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Aging and Economic Growth in Japan: Differential Effects of Multiple Generations

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Abstract
We combine Japanese Population Census, Prefectural Accounts Calculations and other Japanese government data sources to create a panel database covering 47 prefectures over the 2001 to 2014 period. We then used this data to investigate the role of societal and generational aging on national economic growth in Japan. Specifically, we estimate the impacts of multiple Japanese generations that are distinct in characteristics, tastes and experiences, and explore the trajectories of their economic impacts. Our findings suggest that as Generation Z, our base generation, ages, gross domestic product increases at a decreasing rate, peaking at age 39. This is conditional upon the distributions of other generations and their ages. Additional and differential growth effects of aging are attributed to the Baby boomer II, Generation Y, Baby boomer I and Generation X and the Yutori generations, vis-à-vis Generation Z. However, the aging of the Before baby boomer generation leads to slower growth than that of the Generation Z. Our results challenge the use of average societal aging variables and suggest the efficacy of models accounting for the aging of different generations. These results are useful in national policies to promote economic growth through age-specific strategies that target individual generations.

Keywords Aging · Multiple generations · Economic growth · Japan

JEL Classification J11 · J14 · R11

Introduction

Simply defined, the term "population aging" is a phenomenon where the share of older people increases over time in a country or economy. Every country eventually ages and

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countries experience different degrees of population aging (United Nations 2015). The rate of population aging depends on how rapidly life expectancy and fertility are changing over time. These two, in-turn, depend on several factors, including improvements in healthcare and nutrition, changing family structures and changing work-style patterns (Lee 2003). Countries experiencing rapid population aging tend to have low fertility rates, rapidly growing life expectancy, rapid improvements in healthcare and high quality of life (United Nations 2015). On the down-side, there are potential adverse impact of population aging on productivity and economic development.

Japan is an excellent example of a country that made huge socio-economic strides over many years but is now dealing with the adverse effects of population aging. After Monaco (53.8 years), its median age of 47.7 years is the second highest among advanced economies (Central Intelligence Agency 2019). Its growth rate has declined from over 10% in the 1960s to less than 2% in the last decade. Concern about population aging has led the Japanese government to explore novel approaches to economic development. For example, it recently amended its Immigration Control and Refugee Recognition Act (ICRRA) to attract more immigrants to enhance economic performance – something that the Japanese would have rejected vehemently in the past. More recently, under the government of Prime Minister Abe, the government also unfolded new human capital related policies to enhance the performance of working Japanese citizens and improve their economic contributions (Government of Japan 2019). These policies represent a major economic policy paradigm shift in response to population aging. Solutions to the problem of population aging can be few and far between. Therefore, it is important to better understand its nexus to economic development, especially in the context of how various generations affect the economy.

Several studies have examined the effects of population aging on the economy. For example, Oliver (2015) regressed the populations of various age ranges (e.g., 40–44, 45–49, and 50–55) on regional outputs to measure the differential marginal effects of various groups on the economy. This is based on the notion that adding one more person from a given age bracket will add more to regional output than another bracket if people belonging to the former group are more productive. Others have used variables such as the number of older people (e.g., sixty years or over), the proportion of older people, the dependency ratio[1] and the mean or median age of the population as proxies for aging.[2] However, aging is a complicated process that involves the aging of different age brackets with different experiences, outlook toward life, interest in goods and services and expenditure patterns. Between a numerical average age variable and economic outcomes lies several social, demographic, behavioral, taste and market factors that are embodied in each generation. Models explaining population aging have not accounted for these aspects of the literature on demographics.

Given the importance of the relationship between aging and economic development, stronger empirical evidence is needed on the mechanisms through which population aging affects the economy. Previously used aging measures are too simple to

[1] Three dependency ratios are defined in United Nations (2015). The child dependency ratio is the number of persons 0–19 years per one hundred persons aged 20–64 years. The old-age dependency ratio is the number of persons aged 65 years or over per one hundred persons aged 20–64 years. The total dependency ratio is the sum of these two dependency ratios (United Nations 2015, 111).

