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The older, the wiser and also the less innovative? An empirical analysis of the relationship between population aging and innovativeness

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Abstract

Entrepreneurship is generally considered the engine of growth, given its role in introducing innovations into the economic system. Developed countries have already become a victim of rapid aging of their populations, while the similar trend has just started in developing countries. The previous literature has suggested that aging and nascent entrepreneurship are negatively related. This study investigated the relationship between aging and innovation using dynamic panel techniques. We found that the level of innovation activities represented by the number of patent applications is negatively related to aging. This association remains even after other demographic and institutional confounders are taken into account. We also found that education and flexibility of business regulations are positively related to innovation.

Keywords: Innovation; Population aging; Patents; Dynamic panel methods

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1. Introduction

The economic literature has highlighted the strong connection between entrepreneurship, innovation and economic growth. Schumpeter (1934) was the first scholar singling out these associations and pointing out that entrepreneurs are vital to economic development because they translate inventions and scientific discoveries into economic innovations in the forms of new services, products, production processes, and management approaches. According to Schumpeter, the inventor may differ from the innovator. The former is the creator of ideas and inventions, while the innovator recognizes the potential for exploiting the invention for an economic purpose. Schumpeter remarked that both roles are essential for economic development, as the innovations generated by inventors and exploited by innovators contribute to economic growth and progress. In addition, new firms contribute to the economy by introducing new goods or more efficient production methods, displacing underperforming firms, thereby reallocating resources for better use. This phenomenon is known as the process of creative destruction. Numerous empirical studies have supported the role of entrepreneurship in economic growth (Scarpetta *et al.*, 2002; van Praag & Versloot, 2007; Acs *et al.*, 2008; Bosma *et al.*, 2018).

For instance, van Praag and Versloot (2007) reviewed 12 years of high-quality empirical research into the economic value of entrepreneurship, confirming that young and small firms contribute heavily to employment creation as well as to high-quality innovations (measured by the number of patent citations). They concluded that there is little doubt that entry of individuals into self-employment/business ownership and of independent firms into the market are impetus to economic development in developed economies.

Given the importance of entrepreneurs in the economic system, it is crucial to further understand whether the rapid aging of populations in many developing countries and the large share of elderly individuals, which is a typical hallmark of developed economies, will affect their innovative capacity. The potential impact of aging on entrepreneurship is not a new concept in demography. More than 70 years ago, Sauvy (1948) observed that: "In countries suffering from ageing, the spirit of enterprise, and hence the willingness to accept risks, without which capitalism cannot function, gradually declines and is replaced by a new feeling: the desire for security" (p.118).

The French demographer's perspective on aging and risk tolerance has received extensive support on the empirical ground (Löckenhoff & Carstensen, 2007; Mata *et al.*, 2011; Mata *et al.*, 2016; Rolison *et al.*, 2014). As we will discuss later, empirical evidence at the individual level show that the likelihood of becoming an entrepreneur decreases after age 50. Furthermore, at the country level, Lamotte & Colovic (2013) have shown that older countries are also characterized by less nascent entrepreneurship.

Population aging is caused by a declining fertility rate, which reduces the proportion of young people, and an increasing life expectancy, which results in a larger share of elderly individuals (Goldstein, 2009). Many demographic models are based on the assumption of stationarity, which postulates a population with zero growth rate and a stable age structure. However, fertility rates in many developed countries have consistently remained below replacement levels, making stationarity more of a theoretical concept than an accurate description of the population process. Immigration can have temporary rejuvenating effects under certain conditions (Schmertmann, 1992; Alho, 2008), but in the long run, it would still contribute to an older age structure in the host country compared to that in country without migrants, as suggested by the literature in general (see Goldstein 2009, for a review). While aging can be construed as a success in terms of reducing mortality rates, particularly among infants, and as a consequence of improved living standards and health-care systems, it also presents various challenges.

The previous research has predominantly focused on the effects of aging on the labor force, the welfare system, and the increasing need for long-term care while neglecting the link between entrepreneurship and innovativeness (Liang *et al.*, 2018). Thus, this study aimed to empirically assess the effect of population aging on countries' innovativeness. To this end, in the first part of the next section, we will discuss well-known economic models of technological progress, clarifying the role of entrepreneurship and how institutions may shape innovation activities within a country. In the second part of the second section, we will explore the link between aging and entrepreneurship, setting the stage for our research questions. Moving on to the third section, we will present our data and method. In the fourth section, we will show our results which are then discussed in the fifth section. Finally, in the last section, we will provide some concluding remarks and considerations.

1.1. The drivers of innovation

1.1.1. Entrepreneurship, institutional factors and the innovation process

Based on the well-known exogenous growth model proposed by Solow (1956), economic growth is influenced by the growth rate of innovations, which are considered exogenous factors. Nevertheless, the contemporary economic growth is determined using endogenous growth models, including the one developed by Romer (1986). In Romer's model, population growth can contribute to per capita income growth because a larger population working in the research and development (R&D) sector can accelerate technological change. However, it is essential to note that Romer's model neglects the role of the entrepreneur. This omission aligns with Baumol's famous statement about theoretical growth models: "The theoretical firm is entrepreneur-less – the Prince of Denmark has been expunged from the discussion of Hamlet" (Baumol, 1968, p. 66). Treating the entrepreneur as a central figure in theoretical economic models is a concept by Aghion & Howitt (1992; 1997); Howitt & Aghion (1998). In these models, the entrepreneur is portrayed as a profit-seeking individual who competes with others to create innovations that provide competitive advantages.

