumer goods replace older ones (Bils, 2009).

It is important to emphasize that the mechanism described in this paper does not apply to all kinds of innovative activity. Following Acemoglu (2002), the declining demand for innovative goods as in my model will reduce R&D with respect to such goods. However, innovative activity might shift to other sectors in an aging population. Most importantly, there might be more research in the field of health care due to the increased market size for such goods and services. Moreover, the shortage of young workers will affect prices and thus spur innovation with respect to labor-saving technologies.

Overall, my research aims at improving our understanding of the effects of an aging population on innovation. A misunderstanding of this link can have severe consequences if it leads to the imposition of misguided policies. These may arise, for example, from the neglect of slower economic growth in long-term projections which are relevant for retirement schemes (Rojas, 2005; Poterba, 2014). In terms of policy conclusions, my research does not intend to provide any particular recommendations. However, several policies have been suggested

to raise fertility rates. These comprise changes in social security, infrastructure investments, or improving education. However, neither have such policies been particularly successful in the past (see Last, 2013) nor would they prevent population aging. Moreover, altering the fertility rate will not affect the composition of the workforce for at least two decades. Hence, if anything policy interventions must address the rate of innovation directly. Recent empirical evidence provided by Thomson (2015), however, suggests that the effectiveness of tax incentives for R&D remains obscure.

References

Acemoglu, Daron. 2002. "Directed Technical Change." *The Review of Economic Studies*, 69(4): 781–809.

Acemoglu, Daron, and Joshua Linn. 2004. "Market Size in Innovation: Theory and Evidence From the Pharmaceutical Industry." *The Quarterly Journal of Economics*, 119(3): 1049–1090.

Adams, Douglas. 2002. *The Salmon of Doubt: Hitchhiking the Galaxy One Last Time.* New York:Random House.

Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica*, 60(2): 323–351.

Aghion, Philippe, Antoine Dechezlepretre, David Hemous, Ralf Martin, and John Van Reenen. 2014. "Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry." *Journal of Political Economy*, forthcoming.

Aghion, Philippe, Ufuk Akcigit, Antonin Bergeaud, Richard Blundell, and David Hemous. 2015. "Innovation and Top Income Inequality." *NBER Working Paper #21247.*

Ahituv, Avner. 2001. "Be Fruitful or Multiply: On the Interplay between Fertility and Economic Development." *Journal of Population Economics*, 14(1): 51–71.

Barro, Robert J., and Xavier Sala-i Martin. 1992. "Convergence." *Journal of Political Economy*, 100(2): 223–251.

Becker, Gary S., Edward L. Glaeser, and Kevin M. Murphy. 1999. "Population and Economic Growth." *American Economic Review (Papers and Proceedings)*, 89(2): 145–149.

Bils, Mark. 2009. "Do Higher Prices for New Goods Reflect Quality Growth or Inflation?" *Quarterly Journal of Economics*, 124(2): 637–675.

Bloom, David E., David Canning, and Guenther Fink. 2010. "Implications of population ageing for economic growth." *Oxford Review of Economic Policy*, 26(4): 583–612.

Bongaarts, John. 1999. "Fertility Decline in the Developed World: Where Will It End?" *American Economic Review (Papers and Proceedings)*, 89(2): 256–260.

Cutler, David M., James M. Poterba, Louise M. Sheiner, and Lawrence H. Summers. 1990. "An Aging Society: Opportunity or Challenge?" *Brookings Papers on Economic Activity*, 1: 1–56.

De La Croix, David, and Omar Licandro. 2013. "The Child is Father Of the Man: Implications for the Demographic Transition." *The Economic Journal*, 123(567): 236–261.

DellaVigna, Stefano, and Joshua M. Pollet. 2007. "Demographics and Industry Returns." *The American Economic Review*, 97(5): 1667–1702.

Feenstra, Robert C., Robert Inklaar, and Marcel P. Timmer. 2015. "The Next Generation of the Penn World Table." *American Economic Review*, 105(10): 3150–3182.

Föllmi, Reto, and Josef Zweimüller. 2006. "Income Distribution and Demand-Induced Innovations." *Review of Economic Studies*, 73(4): 941–960.

Föllmi, Reto, Tobias Würgler, and Josef Zweimüller. 2014. "The Macroeconomics of Model T." *Journal of Economic Theory*, 153: 617–647.

Garicano, Luis, and Esteban Rossi-Hansberg. 2015. "Knowledge-based Hierarchies: Using Organizations to Understand the Economy." *The Annual Review of Economics*, 7: 1–30.

Jaimovich, Nir, and Henry E. Siu. 2009. "The Young, the Old, and the Restless: Demographics and Business Cycle Volatility." *American Economic Review*, 99(3): 804–826.