[2] In addition to these standard indicators, more refined indicators of population aging are proposed (for example, Spijker et al. (2014)).

effectively explain the economic impact of aging. One area where advancements can be made is the use of population aging proxies that actually more deeply reflect not only changing demographics, but also the impact on the economy through consumption patterns, lifestyles, market behavior and cultures. The multiple generations concept has been used to evaluate the impacts of age-related characteristics on the demand for products and services. For example, overlapping generations model assumes that each person lives for a fixed number of periods and that a number of generations exist in each period. Marketing research considers each generation as having different preferences, attributes, collective experiences and similar ideals (Novak 2014). The multiple generation model can explain how the unique aspects of multiple generations impact on the economy as they grow older.

In this study, we posit that disaggregate measures of aging allow added understanding of aging impacts. We propose to improve the literature by leveraging information on multiple generations from the fields of finance and marketing because the impacts of economic generations may vary due to the distinct behavior and characteristics, tastes, common experiences and common history of each generation. Therefore, we use a traditional aging variable (average age) along with the average age of multiple generations as proxies for the aging process. We account for general aging (aging of all cohorts) and generational aging (cohort effect, which is specific to a group of people born in a certain period) and the period effect of aging. We also address the regional difference in generational distribution by leveraging available prefectural panel data. These allow several things. First, we shed light on the influence of economic generations, which enables us to predict future growth more precisely based on demographic changes and overall population aging. Second, we identify generations whose production and consumption impacts are more (or less) than average. This may allow more focused government policies and strategies in support of generations. Third, we explain the impacts of generations based on their values and experiences.

We organize the rest of this paper as follows. Sections 2 and 3 respectively present the literature review and conceptual framework. Section 4 presents the empirical framework, data, estimated model and estimation technique. Section 5 presents our results while section 6 concludes.

Literature Review

In some countries, population aging increases the working age population and the number of experienced workers, with positive economic impacts (demographic bonus or population bonus) (Lee 2003). In others, it increases the number of retirees who are dependent on public welfare or their families, thereby raising the dependency ratio. The increased cost of social welfare may hinder economic growth (population onus).

Studies have examined the effects of aging on various dimensions of the economy, not just gross domestic product (GDP) or growth rate. For example, aging effects on labor supply was examined by the United Nations (2015), Bloom and Luca (2016) and Kaschützke and Maurer (2016). Aging effects on consumption was examined by Börsch-Supan et al. (2016). Börsch-Supan et al. (2016) and Bloom and Luca (2016) also examined the impact of aging on savings while Kaschützke and Maurer (2016) further examined the impact on housing and medical expenditures. Lee (2011) examined the roles of public and private transfers in aging society. Two conclusions from these studies are that researchers recognize a variety of aging impacts and aging has an overall negative economic effect.

There are many reasons to expect aging to affect the economy. Nagarajan et al. (2016), for example, pointed out three main causal mechanisms: public social expenditure, consumption and saving patterns and human capital. They argued the demand for medical services and care services increases with age, thereby increasing public expenditures on social insurance programs. Novak (2014) also argued that American people in the GI generation (born in 1901–1926) avoid debt, while most members of generation X (born in 1965–1980) are deeply in credit-card debt. Workers' productivity and wages increase as they gain more work experience (see the Mincer equation, for example, Heckman et al. 2006). However, after some age, these are expected to decrease (Van Der Gaag and de Beer 2015). Also, the ratios of part-time and full-time workers in some age groups is larger than that in other age groups due to such things as mandatory retirement age and the existence of a recession. Therefore, using only one demographic indicator of aging is too simple to effectively explain the economic impact of aging and limited in their capacity to explain how the unique aspects of multiple generations impact on the economy as they grow older.

Oliver (2015) linked a disaggregated aging indicator to economic outcome in Japan. Using population composition and dependency ratios as proxies for demographic composition, she found that an increase in the 70–74 population age group is negatively correlated with economic growth, while an increase in the 75 and over population age group is positively correlated. Unfortunately, in exploring the roles that different age groups and their composition play, Oliver (2015) did not consider the roles of multiple generations. The characteristics of people in their sixties in 2010 are essentially the same as for people in their fifties in 2000 because they are the same people. She ignored the possibility that habits associated with different cohorts may vary as they move through the aging process. By controlling for the distribution of generations, one may be able to clarify the economic impacts of aging to the economy more clearly.

Given our goals for this paper, we briefly explain the multiple generations concept. In the US, the roles of the so-called six living generations of Americans has been well studied in the literature (see Novak 2014). Similar concept appears in Japan. For example, Matsuda (2006) identified thirteen Japanese generations and Takaoka (2016) identified eight generations. Although the definitions of each generation are different between these authors, three generations appear in all definitions: The first baby boomer ("*Dankai-no-sedai*"); the second baby boomer ("*Dankai-junior-sedai*"); and the Yutori generation ("*Yutori-sedai*").