Human capital and entrepreneurship are vital elements for economic progress. However, institutions also play a crucial role in the innovation process. This has been emphasized by Baumol (1990), who highlights that entrepreneurial activity is categorized as productive and unproductive entrepreneurships, and the direction of entrepreneurial efforts depends on the quality of prevailing economic, political, and legal institutions. This institutional framework determines the relative rewards of investing entrepreneurial efforts in productive market activities (e.g., R&D) versus unproductive ones such as political lobbying and lawsuits. Good institutions characterized by secure property rights, a fair and balanced judicial system, contract enforcement, and effective constitutional limits on the government's ability to transfer wealth through taxation and regulation encourage productive entrepreneurship and foster economic development (Acemoglu & Johnson, 2005). Furubotn & Richter (2005) have also extensively explored how institutions, including laws, property rights, social norms, and governance systems, can either facilitate or hinder economic development.

Figure 1 provides a schematic representation of the innovation process. The core of the process (depicted in the yellow area) revolves around the firm and its entrepreneurial drive to innovate, which influences investment in R&D and other innovation-related activities. Thus, the firm is ultimately responsible for introducing innovation into the economy. The blue area in Figure 1 encompasses institutional and structural factors such as legal, economic, financial, and educational elements, which establish the rules and range of opportunities for innovation. At the same level, scientific knowledge cumulated in a society is a fundamental component in the innovation process, as remarked by Schumpeter and later on proven by both exogenous and endogenous growth models.

The transfer factors (represented in the green area) include all the elements that facilitate the flow of information and skills from the scientific environment to the firm level. This concept is borrowed from the second edition of the OSLO Manual, jointly proposed by OECD & EUROSTAT (1997), for collecting data on innovation. For instance, this dimension includes university dissemination activities, collaborations between research institutions and firms, workforce mobility from the research sector to the private sector, and cultural values like trust that can promote information sharing and collaboration.

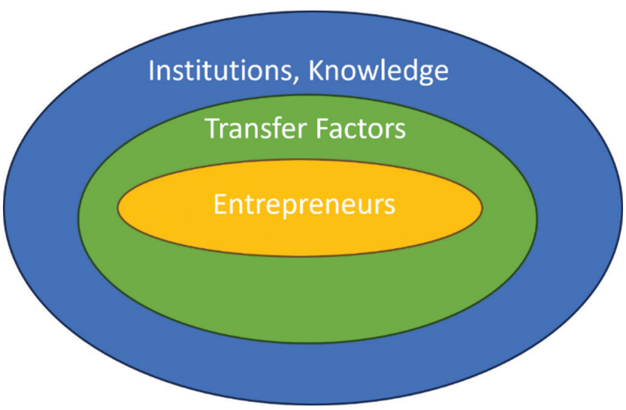

Figure 1. A representation of the factors that lead to innovation
Note: The authors' reworking of a scheme originally proposed in OECD and Eurostat (1997).

1.1.2. Aging, entrepreneurship, and innovation

Parker (2009) emphasizes that the U-reverse-shaped relationship between age and the probability of becoming an entrepreneur is one of the most robust findings in the empirical literature about entrepreneurship. Specifically, numerous studies have shown that the probability of starting a business tends to increase with age up to a threshold point (between 35 and 44 years of age) and then decreases thereafter (among others, Kautonen *et al*., 2014; Levesque & Minniti, 2006; 2011). More recently, Zhang & Acs (2018) suggested that the shape of this relationship varies depending on the type of entrepreneur. They found that the probability of being a full-time entrepreneur tends to decrease with age, while the opposite trend was observed for part-time entrepreneurs. In addition, they confirmed the U-reverse-shaped relationship for incorporated entrepreneurs but not for unincorporated ones. Interestingly, they also found that the propensity of novice entrepreneurs compared to non-novice entrepreneurs follows a U-shaped age pattern, with a dip around the age of 60.

To avoid confusion, we need to specify that the age distribution of entrepreneurs is not generally skewed toward young ages. On the contrary, as highlighted in a report jointly released by the OECD and the European Commission in 2019, individuals over 50 make up more than 48% of self-employed people. Hence, it is nascent entrepreneurship but not entrepreneurship as a whole to be menaced by population aging. Our paper also attempted to investigate if this will affect the innovative capabilities of societies.

Recently, Liang *et al.* (2018) proposed a model highlighting the importance of the skills acquired through on-the-job training, the perception of the business opportunity, and the risk tolerance involved in deciding to start a business. In an older society, older individuals typically occupy leadership positions in firms, which reduce the opportunities for young workers to acquire business skills early in their careers. This implies that younger individuals, even if highly skilled, have a lower expectation of becoming entrepreneurs. Azoulay *et al.* (2020) also showed that the fastest-growing firms are founded by middle-aged entrepreneurs rather than younger individuals.

Using data from the Global Entrepreneurship Monitor on nascent entrepreneurship, Ruiu & Breschi (2019) found that while individuals over the age of 50 are less likely to become entrepreneurs, if they decide to do so, they are more likely than their younger counterparts to introduce radical and innovative products or services. However, older nascent entrepreneurs are not very likely to bring in technological advancements in production. The authors argue that older individuals face more barriers to becoming entrepreneurs compared to younger individuals, such as having more economic resources, the risk of losing more in case of failure, less time to collect the rewards of an uncertain activity, and less time to recover their economic situation in the case of business failure. Consequently, when an older individual decides to become an entrepreneur, their entrepreneurial project should be worth the risk, aligning with Liang *et al.*'s perspective on the role of experience in business perception. At the same time, older individuals seem less comfortable with new technologies (Fernàndez-Lòpez *et al.,* 2022).