Jones, Larry E., and Michele Tertilt. 2008. "An Economic History of Fertility in the U.S.: 1826-1960." *NBER Working Paper #12796.*

Krueger, Dirk, and Alexander Ludwig. 2007. "On the consequences of demographic change for rates of returns to capital, and the distribution of wealth and welfare." *Journal of Monetary Economics*, 54(1): 49–87.

Last, Jonathan V. 2013. *What to Expect When No One's Expecting: America's Coming Demographic Disaster.* New York:Encounter Books.

Lee, Ronald, and Andrew Mason. 2014. "Is Low Fertility Really a Problem? Population Aging, Dependency, and Consumption." *Science*, 346(6206): 229–234.

Miao, Qing, and David Popp. 2013. "Necessity as the Mother of Invention: Innovative Responses to Natural Disasters." *NBER Working Paper #19223.*

Poterba, James M. 2014. "Retirement Security in an Aging Society." *NBER Working Paper #19930.*

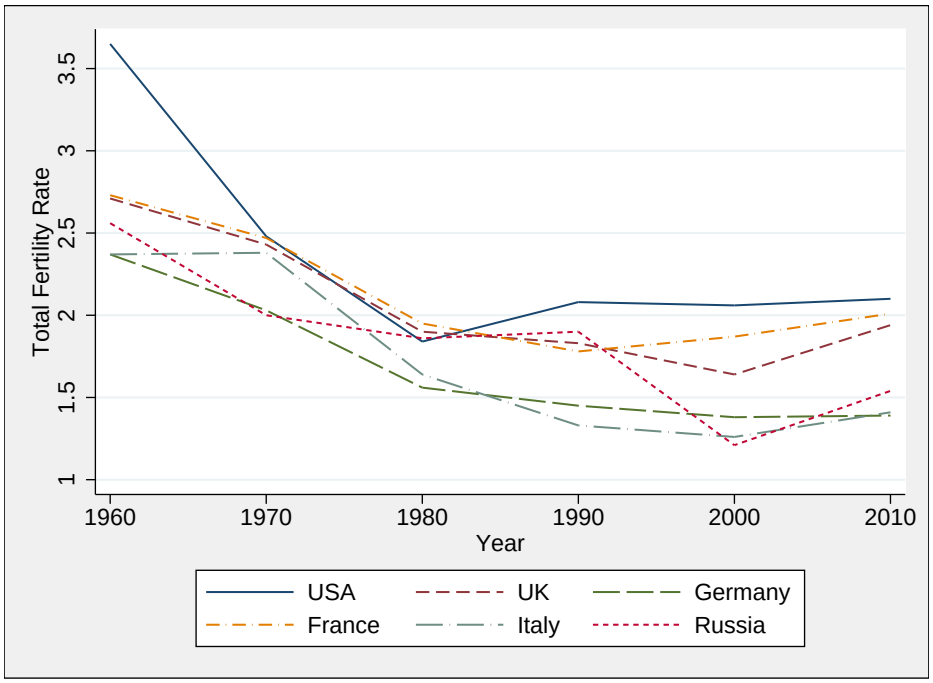
Prettner, Klaus. 2013. "Population aging and endogenous economic growth." *Journal of Population Economics*, 26(2): 811–834.

Rojas, Juan A. 2005. "Life-cycle earnings, cohort size effects and social security: A quantitative exploration." *Journal of Public Economics*, 89(2-3): 465–485.

Thomson, Russell. 2015. "The Effectiveness of R&D Tax Credits." *The Review of Economics and Statistics*, forthcoming.

Figures and Tables

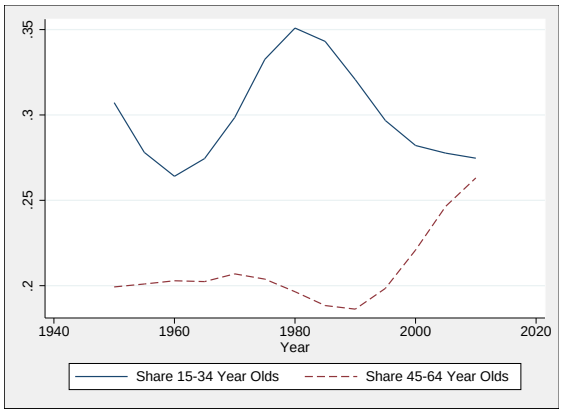
Figure 1: Historical Trends in Fertility Rates of Selected Countries



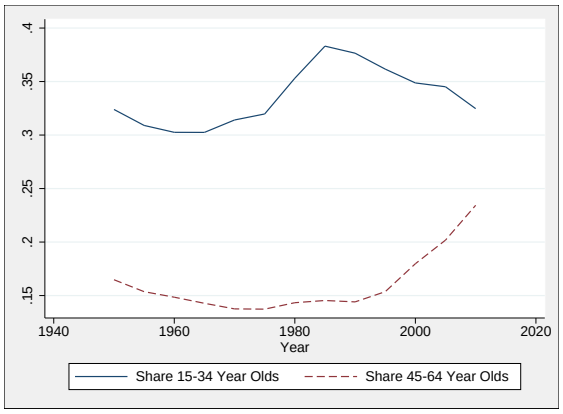
Note: The figure plots trends in fertility rates for six countries and the time period after 1960. Sources: Bundesinstitut für Bevölkerungsforschung and U.S. Census Bureau.