The "first Japanese baby boomer" (Bb1) generation is defined as people born in 1947, 1948 or 1949. This definition is used by the Ministry of Health, Labor and Welfare (MHLW), Japan. Note that the period of birth for the Japanese Bb1 generation is much shorter than the US Baby boomers, which is 1947–1964. We believe that this unique distinction is warranted based on the unique impact of World-War II (WWII) on Japan. The Bb1 generation is often mentioned as one of the most unique generations in Japan (e.g., Takao 2009). They organized student movements in late 1960s and entered the workforce during the economic miracle with ample job opportunities (Tashiro and Lo 2020). They left rural areas in the 1960s and early 1970s seeking a better life in urban areas. They spearheaded the effort to reinvent Japan in the wake of the 1973 oil crisis. Since many Japanese retire around the age of 60, most of the Bb1 generation retired before 2015 and are expected to have a long retirement. They are financially sound and have positive economic outlook.

The "second Japanese baby boomers" (Bb2) are people born during the 1971 and 1974 period. This definition is also used by the MHLW. This generation is analogous to the US baby-boom-echo (generation Y or Millennials) population born between 1981 and 2000. Since most Bb2 generation are the children of the Bb1 generation, they grew up in an information and material-rich society and this has impacted their purchasing patterns. However, they had a hard time finding jobs since the Japanese asset bubble burst occurred around 1990 and the Japanese economy entered a long period of deflation and recession (Ohno 2006; Ohta et al. 2008). Like the US millennials, they are more cautios and have less consumption impact on the economy.

The "Yutori generation" (Ytr) is defined as people born during the 1987 to 2004 period. They received their compulsory education based on the curriculum guideline enforced during 2002 and 2011("Yutori" (pressure-free) education). People in the Ytr generation are said to be highly conservative, less ambitious, more realistic and more practical than previous generations. For example, they spend less on luxury goods than previous generations.

The other four generations are the people born before, after or between the three generations described above. The "before baby boomer" (Bbb) generation comprises people born before 1947. They went through growth and depression and most are now retired. This generation worked hard for everything, experienced WWII, witnessed the resurgence of Japan, and are very cautious in their spending. People born between 1950 and 1970 are classified as the "generation X" (Gnx). The name comes from the US generation born just after baby boomers (Novak 2014). Their characteristics are a mixture of those of the Bb1 and Bb2 generations. They spend much of their formative years in Japanese rapid economic development and they are high spenders. However, they were more affected by the rise and fall of the bubble economy.

People born between 1975 and 1986 are in "generation Y" (Gny). The name also draws from the US generation Y. Their characteristics are similar to the Bb2 generations. The asset bubble burst when they were children or at the beginning of their adulthood. According to Hirayama and Ronald (2008), the Bb2 and part of the Gny generation (called "Lost generation") suffered from a rapid decrease in stable employment and thus have noticeably delayed family formation and entry into the home ownership market. Finally, the youngest generation is comprised of the people born after 2004, named the "generation Z" (Gnz). They grew up in an information and material rich society. However, since they are aged less than ten in 2014, it is difficult to define their characteristics regarding consumption, preferences, and working profile. These group is similar to the American Generation Z.

Conceptual Framework

To estimate the contributions of generations to the Japanese economy, consider the case of an economy with w generations ($g = 1, 2, \cdots, w$) and denote its output in year t as Y_t. Note that

$$Y_t = \sum_{g=1}^{w} Y_{gt} \tag{1}$$

where Y_t is national GDP and Y_{gt} is generational GDP for the gth generation. Further, denote the growth rate of national GDP for a given year as $\dot{Y}_t = \partial Y_t / Y_t$. Note that

$$\dot{Y}_t = \sum_{g=1}^{w} s_{gt} \partial Y_{gt} / Y_{gt} = \sum_{g=1}^{w} s_{gt} \dot{Y}_{gt} \tag{2}$$

where $s_{gt} = Y_{gt}/Y_t$. Therefore, the growth rate of national GDP is the weighted average growth rate of generational contributions to national GDP. The weights are the generational GDP shares.