Indeed, the previous research has consistently found that older individuals tend to have negative attitudes toward new technological devices and innovations. Studies by Vorrink *et al.* (2017), Ellis & Allaire (1999) and Tacken *et al.* (2005) have demonstrated a negative association between age and the use of various technological devices, including computers, smartphones, tablets, and other digital tools. Furthermore, Ragnedda *et al.* (2020) have shown a strong relationship between age and the digital divide, indicating that older individuals are more likely to face challenges in accessing and utilizing digital technologies effectively.

Angelini (2021) developed a theoretical model that supports the notion that additional aging within a workforce hampers the adoption of innovative technologies and diminishes productivity. As young employees, who typically have a comparative advantage in utilizing modern technologies, become scarce, older individuals can further impede the adoption and integration of innovative technologies within organizations, potentially affecting the overall productivity. These findings collectively suggest that older individuals are less comfortable and familiar with new technologies, affecting their ability to engage in entrepreneurial activities that heavily rely on technological innovation.

In summary, older entrepreneurs, due to their accumulated market experience, may possess a heightened ability to identify untapped opportunities for introducing new products and services. Moreover, they are likely to have a deeper understanding of the needs and preferences of an aging population, enabling them to capitalize on the prospects presented by the "silver economy." The silver economy refers to "the economic opportunities arising from the public and consumer expenditure related to aging population and the specific needs of the population over 50 and it comprises a large part of the general consumer economy, but with considerable differences in spending priorities and patterns" (Pauhofova & Dovalova, 2015, p. 191). According to Drucker (1985), an entrepreneur should be able to recognize the opportunity to innovate in face of the environmental changes. Among the catalysts for such changes, Drucker emphasizes the potential for leveraging emerging needs resulting from demographic shifts. However, it is worth noting that older entrepreneurs may encounter challenges in keeping up with rapid technological advancements. Therefore, it is challenging to predict the specific effect that population aging will have on the innovativeness of a country.

In addition, population aging is associated with various demographic phenomena, such as increased life expectancy, decreased natural growth rate, and limited support from migration to offset potential negative natural balances. These factors, when combined, may contribute to depopulation. Based on Romer's model, population growth is closely linked to the rate of innovation, making it crucial to analyze the impact of aging in conjunction with other demographic forces that contribute to the growing proportion of elderly individuals.

With this, we formulated two research questions (RQ), which are given below as follows:

- *RQ1:* Considering the natural growth rate of the population, the increase in life expectancy and the migratory balance, does aging still impact the innovation rates?

Furthermore, in light of the discussion in the first part of the second section, where the importance of institutional settings in determining innovation rates was remarked, and considering that developed countries typically have both a higher proportion of older populations and more efficient institutional frameworks, we aim also to answer to the following question:

- *RQ2:* Considering the heterogeneity in institutional settings, are countries characterized by an old population less innovative than the younger ones?

The findings in response to these research questions highlight the importance of both demographic factors and institutional environments in shaping a country's innovation capacity.

2. Data and methods

2.1. Data

The data panel used in this study comprises data from various official sources. The number of patent applications by residents is obtained from The World Bank Data, while the demographic data are sourced from the Population Division of the United Nations. The quality of the legal system and business regulation is measured using indicators from the Fraser Institute. Educational attainment data were derived from the Barro-Lee dataset. The dataset covered 38 countries over the 1985 – 2019 period. The data were divided into non-overlapping 5-year intervals to ensure comparability between the data provided by the United Nations (grouped by 5-year intervals) and the annual data on patent applications per resident provided by the World Bank. Table 1 provides the definition and the source of each variable used in the subsequent analyses. Patent applications per 1000 inhabitants will be used as the variable to gauge each country's level of innovation effort in this study. Smith (2005) has discussed the pros and cons of using this variable as a proxy of innovation. The most evident limitation of using this variable is that patents mainly reflect technological innovations rather than commercial ones. However, as mentioned in the previous section, given the potential threat of population aging to technological progress, this variable allows for a precise examination of the relationship between population aging and technological progress is crucial driver of economic development.

The countries included in the analysis were selected based on data availability to ensure the longest possible observational period. These countries (and regions) include: Austria, Bangladesh, Belgium, Bulgaria, Brazil, Canada, Chile, China, Hong Kong (China), Costa Rica, Denmark, Finland, France, Germany, Greece, Guatemala, India, Iceland, Israel, Japan, Republic of Korea, Malaysia, Mexico, Netherlands, New Zealand,