Figure 2: Young and Senior Workers in Four Countries, 1950–2010

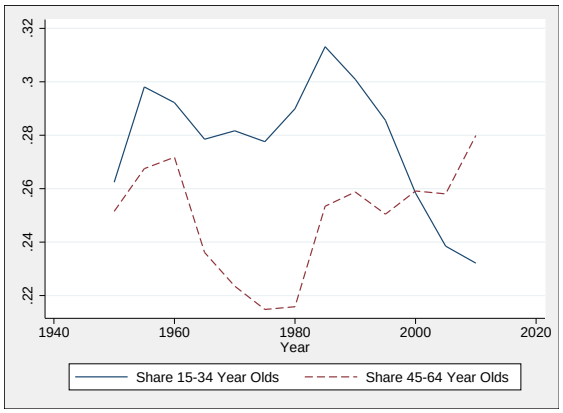
(a) United States



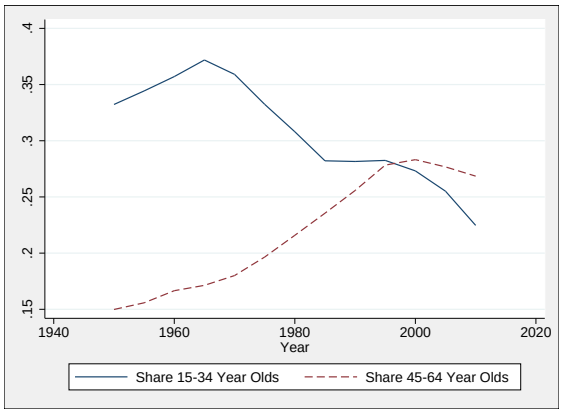
(b) China



(c) Germany

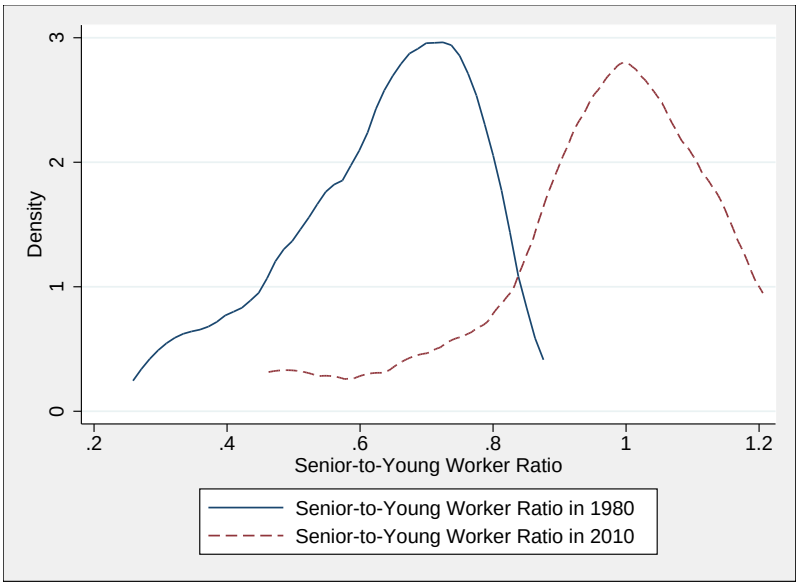


(d) Japan



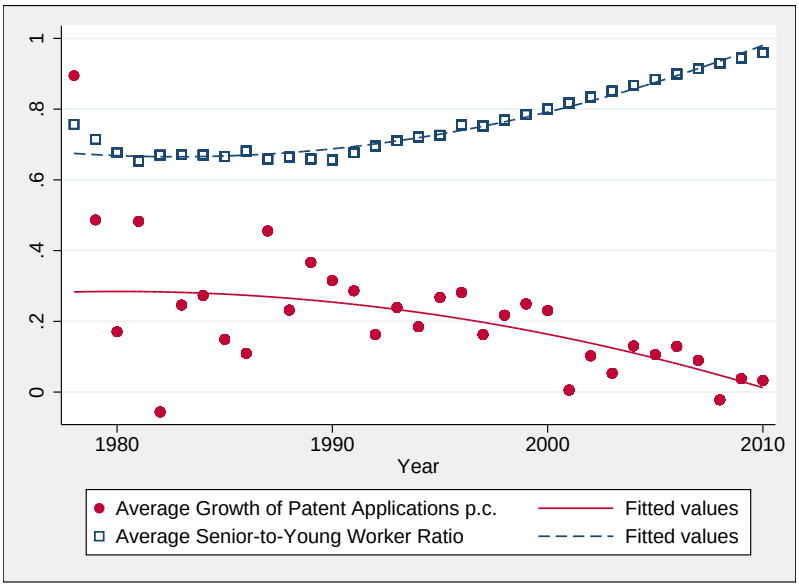
Note: The figures plot the share of young workers (15-34 years old) and senior workers (45-64 years old). The time period ranges from 1950 to 2012. Data obtained from the UN Population Division.