Our conceptual challenge in this paper is to specify a growth model that accounts for the impacts of aging, including the effects of multiple generations and their impacts as they age. The output of generation g in year t is implicitly specified as follows:

$$Y_{gt} = F\left(K_t, G_{gt}, X_t, t\right), \tag{3}$$

where K_t is national capital input in year t, G_{gt} measures generational capacity in year t for generation g, X_t is a vector of other contributory factors including natural resources, national management capacity and other control variables in year t, and t is a trend variable which accounts for the independent period effect. Equation (3) can be specified to account for GDP growth at the prefectural level. Therefore, for the ith prefecture,

$$Y_{igt} = F\left(K_{it}, G_{igt}, X_{it}, t\right), \tag{4}$$

where Y_{igt}, K_{it}, G_{igt} and X_{it} are prefecture level outputs, capital inputs, generational capacities and other contributory factors.

Assume that each generation's capacity (G_{igt}) is defined as the product of the population (L_{igt}) and the average characteristics of its population (V_{igt}), which is unobservable but is a function of some observable characteristics (Z_{igt}) such as average age of the generation. That is,

$$G_{igt} = L_{igt} \cdot V_{igt} = L_{igt} \cdot \theta_{igt}\left(Z_{igt}\right). \tag{5}$$

The production function in Eq. (4) becomes

$$Y_{igt} = F\left(K_{it}, L_{igt} \cdot \theta_{igt}\left(Z_{igt}\right), X_{it}, t\right). \tag{6}$$

The outputs of prefecture i in year t is

$$Y_{it} = \sum_{g=1}^{w} Y_{igt} = \sum_{g=1}^{w} F\left(K_{it}, L_{igt} \cdot \theta_{igt}\left(Z_{igt}\right), X_{it}, t\right). \tag{7}$$

Therefore, the total derivative of the production function in Eq. (7) is specified as follows:

$$
\begin{aligned}
dY_{it} &= \sum_{g=1}^{w}\left\{\frac{\partial F}{\partial K}dK_{it} + \frac{\partial F}{\partial X}dX_{it} + \frac{\partial F}{\partial t}dt + \frac{\partial F}{\partial G}\left(\frac{\partial G}{\partial \theta}\frac{\partial \theta}{\partial Z}dZ_{igt} + \frac{\partial G}{\partial L}dL_{igt}\right)\right\} \\
&= w\left(\frac{\partial F}{\partial K}dK_{it} + \frac{\partial F}{\partial X}dX_{it} + \frac{\partial F}{\partial t}dt\right) \\
&+\sum_{g=1}^{w}\frac{\partial F}{\partial G}\left(L_{igt}\frac{\partial \theta}{\partial Z}dZ_{igt} + \theta_{igt}\left(Z_{igt}\right)dL_{igt}\right).
\end{aligned}
\tag{8}
$$

This can be expressed as

$$
\begin{aligned}
\frac{dY_{it}}{Y_{it}} &= w\left(\frac{\partial F}{\partial K}\frac{dK_{it}}{K_{it}}\frac{K_{it}}{Y_{it}} + \frac{\partial F}{\partial X}\frac{dX_{it}}{X_{it}}\frac{X_{it}}{Y_{it}} + \frac{\frac{\partial F}{Y_{it}}}{\partial t}dt\right) \\
&+\frac{\partial F}{\partial G}\frac{G_{it}}{Y_{it}}\sum_{g=1}^{w}\left(\frac{L_{igt}\cdot\theta_{igt}\left(Z_{igt}\right)}{G_{it}}\frac{\partial \theta}{\partial Z}\frac{Z_{igt}}{\theta_{igt}\left(Z_{igt}\right)}\frac{dZ_{igt}}{Z_{igt}}\right) \\
&+\frac{\partial F}{\partial G}\frac{G_{it}}{Y_{it}}\sum_{g=1}^{w}\left(\frac{L_{igt}\cdot\theta_{igt}\left(Z_{igt}\right)}{G_{it}}\frac{dL_{igt}}{L_{igt}}\right)
\end{aligned}
\tag{9}
$$

and

$$
\ln Y_{it} = \alpha_K \ln K_{it} + \alpha_X \ln X_{it} + \alpha_t dt + \alpha_G \sum_{g=1}^{w}\gamma_{gt}\delta_Z \ln Z_{igt} + \alpha_G \sum_{g=1}^{w}\gamma_{gt}\ln L_{igt} \tag{10}
$$

where α_j is the elasticity of output with respect to the jth input ($j \in \{K, X, G\}$), $\alpha_t = \partial \ln Y_{it}/\partial t$ is the productivity growth, $G_{it} = \sum_{g=1}^{w} G_{igt}$ is the total capacities of prefecture i in year t, $\gamma_{gt} = \theta_{igt}L_{igt}/G_{it}$ is the ratio of generational capacity for generation g and δ_Z is the elasticity of average characteristics of generation g with respect to Z.