Table 1. Description and source of the variables used in the analysis

Variable name	Extended name	Definition	Source
PAT	Patents per inhabitants	Number of patents applications (by residents in the country) per 1,000 inhabitants. Averaged by 5 years intervals.	Numerator: World Bank: https://data.worldbank.org/indicator/IP.PAT.RESD Denominator: United Nations Population Division: https://population.un.org/wpp/
UNI	Tertiary education	Percentage of the population aged 25 – 64 that has completed tertiary education	Barro-Lee Estimates of Educational Attainment for the Population Aged 25–64 from 1950 to 2015 Source: Barro and Le (2013)
SPRP	Security and Property Rights protection Index	This index ranges from 0 to 10, where 0 corresponds to "no judicial independence," "no trusted legal framework exists," "no protection of intellectual property," and "no integrity of the legal system," while 10 corresponds to "high judicial independence," "trusted legal framework exists," "protection of intellectual property," and "integrity of the legal system."	Economic Freedom Index proposed by the Fraser Institute: https://www.fraserinstitute.org/economic-freedom/approach Source: Gwartney *et al.* (2019)
BUS	Business regulation index	This index is designed to identify the extent to which regulations and bureaucratic procedures restrain entry and reduce competition. It ranges from 0 to 10 where 10 indicates the maximum level of flexibility in the regulation of business activities.	Economic Freedom Index proposed by the Fraser Institute: https://www.fraserinstitute.org/economic-freedom/approach
LEXP	Life expectancy at birth	It captures how long, on average, a newborn can expect to live, if current death rates do not change	United Nations Population Division: https://population.un.org/wpp/
NAT	Population natural increase rate	Difference between the crude birth rate and the crude death rate.	United Nations Population Division: https://population.un.org/wpp/
NMR	Net migration rate	(Migratory balance×1,000)/Total population	United Nations Population Division: https://population.un.org/wpp/
OVER	Over 65	Percentage of the population aged 65 and over in the total population	United Nations Population Division: https://population.un.org/wpp/
HIGH	High income	Dummy=1 when the country is classified as a high income country by the World Bank	Source: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
TRADE	Trademark application per 1,000 inhabitants	Number of trademark applications (by residents in the country) per 1,000 inhabitants. Averaged by 5-year intervals.	Numerator: World Bank: https://data.worldbank.org/indicator/IP.TMK.RESD Denominator: United Nations Population Division: https://population.un.org/wpp/

Norway, the Philippines, Poland, Portugal, Romania, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, and United States. While the choice of countries may have been somewhat constrained by data availability, the dataset was considered sufficiently heterogeneous in terms of institutional settings and demographic conditions. The heterogeneity in data was crucial for examining the relationship between population aging and innovation across different contexts. By including countries with diverse institutional frameworks and demographic characteristics, the analysis could capture a wide range of factors that may influence the innovativeness of nations. This heterogeneity strengthens the robustness of the analysis and enables more nuanced insights into the relationship under investigation.

2.2. Methods

To answer *RQ1* and *RQ2*, we estimated the following dynamic data panel model:

$$Pat_{it}=\rho Pat_{i,t-1}+\beta x_{it}+v_i+\varepsilon_{it} \quad \text{(I)}$$

Where

$$E(\varepsilon_{it}|x_{i,1985_{1989}},\ldots,x_{i,2015_{2019}},v_i)=0 \quad \text{(II)}$$

Pat_{it} is the number of patent applications per 1,000 inhabitants of country *i* at time *t* (*t* = 1985 – 1989,…, 2015 – 2019). Given that innovation is generally an incremental process, we allowed a certain degree of persistence by including a lag of the dependent variable in our empirical model. Rho is the coefficient associated to the lagged dependent variable. The explicative variables x_{it} are the share of population over the age of 65 (as our proxy of country aging), the life expectancy at birth, the natural growth rate of the population, the net migration rate, the share of population aged 25–64 who have had tertiary education, the security and property rights protection index, the flexibility in the business regulation index, and a dummy equal to one when the country is classified as a high-income country by the World Bank. Beta represents the vector of coefficients associated to our explicative variables. The v_i are the panel-level effects. By construction, we consider that the lag of the dependent variable is endogenous given that it will be correlated with v_i, making the most common estimators (for instance, ordinary least squares) inconsistent. The model can be consistently estimated through the Arellano-Bover/Blundell-Bond Generalized Method of Moments (GMM) system estimator (Arellano & Bover, 1995; Blundell & Bond, 1998), which is designed to deal with panels with few periods and larger cross-section units (our necessity to group data in 5-year intervals led us to have only seven periods). The method assumes that no autocorrelation exists in the idiosyncratic errors ε_{it} (this can be tested through the Arellano-Bond test).

We also performed an alternative estimation by implementing a two-step GMM system estimation with standard errors corrected to account for the small size of our sample. It should be noted that the two-step estimator is more efficient than the one-step GMM system. However, standard errors tend to be downward biased in small samples. To consider this, Windmeijer (2005) proposed a finite sample correction to estimate the variance in this linear dynamic model. Therefore, we applied Windmejer' s correction in the two-step system GMM estimator. We also estimated a model including the number of trademark applications per 1,000 inhabitants in the right-hand side of Equation I (labeled as one-step GMM'). This variable is included as a proxy of the level of creativity in the country (Williams & McGuire, 2010; Flikkema *et al.*, 2019). Given that its inclusion implies a reduction of the sample size due to missing observations for some years/countries, we decided not to include it in our baseline model. All the statistical analyses are carried out using STATA 17.

3. Results

Figure 2 shows the evolution of patent applications in 100,000 residents from 1985 to 2019 in our sample. It is essential to clarify that the scale used in Figure 2A–D differs from the dependent variable used in Equation I as it is meant for visual purposes. All analyses were indeed conducted using the number of patents per 1,000 residents. To allow readability, we divided the figure into four panels (low, low-medium, medium-high, and high innovative countries) based on the following criteria: 2019 patent applications for inhabitants (PAI) in country $i \le$ the 2019 cross-country first quartile; the 2019 cross-country median < 2019 PAI in country $i \le$ the 2019 cross-country median; the 2019 cross-country median < 2019 PAI in country $i \le$ the 2019 cross-country third quartile; 2019 PAI in country $i >$ the 2019 cross-country third quartile.

It is interesting to note that one of the most innovative and, at the same time, the oldest country in the world, such as Japan, is experiencing a declining trend in the number of patent applications in the last 20 years. Only the Republic of Korea exhibits an increasing trend in the number of applications in the whole period under analysis.