Figure 3: Senior-to-Young Worker Ratio, 1980 and 2010



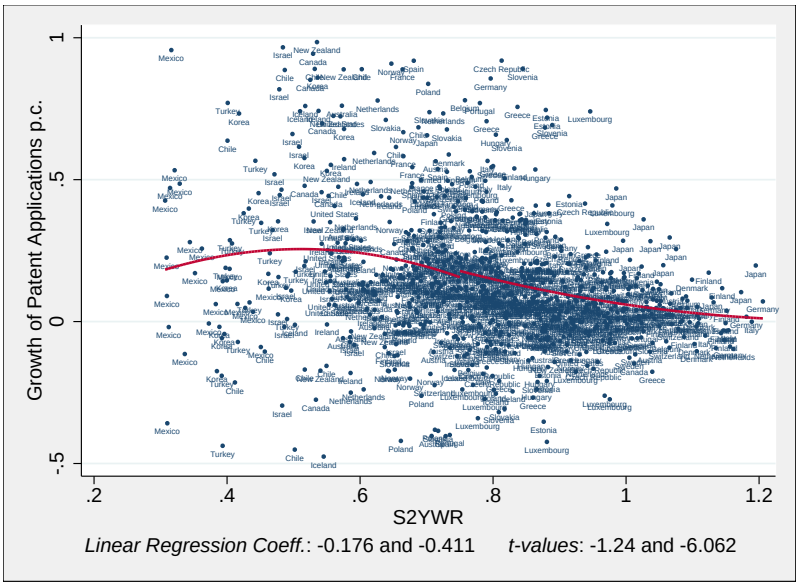
Note: The figure plots the kernel density of the senior-to-young worker ratio in all OECD countries. The solid blue line shows data from 1980 while the dashed red line is based on 2010. Data obtained from the UN Population Division.

Figure 4: Average Senior-to-Young Worker Ratio and Average Innovation



Note: The figure plots the average senior-to-young worker ratio (dashed blue line) as well as the average growth in patent applications per capita (solid red line) for the time period 1978–2010. The data includes all OECD countries. A quadratic fit is shown.

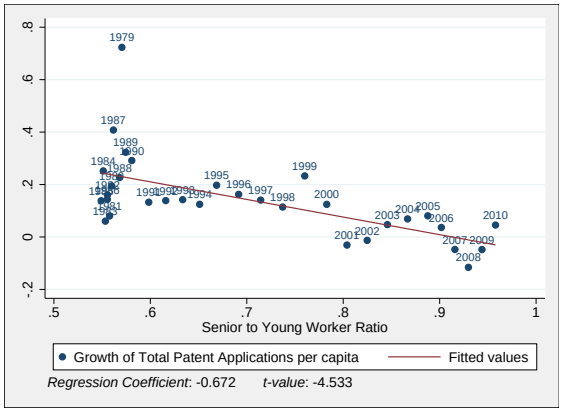
Figure 5: Senior-to-Young Worker Ratio and Innovation



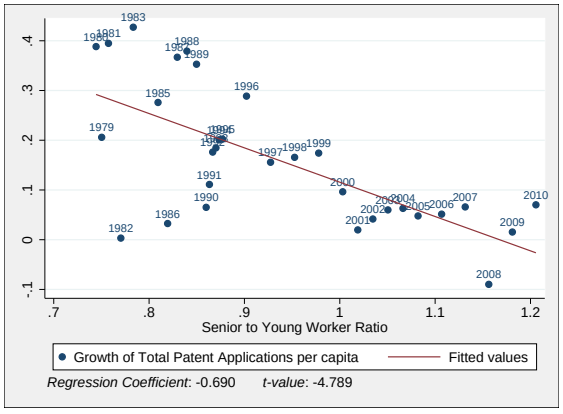
Note: The figure plots the growth in patent applications per capita against the senior-to-young worker ratio. Each dot represents a country-year observation. The data includes all OECD countries for the period 1978 to 2012. A quadratic fit is shown for S2YWR below and above 0.75. The coefficients and t-values for a split linear regression are indicated below the figure.