The penultimate term in Eq. (10) suggests that the impact of the population of each generation is affected by their characteristics. For example, when a younger generation enters the labor market, an older generation retires and generations in the middle get more working experience, their contributions to the economy change. We make no assumptions regarding economies of scale in Eq. (10). Equation (10) shows the impacts of various factors. Of particular interest is the impact of the characteristics (Z_{igt}) on regional economic growth rate. From Eq. (10), α_X shows the effects of overall population aging where X_{it} represents the average age for all population, $\alpha_G\gamma_{gt}$ shows the effect of the population of generation g and $\alpha_G\gamma_{gt}\delta_Z$ shows the effect of general characteristics such as generational aging of each generation.

Empirical Framework and Data

Empirical Model

To estimate the impacts of changes in generational distribution and their characteristics on regional economic growth in Japan, the following empirical model is estimated. The unit of analysis is Japanese prefectures. There are 47 prefectures in Japan.

$$\ln GDP_{it} = \beta_0 + \sum_g \left(\beta_{1g} GenPop_{igt} + \beta_{2g} GenPop_{igt} \times Z_{igt} \right) + \beta_3 K_{it} + \beta_4 X_{it} + \beta_t + \varepsilon_{it}. \tag{11}$$

Note that $\ln GDP_{it}$ is the log of real gross prefectural product in prefecture i at time t. $GenPop_{igt}$ is the vector of the population of generation g. No restrictions are imposed on the parameters of the Eq. (11) to reflect constant, increasing or decreasing returns to scale. Since it is assumed that the impacts of a generation may change with the generations' characteristics, interaction terms with time trend or average age of each generation (Z_{igt}) are included.

In the specification in Eq. (11), the coefficients have important meanings. β_0 is the intercept. β_{1g} is the marginal impacts of the population of each generation on GDP in percentage terms. The different measures of β_{1g} essentially show the marginal differential impacts of each person in that generation. Therefore, there are reflective of marginal products in percentage terms. β_{2g} is the coefficients of cross terms between generation's population and average age of each generation. It is intended the diminishing effects of specific generations' aging. Again, it measures the marginal impacts of a person in a given generation, adjusted for an aging. The K_{it} variable represents capital input. The X_{it} variables include an urban dummy and an educational attainment (human capital) variable, as well as the mean age of the population. Since one expects that increasing working age population positively affects economic growth but increasing the number of retired people will negatively affect growth (Van Der Gaag and de Beer 2015), the impact of mean age may be nonlinear. Therefore, a square term for average age is also included as a control variable to capture the possibility of quadratic relationship. β_t represents time fixed effects and ε_{it} represents the error term, which is assumed to be normally distributed.

Given the facts that previous studies on multiple generations present conflicting definitions, we had to decide which generational boundaries provide the generational distinction. To correct for these inconsistences and harmonize several confusing definitions, in this paper, seven living generations of Japanese are defined (see Table 1). Note that the three generations common to previous literature are retained: (1) "First baby boomer" (Bb1), (2) "second baby boomer" (Bb2) and (3) the "Yutori generation" (Ytr). We also retain the "before baby boomer" (Bbb) generation, "generation X" (Gnx), "generation Y" (Gny) and "generation Z" (Gnz). Figure 1 shows a comparison of the US and Japanese generations. The contributions of different generations to Japan's total population is summarized in Fig. 2. Bbb's population rapidly declined since 2001 due to aging and dying. Bb1's population also declined since 2001, but more slowly over time. The populations of Gnx, Bb2, and Gny have been generally stable. Since some of them were born after 2001, Ytr's populations grew slightly over time. For similar reasons, Gnz's population is rapidly growing.