Figure 3 shows the percentages of the population over the age of 65 in 2019 for each country under consideration. Note that all the countries that are currently in the highest quartile in the number of patents application are also, except for China and South Korea, characterized by a larger share of population over 65 and, at the same time, are experiencing a flattening or a decline in the number of submissions to the patent office. To explain this decline,

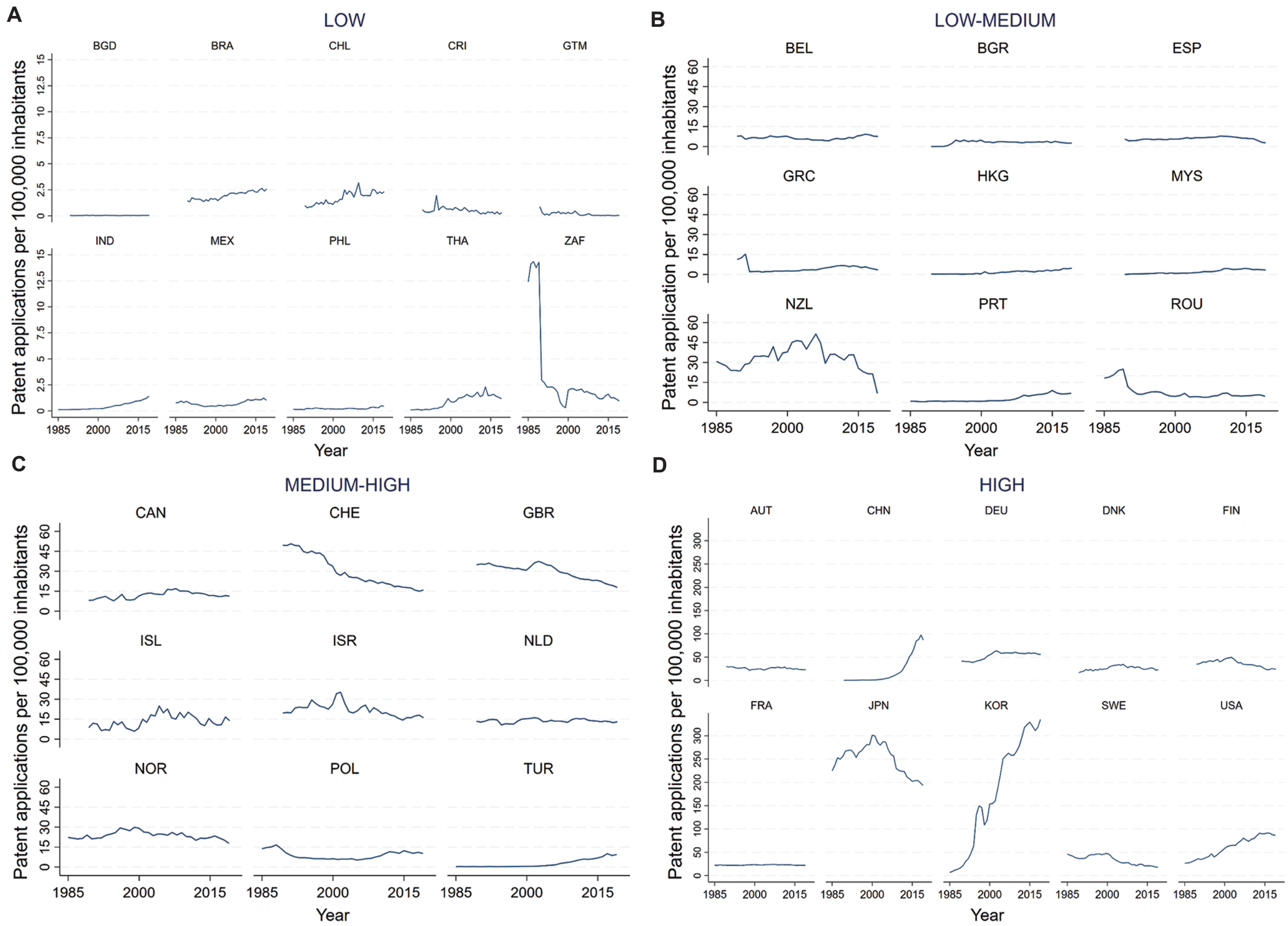

Figure 2. Patent applications per 100,000 residents by quartile, 1985 – 2019

Note: Country ISOCODES: AUT: Austria; BGD: Bangladesh; BEL: Belgium; BGR: Bulgaria; BRA: Brazil; CAN: Canada; CHL: Chile; CHN: China; HKG: Hong Kong; CRI: Costa Rica; DNK: Denmark; FIN: Finland; FRA: France; DEU: Germany; GRC: Greece; GTM: Guatemala; IND: India; ISL: Iceland; ISR: Israel; JPN: Japan; KOR: Republic of Korea; MYS: Malaysia; MEX: Mexico; NLD: Netherlands; NZL: New Zealand; NOR: Norway; PHL: the Philippines; POL: Poland; PRT: Portugal; ROU: Romania: ZAF: South Africa; ESP: Spain; SWE: Sweden; CHE: Switzerland; THA: Thailand; TUR: Turkey; GBR: United Kingdom; USA: United States. Low, medium, medium-high, and high refer to each quartile of the patent applications for inhabitants (PAI) in 2019.

Jones (2009) introduced the concept of the "burden of knowledge." In particular, Jones argued that the higher the level of knowledge that is reached, the more difficult it becomes to produce a newer one. This implies, for instance, that in the academic and/or the scientific ambit, researchers need to spend more time on the path to discoveries and innovations, and as a result, they are no longer young by the time they attain the first achievements; thus, the life cycle of a researcher is inevitably, by the natural course, reducing their overall scientific productivity (see also Schweitzer & Brendel, 2021). In our opinion, this is another reason, we need to explore the relationship between aging and innovativeness.