Figure 6: Senior-to-Young Ratio and Innovation in Selected Countries

(a) United States

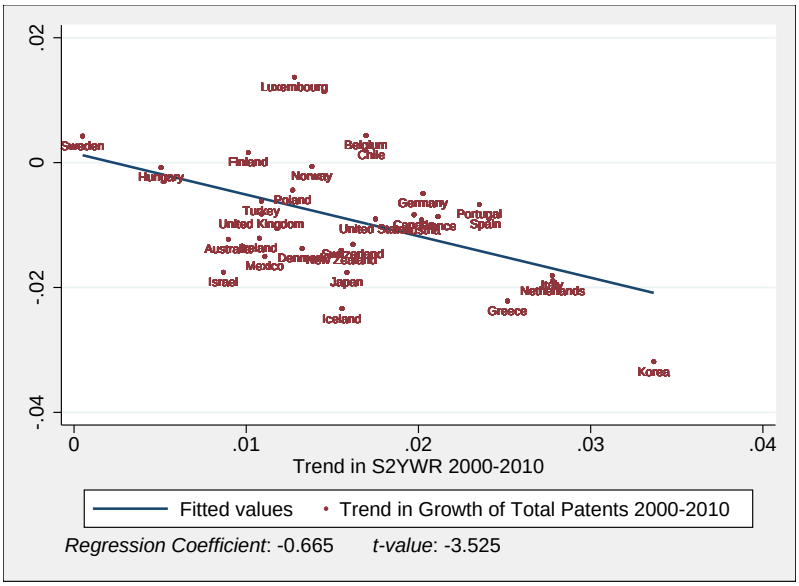


(b) Germany



Note: The figures plot the growth in patent applications per capita against the senior-to-young worker ratio. Plot (a) is based on data from the United States and Plot (b) from Germany for period 1978 to 2012. A linear fit is shown.

Figure 7: Ten-Year Trends in Patent Applications Per Capita



Note: The figure plots a country's ten-year trend in total patent growth against its ten-year trend in the senior-to-young worker ratio (S2YWR). The data includes all OECD countries for the period 2000 to 2010.

Table 1: Summary Statistics

Variable	Mean	SD	Min	Max	N
S2YWR	0.75	0.19	0.31	1.21	1122
Total Patent Applications	49.21	71.77	0	345.51	1122
Growth of Patent App. p.c.	0.51	5.32	-1	162.14	986
GDP p.c.	22644.28	10529.94	4380.1	82814.16	1074
Population	32.51	50.82	0.22	312.25	1122
Share 65+ Year Olds	12.9	3.53	3.83	22.96	1054

Note: The table shows descriptive statistics for the data set used in the empirical analysis. Patent Applications are expressed per one million people in the population. GDP per capita is given in 2005 US Dollar. Population size is measured in million. Trade is defined as the sum of imports and exports divided by total GDP.

Table 2: Population Aging and Growth in Patent Applications

	Dep. Variable: Growth in Patent Applications							
Mean of dep. var.	All Industries (0.08)					ICT (0.12)	MedTec (0.22)	Pharma (0.19)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
S2YWR	-0.240***	-0.198*	-0.863***	-0.923***		-1.154**	-1.251	-1.128
	(0.088)	(0.112)	(0.270)	(0.332)		(0.520)	(1.567)	(1.121)
Share 65+		0.004	-0.045*	-0.035		-0.079*	0.113	0.030
		(0.007)	(0.023)	(0.026)		(0.046)	(0.120)	(0.083)
Share 15–34					4.081**			
					(1.523)			
Share 45–64					-2.813*			
					(1.584)			
Control Variables	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	-	-	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	-	-	-	Yes	Yes	Yes	Yes	Yes
Observations	374	374	374	374	374	373	368	372
R-squared	0.039	0.070	0.072	0.148	0.152	0.076	0.037	0.055

Note: The table shows the result of eight separate regressions using dependent variables as indicated in the top row. Control variables include the GDP per capita, population size, and trade openness. The sample includes all 34 OECD countries and the time period 2000-2010. Standard errors are clustered at the country level and shown in parentheses. Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