Because our defined Japanese generations vary in length, we depart from the standard definition of Japanese generation by combining the Bb2 and Gny generation to generate the Bb2Y generation. The characteristics of the combined categories are not majorly different. As previous research such as Hirayama and Ronald (2008) and Takao (2009) did, we retain the Bb1 generation though it has the smallest population share. Generation Z is excluded

Table 1 Describing the seven living generations of Japan

Generation	Acronym	Born Between	Number of Years	Age in 2001	Age in 2014	Share in 2014
Before Baby Boomer	Bbb	1900–1946	47	55–101	68–114	20.6%
Baby Boomer I	Bb1	1947–1949	3	52–54	65–67	4.1%
Generation X	Gnx	1950–1970	21	31–51	44–64	27.7%
Baby Boomer II	Bb2	1971–1974	4	27–30	40–43	6.2%
Generation Y	Gny	1975–1986	12	15–26	28–39	15.5%
Yutori Generation	Ytr	1987–2004	18	0–14	10–27	17.6%
Generation Z	Gnz	2005–2014	10	–	0–9	8.4%

Source: Population Census (Statistics Bureau 2017a)

from the specification and used as numeraire to reduce multicollinearity in our estimation.[3]

To estimate the impacts of multiple generations on regional growth and GDP, data from multiple sources are used. The data spanned the period 2001 to 2014. While the fourteen-year time frame is a limitation, we are constrained by the fact that a longer consistent GDP data set is unavailable at the prefecture level.[4] The log of real GDP, obtained from the Prefectural Account Calculation (Cabinet Office 2017), is the dependent variable. The number of people in each generation is calculated from the Population, Population Dynamics and Household Survey produced by the Residential Basic Book (Statistics Bureau 2017b). It only provides information on the number of people in 5-year age brackets. In the absence of yearly details, in calculating the populations of each generation and their average ages, we assume uniform population distribution within each 5-year age bracket. We admit that this assumption may not be reasonable for estimating the average age of the oldest generation (Bbb) as the number of people aged ninety in 2001 is smaller than the number aged sixty. Hence, we use the youngest age of Bbb as a proxy for the average age of Bbb.[5]

The average age of a prefecture's population is estimated from the Population Census (Statistics Bureau 2017a), which is carried out every five years.[6] In generating approximations of the average age of each prefecture, we assume that the average age

[3] We dropped GnZ from the estimation to reduce the possibility of multicollinearity between GnZ and Year since not some of them were not already born during our study period and their population seems correlated with time.

[4] Several short datasets of GDP are available at the prefecture level. However, they were calculated by different base year and the system of national accounts (SNA).

[5] Please note that rather than use the populations of each generation as exogenous variables, we could have used the shares of each generation. We used the former because it has more direct policy implications as it allows the estimation of differential effects across generations of adding one more person.

[6] In our empirical analysis, we tried both median age and average age. The results were practically the same. We therefore report on only the results using average age.

United States	Year	Japan
GI Generation	-1926	Before Baby Boomer
Mature/Silents	1927 1945	
Baby Boomers	1946	
	1947 1949	Baby Boomer I
	1950 1964	Generation X
Generation X	1965 1970	
	1971 1974	Baby Boomer II
	1975 1980	Generation Y
Generation Y/Millennium	1981 1986	
	1987 2000	Yutori Generation
Generation Z/Boomlets	2001 2004	
	2005-	Generation Z

Fig. 1 Comparing the US and Japan's generations. Note: The definition of generations in the US is based on Novak (2014). For Japan, it is defined by the authors

changes linearly. We use the percentage of people who have a university or higher-level degree from the System of Social and Demographic Statistics (Ministry of Internal Affairs and Communications 2018) as a proxy for human capital. Although the survey is conducted yearly, population by last school completed is collected every ten years. Therefore, linear approximations are made for other years from the 2000 and 2010 data.[7]

[7] Education is seen as an important control variable. Given the limited data, we debated whether to include or exclude it. Our choice was to include it as a control variable to reduce the likelihood of an omitted variable problem.

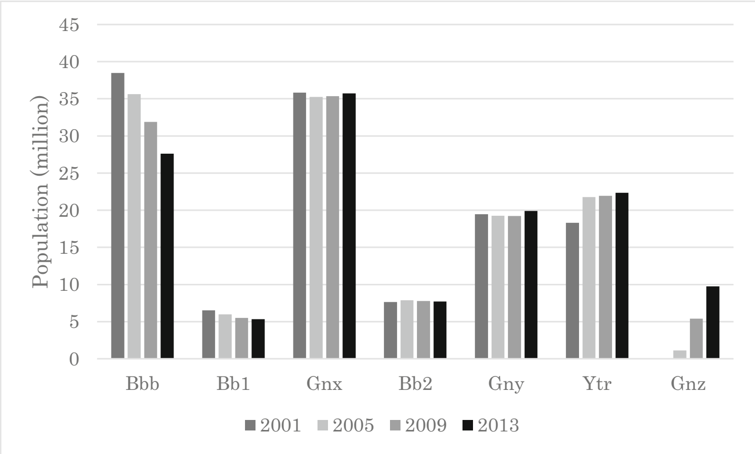


Fig. 2 Seven living generations in Japan: population changes. Source: Population Census (Statistics Bureau 2017a)