Table 2 shows the results of the estimation of Equation I. In particular, Columns 1, 2 and 3 report, respectively, the estimates derived from the one-step GMM estimator (with robust standard errors that take into account arbitrary forms of heteroskedasticity), the two-step estimator with robust standard errors, and the same model as in Column 1 but with the number of trademark applications incorporated for analysis. We also report the Arellano-Bond's test for all the models, whose null hypothesis is that autocorrelation in first-differenced errors is zero. Then, a rejection of the null hypothesis indicates that the model is misspecified.

4. Discussion

First of all, it should be remarked that the coefficient associated with the first lag of the dependent variable is positive, smaller than one (ensuring the dynamic stability of the model) and highly statistically significant. This result supports the notion that innovation is a path-dependent process, whereby a country's current efforts in innovation positively affect its future efforts.

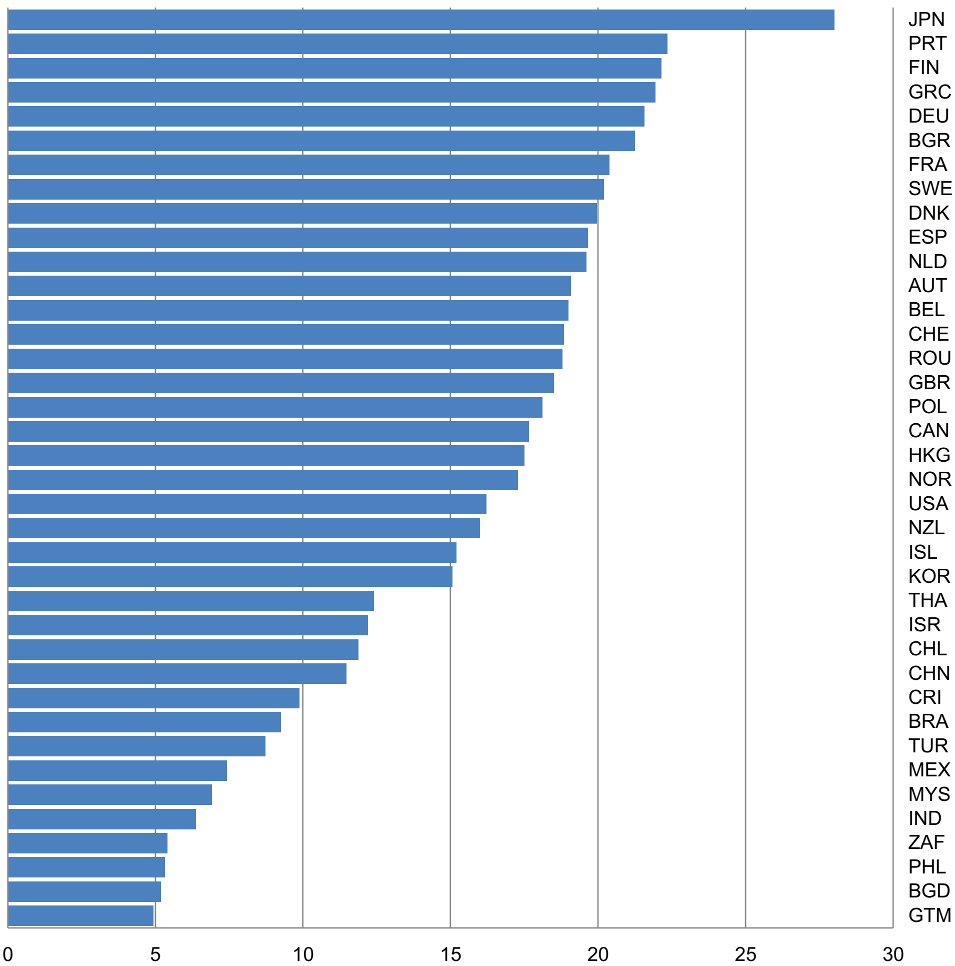

Figure 3. Percent share of population over the age of 65 for selected countries in 2019
Note: Country ISOCODES: AUT: Austria; BGD: Bangladesh; BEL: Belgium; BGR: Bulgaria; BRA: Brazil; CAN: Canada; CHL: Chile; CHN: China; HKG: Hong Kong; CRI: Costa Rica; DNK: Denmark; FIN: Finland; FRA: France; DEU: Germany; GRC: Greece; GTM: Guatemala; IND: India; ISL: Iceland; ISR: Israel; JPN: Japan; KOR: Republic of Korea; MYS: Malaysia; MEX: Mexico; NLD: Netherlands; NZL: New Zealand; NOR: Norway; PHL: the Philippines; POL: Poland; PRT: Portugal; ROU: Romania: ZAF: South Africa; ESP: Spain; SWE: Sweden; CHE: Switzerland; THA: Thailand; TUR: Turkey; GBR: United Kingdom; USA: United States.

An interesting result pertaining to the variable UNI indicates that a one-point percentage increase in the number of graduated people leads to a nine-unit rise in patent applications per 1,000 inhabitants. This result holds statistical significance across all model specifications and confirms the importance of highly skilled human capital in driving innovation. Regarding the institutional variables, only flexibility in business regulation exhibits a positive and significant correlation with the number of patent applications, at least in two out of three specifications. This suggests that lowering the rigidity of market regulations may incentivize more individuals to become entrepreneurs, thereby fostering innovation or, as per Baumol's perspective, channeling efforts away from unproductive entrepreneurship.