Table 3: Instrumental Variables and Trend Regressions

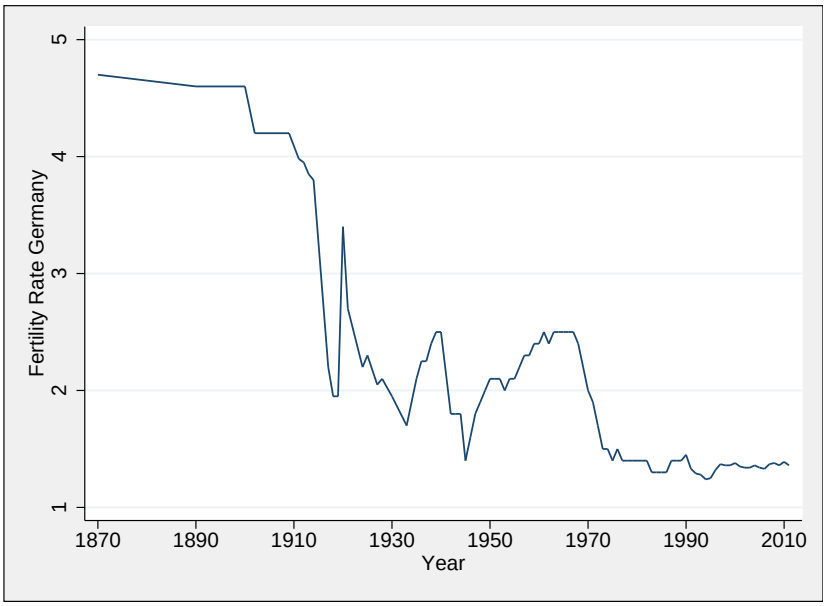
	IV Estimation			Trend Regression	
Mean of dep. var.	All Patents (0.08)		ICT Patents (0.12)	Patents 2000-2010 (0.011)	
	(1)	(2)	(3)	(4)	(5)
S2YWR	-0.613***	-0.501***	-0.621**		
	(0.103)	(0.159)	(0.288)		
Share 65+		-0.016	-0.035		
		(0.017)	(0.024)		
Trend in S2YWR				-0.954***	-0.762***
				(0.220)	(0.215)
Share 65+ in 2000				0.001	
				(0.001)	
Trend in Share 65+					-0.004
					(0.014)
Control Variables	-	Yes	Yes	2000	Trends
Country FE	-	Yes	Yes	-	-
Year FE	-	Yes	Yes	-	-
1st Stage F-stat	213.8	87.9	87.4	-	-
Observations	374	374	373	34	34
R-squared	0.039	0.031	0.015	0.332	0.345

Note: The table shows the results of three separate IV regressions in columns (1)–(3) with the SY2WR being instrumented by the lag-10 of the MAW2CR (ratio of 35–54 to 5–24 year olds). In columns (4) and (5), the time trend in patent applications is regressed on the time trend in the S2YWR. Control variables include the GDP per capita, population size, and trade openness. Standard errors shown in parentheses are Jacknife in columns (1)–(3) and Huber-White in (4) and (5). Significance at the 10% level is indicated by *, at the 5% level by **, and at the 1% level by ***.

Appendix

Additional Tables and Figures

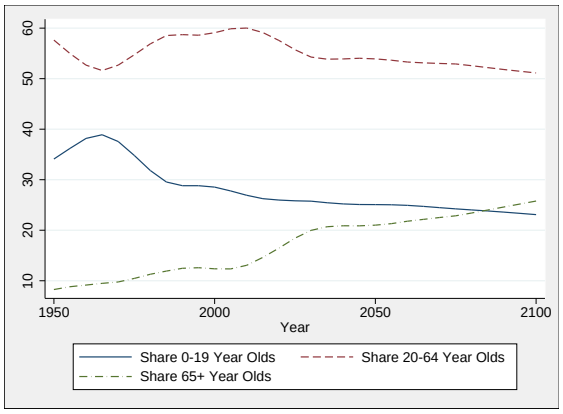
Figure A.1: Historical Fertility Rates in Germany



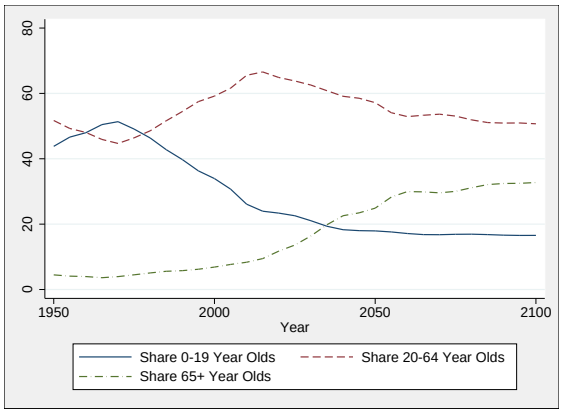
Note: The figure plots the fertility rate in Germany since 1870. Data obtained from the Bundesinstitut für Bevölkerungsforschung.

Figure A.2: Age Group Shares in Selected Countries, 1950–2100

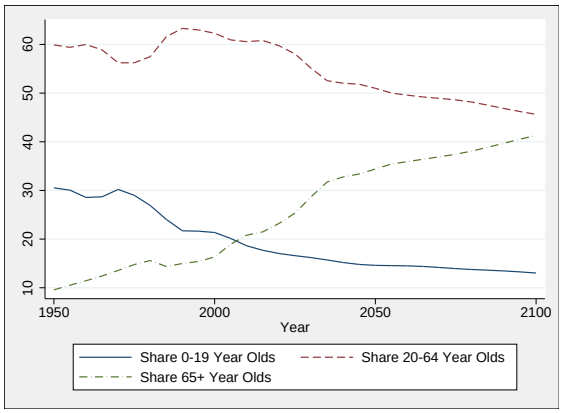
(a) United States



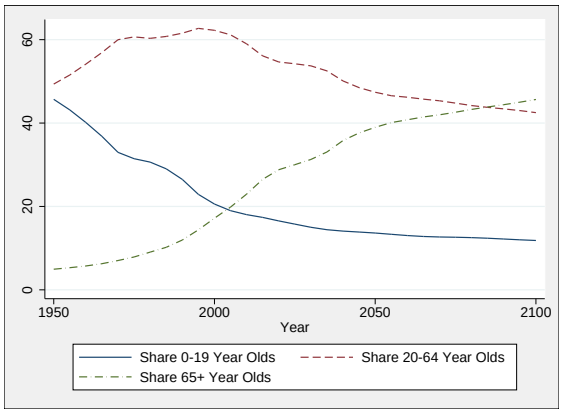
(b) China



(c) Germany

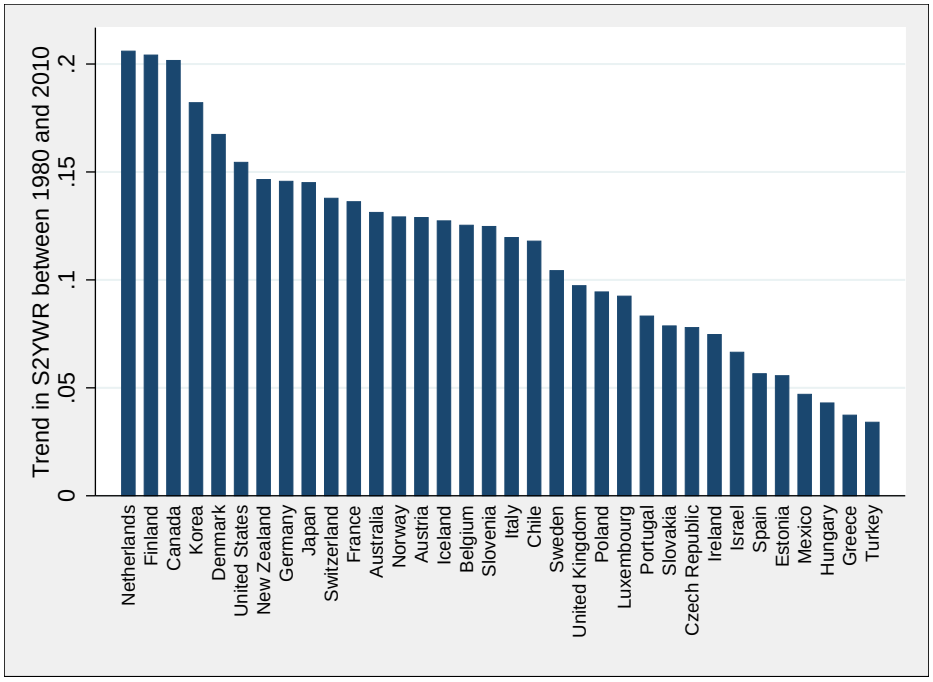


(d) Japan



Note: The figures plot the share of children (0-19 year old), working-age adults (20-64), and retirees (65 plus). Estimates for the years after 2010 are based on a constant fertility rate (CFR). Data obtained from the UN Population Division.

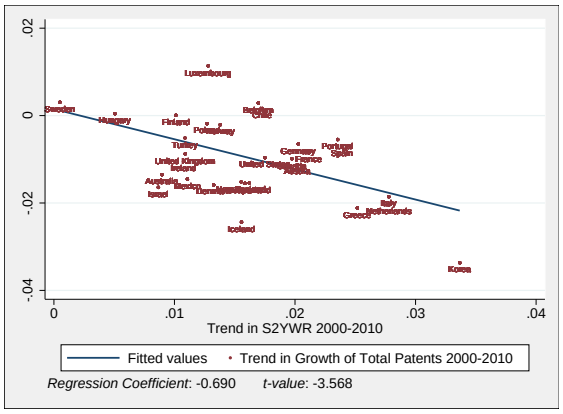
Figure A.3: Time Trends in the S2YWR in OECD Countries



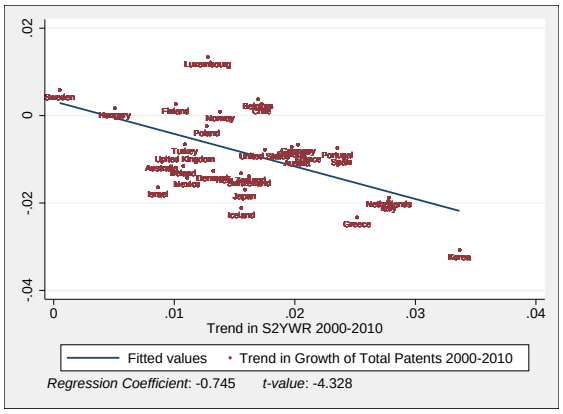
Note: The figure plots the estimated coefficients from regressing the senior-to-young worker ratio (S2YWR) on a year variable. The coefficients are estimated for each country separately and multiplied by ten. The time period is from 1980–2010.