It is worth noting that there is a relatively strong correlation between the SRPR indicator and the indicator of business flexibility (r = 0.53). Given the relatively limited number of observations in our sample, the lack of significance of SRPR may be attributed to collinearity issues. Indeed, this seems confirmed by the fact that when an alternative model specification (not reported here) was employed, excluding the SRPR variable, the coefficient associated with BUS became statistically significant.

As shown in Figure 2, high-income countries are characterized by a higher number of patent applications. The coefficient associated with the variable TRADE suggests that for every additional 100 trademarks per 1,000 individuals, there is an expected increase of 12.6 patent

Table 2. A comparison of coefficients across different models

	(1)		(2)		(3)	
	One-step GMM		Two-Step GMM		One-step GMM'	
Lag.PAT	0.890***	(0.035)	0.892***	(0.063)	0.775***	(0.038)
OVER	-0.058***	(0.005)	-0.054***	(0.011)	-0.044***	(0.004)
NAT	-0.011***	(0.004)	-0.008*	(0.004)	-0.007**	(0.003)
NMR	-0.002	(0.003)	-0.002	(0.003)	-0.002	(0.003)
UNI	0.009***	(0.002)	0.009***	(0.002)	0.008***	(0.002)
SPRP	-0.006	(0.022)	-0.010	(0.026)	0.027	(0.021)
BUS	0.027**	(0.011)	0.024**	(0.012)	0.011	(0.011)
LEXP	0.008*	(0.004)	0.006	(0.007)	0.000	(0.004)
HIGH	0.647***	(0.106)	0.699*	(0.359)	0.940***	(0.103)
TRADE					0.126***	(0.030)
_cons	-0.439	(0.313)	-0.351	(0.593)	-0.371	(0.284)
N	228		228		219	

Arellano Bond's test

Order	z (sig)
Model 1	
1	-.99349 (0.3205)
2	.70122 (0.4832)
3	-.84927 (0.3957)
Model 2	
1	-.94232 (0.3460)
2	.70087 (0.4834)
3	-.80401 (0.4214)
Model 3	
1	-1.0702 (0.2845)
2	.63955 (0.5225)
3	-.80996 (0.4180)

Note: LAG.PAT: first lag of Patents per inhabitants; OVER: % of over 65 in the population; NAT: Population natural increase rate; NMR: Net migration rate; UNI: % of people with tertiary education; SPRP: Security and property rights protection Index; BUS: Business regulation index; LEXP: life expectancy at birth; HIGH: Dummy =1 if the Country is classified as high income country by the World Bank; TRADE: trademark applications per 1,000 inhabitants. GMM: Generalized Method of Moment. One-step GMM', indicates the inclusion of an additional variable of TRADE in the model. For each model, tests were performed for up to the third order of auto-correlation in the first differenced residuals. Heteroskedasticity Robust Standard errors in parentheses in all the columns; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

applications per 1,000 inhabitants. Our results are thus coherent with Flikkema *et al.* (2019).

Finally, we found that both the population aging and the natural increase rate negatively affect innovation. In particular, an increase of 1% point in the incidence of population over 65 is associated with a decrease of 58 patent applications per 1,000 inhabitants. Hence, our answer to *RQ2* seems to be positive, and the magnitude of the effect is relatively strong compared to other coefficients.

The negative coefficient associated with NAT may seem surprising given Romer's prediction about its effect. However, according to the framework proposed by Porter *et al.* (2002), economic development can be categorized into three stages: (i) factor-driven, (ii) efficiency-driven, and (iii) innovation-driven stages.

During the factor-driven stage, countries focus on non-agricultural self-employment, often consisting of small manufacturing and service firms. Countries in this stage compete in producing commodities or low-value-added products. Institutions' role becomes crucial to transit into the efficiency-driven stage. During this stage, countries must enhance production efficiency and educate the workforce to adapt to technological advancement. They also must develop financial institutions that support the birth of large firms capable of exploiting economies of scale. Finally, the innovation-driven stage is marked by an increase in knowledge-intensive activities. In this stage, the focus shifts from firms to agents possessing new knowledge (Acs *et al.*, 2008).

Since developed economies generally have fertility rates below the replacement rate, resulting in a negative or low natural increase rate, countries with the higher natural increase rates are more likely to be in phase 1 or 2 of economic development. This may explain why we observe a negative coefficient for the natural increase rate, as countries in earlier stages of development may prioritize production factors other than innovation.

Regarding the negative impact of aging, our results confirm the concern about its relationship with technological progress. Thus, not only aging produces a detrimental effect on nascent entrepreneurship, as shown by Lamotte & Colovic (2013), but it may also undermine the ability of countries to introduce technological innovations. This is also coherent with the findings reported at the individual level by Fernández-Lopez *et al.* (2022). In particular, they showed that senior entrepreneurs (intended as those over 50) are less likely to enter high-medium technological sectors than younger entrepreneurs. This paper complements their findings showing a link between aging and patenting activities.

Considering another demographic variable, a surprising finding is that the variable NMR is not significant from a statistical point of view. This contradicts common sense, according to which we may be tempted to believe the opposite. However, based on economic literature, the focus is not on the number of immigrants but rather on their quality in terms of human capital and the diversity they bring (Fairlie & Lofstrom, 2015; Li *et al.*, 2018; Burchardi *et al.*, 2020; Ozgen *et al.*, 2012). Burchardi *et al.* (2020) found that low-educated migrants do not significantly impact local innovation, while medium-educated migrants have an effect about half as strong as the average migrants. Only high-educated migrants exhibit a positive and more significant impact on innovation compared to the average migrants. Due to the limitation in our data, we were unable to distinguish among the type of migrants, and given that part of our sample was composed of data from developing countries, our sample likely included data of a significant portion of low-skilled migrants, particularly in developing countries. This could explain why the variable NMR is not significant in our analysis, as low-skill migration may not contribute significantly to the innovation patterns we are examining.