Figure A.5: Trends in Patent Applications Per Young and Senior Worker

(a) Per Young Worker



(b) Per Senior Worker



Note: The figures plot a country's ten-year trend in total patent growth against its ten-year trend in the senior-to-young worker ratio (S2YWR). Patent growth is measured per young worker (aged 15-34) in Panel (a) and per senior worker (45-64) in Panel (b). The data includes all OECD countries for the period 2000 to 2010.

Table A.1: Trends in Fertility Rates

Country	Total Fertility Rate					
	1960	1970	1980	1990	2000	2010
Australia	3.45	2.86	1.89	1.90	1.76	1.95
Austria	2.69	2.29	1.65	1.46	1.36	1.44
Belgium	2.54	2.25	1.68	1.62	1.64	1.84
Canada	3.90	2.33	1.68	1.71	1.49	1.63
Chile	5.58*	3.95	2.72	2.59	2.05	1.89
Czech Republic	2.11	1.91	2.10	1.89	1.14	1.49
Denmark	2.54	1.95	1.55	1.67	1.77	1.87
Estonia	1.98*	2.17*	2.02	2.05	1.36	1.72
Finland	2.71	1.83	1.63	1.79	1.73	1.87
France	2.74	2.48	1.95	1.78	1.87	2.02
Germany	2.37	2.03	1.56	1.45	1.38	1.39
Greece	2.23	2.40	2.23	1.40	1.27	1.47
Hungary	2.02	1.97	1.92	1.84	1.33	1.26
Iceland	4.26	2.81	2.48	2.31	2.08	2.20
Ireland	3.76	3.87	3.23	2.12	1.90	2.06
Israel	3.87*	3.78*	3.14	3.02	2.95	3.03
Italy	2.41	2.42	1.68	1.36	1.26	1.41
Japan	2.00	2.13	1.75	1.54	1.36	1.39
Korea	6.00	4.53	2.82	1.57	1.47	1.23
Luxembourg	2.28	1.98	1.50	1.62	1.78	1.63
Mexico	6.78	6.72	4.71	3.36	2.65	2.28
Netherlands	3.12	2.57	1.60	1.62	1.72	1.80
New Zealand	4.24	3.17	2.03	2.18	1.98	2.17
Norway	2.91	2.50	1.72	1.93	1.85	1.95
Poland	2.98	2.20	2.28	1.99	1.37	1.38
Portugal	3.10	2.83	2.18	1.56	1.56	1.39
Slovakia	3.07	2.40	2.31	2.09	1.29	1.40
Slovenia	2.18	2.21	2.11	1.46	1.26	1.57
Spain	2.86	2.90	2.22	1.36	1.23	1.37
Sweden	2.20	1.94	1.68	2.14	1.55	1.98
Switzerland	2.44	2.10	1.55	1.59	1.50	1.54
Turkey	6.40	5.00	4.63	3.07	2.27	2.06
United Kingdom	2.72	2.43	1.90	1.83	1.64	1.92
United States	3.65	2.48	1.84	2.08	2.06	1.93
Brazil	6.21	5.02	4.07	2.81	2.36	1.84
China	5.76	5.47	2.71	2.51	1.51	1.65
Colombia	6.81	5.60	3.99	3.10	2.64	2.38
Indonesia	5.67	5.47	4.43	3.12	2.48	2.43
India	5.87	5.49	4.68	3.88	3.15	2.56
Lithuania	2.56*	2.40	1.99	2.03	1.39	1.50
Latvia	1.94	2.02	1.90	2.01	1.25	1.36
Russia	2.42	2.01	1.90	1.89	1.20	1.57
South Africa	6.17	5.59	4.79	3.66	2.87	2.50

Note: The table shows total fertility rates for all OECD countries and some selected non-OECD countries for the period 1960–2010. The total fertility rate in a specific year is defined as the total number of children that would be born to each woman if she were to live to the end of her child-bearing years and give birth to children in alignment with the prevailing age-specific fertility rates. It is calculated by totaling the age-specific fertility rates as defined over five-year intervals. Assuming no net migration and unchanged mortality, a total fertility rate of 2.1 children per woman ensures a broadly stable population. The data is taken from OECD (2015): Fertility rates (indicator). Data indicated by * is taken from the World Bank.