Finally, our results suggested that other demographic forces do not drive the effect of aging; thus, our answer to *RQ1* is positive. In addition, the coefficient associated with aging is also characterized by the largest magnitude. Hence, not only the effect of aging survives to the inclusion of possible confounders, but it has a substantial impact on innovativeness.

The Arellano-Bond tests for all three models indicate that these are correctly specified.

5. Conclusions

In 2007, with regard to the ability to innovate, the CEO and founder of Facebook, Mark Zuckerberg, at Y Combinator Startup School event in Stanford, affirmed that "younger people are just smarter." Even though the same Zuckerberg represents a case of a very young innovator, the relationship between innovativeness and age is not as straightforward in literature as he postulated. In particular, older entrepreneurs may be less likely to introduce technological innovation, but this may not be true for product innovations (Ruiu & Breschi, 2019).

Almost all developed economies have experienced a robust aging process; the same process is also happening in the developing ones. On the one hand, this reflects essential improvements in living standards and the scientific conquests in health; on the other hand, the aging issue flags a potential concern for weakening economic development if the intensity of entrepreneurship booming dwindles, leading to less innovation activities. Adopting a macroeconomic point of view, this paper investigated the relationship between population aging and innovation activities as proxied by the number of patent applications. Our results obtained using data panel techniques seem to confirm this association that aging is negatively related to the number of patent applications. This relationship remains significant when we controlled for important contextual variables, such as the workforce's education level, business regulation flexibility, economic development level, and other possibly confounding demographic variables. Of particular relevance is the result associated with the net migration rate.

Immigration is often viewed as a temporary solution to address labor force shortages. However, according to demographic theory, immigration alone may not be sufficient to rejuvenate a population with fertility rates below replacement levels. Nevertheless, it is widely recognized that immigrants are generally highly entrepreneurial (OECD-EU, 2019; Parker, 2009; Dheer, 2018).

Consistent with the previous empirical findings (Burchardi *et al.*, 2020), our analysis suggested that the impact of immigrants on technological advancement depends on their level of human capital. When immigrants predominantly comprise low-skilled individuals, they are more likely to engage in entrepreneurship out of necessity rather than pursuing innovative ventures. Furthermore, the success of immigrant entrepreneurship may also be influenced by the support provided by local institutions (Dheer, 2018).

In summary, while immigration can contribute to entrepreneurship and economic growth, its impact on technological advancement depends on the composition of immigrants in terms of human capital and the level of support provided by local institutions. Low-skilled immigration may not significantly affect innovation, and immigrant entrepreneurs' success may vary depending on institutional support.

Fortunately, the effect of aging could be, in principle, counteracted by increasing the level of education and allowing for more flexibility in business regulations. In addition, even though aged entrepreneurship may imply lesser innovation in terms of technological advancement, this does not automatically mean that innovations stemming from the Silver Economy are not possible.

Overall, the key message that emerges from our analysis is that a policy in favor of mature-aged entrepreneurship is crucial for the growth of developed economies. On this line, the European Union and the OECD-EU (2021) have recognized the importance of senior entrepreneurship. They have emphasized the need to create an enabling environment that supports older individuals in starting and running their businesses, including access to finance, business support services, training and skills development, networking opportunities, and overcoming age-related barriers and stereotypes. European Union and OECD have also emphasized the importance of promoting intergenerational collaboration and knowledge exchange to leverage older entrepreneurs' experience, skills, and networks. In addition, they have highlighted the need to address specific challenges faced by senior entrepreneurs, such as limited access to capital, age discrimination, and inadequate tailored support mechanisms. Therefore, paraphrasing Zuckerberg, if youngsters are smarter in the technological field, mature entrepreneurs may be "wiser" in judging new market opportunities thanks to their cumulated experience (see, among others, Ruiu & Breschi, 2019; Kitchell, 1997).

A limitation of our work stems from using patent applications as a proxy of innovation activities. Indeed, a patent does not necessarily represent a commercially exploited innovation, and the submitted applications can turn out to be unsuccessful. In any case, we believe that this variable is suited to capture the efforts exerted in a country to introduce technological innovations. As pointed out by the literature, the negative attitude of older people toward technology is one of the most severe challenges that aging populations should face soon. In addition, we did not consider other forms of innovation, such as social innovations, in the current analysis. However, we believe that even though these are important for development, this paper was oriented to explain the possible consequences of aging on technological progress. Therefore, offering reflections on other forms of innovation is out of the scope of this specific paper.

In conclusion, it is essential to advocate for a broader interdisciplinary dialogue among social scientists, and specifically, strengthen the collaboration between demographers, economists, sociologists, and business management scholars to maintain the innovativeness of an aging population. We believe that the challenges and opportunities a rapidly aging society presents require an integrated approach that transcends disciplinary boundaries. By bringing together expertise from various fields, researchers can gain a more comprehensive understanding of the complex dynamics and implications of population aging.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Gabriele Ruiu, Marco Breschi, Alessio Fornasin
Formal analysis: Gabriele Ruiu
Methodology: Gabriele Ruiu
Writing – original draft: Gabriele Ruiu
Writing – review & editing: Gabriele Ruiu, Marco Breschi, Alessio Fornasin

Ethics approval and consent to participate

Not applicable.

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Availability of data

All the data used in this paper are taken from several public sources. The final dataset is available from the Harvard Datavarse Repository at the following address: https://doi.org/10.7910/DVN/KYJFQL

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