The value of the urban dummy variable equals to one when the prefecture belongs to one of the Metropolitan Areas of Japan. Japanese Metropolitan Area is defined based on a Population Census, which is conducted every five years. Therefore, the urban dummy may change every five years. Finally, the consumption of fixed capital obtained from the Prefectural Account Calculation (Cabinet Office 2017) is used as a proxy for capital input. The unit is million Japanese Yen (JPY). The descriptive statistics for all variables are reported in Table 2.

Table 2 Descriptive statistics

Variable	Description	Mean	Std. Dev.	Min	Max
LnGDP	Log of real GDP	15.79	0.83	14.47	18.43
Bbb	1000 people	698.25	603.49	137.92	3464.06
Bb1	1000 people	123.93	114.91	24.21	589.06
Gnx	1000 people	756.91	727.99	160.53	3618.06
Bb2	1000 people	163.73	180.92	29.42	937.06
Gny	1000 people	413.89	438.01	80.91	2497.95
Ytr	1000 people	455.83	415.20	92.69	2297.82
Ayr	1000 people	90.83	141.08	0	1040.74
Capital	Trillion JPY	2.11	2.57	0.37	16.71
AvgAge	Average age	44.88	2.10	37.82	50.88
Education	University graduates/Population	0.11	0.03	0.06	0.21
Urban	Urban dummy	0.38	0.49	0	1

Sources: LnGDP and Capital data are from Prefectural Account Calculation (Cabinet Office 2017); Bbb, Bb1, Gnx, Bb2, Gny, Ytr, and Ayr data is from Population, Population Dynamics and Household Survey from Residential Basic Book (Statistics Bureau 2017b); Education data is from Social and Demographic Statistics (Ministry of Internal Affairs and Communications 2018); AvgAge and Urban data is from Population Census (Statistics Bureau 2017a)

Empirical Results

Ordinary Least Squares (OLS) estimates of Eq. (11) are presented in the first column of Table 3 as model 1A, which assumes time-variant marginal impacts of each generation. The coefficients reflect the impacts of independent variables on prefectural GDP growth rate. For example, the urban dummy coefficient suggests that urban prefectures experience a 11.2-percentage point advantage over non-urban prefectures. Such advantage has been well documented in the economic growth and urban development literature. For example, Ng and Hui (2010) showed that cities are more competitive because they possess favorable business environments, agglomeration economics and strategic factors such as higher concentration of infrastructure, knowledge institutions, global connectivity, modern enterprises and productive generations.

Unobserved factors (e.g., geography, climate, place personality, character of residents, policy changes and natural disasters) can affect both GDP and the independent variables. Although we control for the unobserved prefecture-invariant factors that affect all prefectures (e.g., national policy) through time-fixed effects, model 1A cannot yield consistent estimates of the impacts of multiple generations due to other unobserved time-invariant prefectural characteristics. To control for these, we include prefecture fixed effects and the results are presented in the second column of Table 3 (model 1B). These results form the basis of our main discussions.

In the fixed effects (FE) model (model 1B) in Table 3, the estimated coefficient of capital is 0.074, which is statistically significant at the 1% level. Therefore, a one trillion yen increase in fixed capital consumption translates into a 7.4% increase in prefecture GDP. Hence differentials in capital explain differences in growth, implying that the limited capital is a limiting factor in prefectural development.[8] This is consistent with economic theory of growth and development.

The 1.83 estimated coefficient for education is statistically significant at the 5% level, suggesting that a one percentage point increase in the high education completion rate will increase the growth rate by about 1.8%. This finding is important, especially given Japan's growth rate decline in recent years. Our estimates are much larger than that of Panagiotis and Constantinos (2014), whose estimates was 0.52% for Greece.[9] The statistically insignificant coefficient of the urban dummy variable suggests that urban prefectures are no more productive than rural prefectures. This finding contradicts Seya et al. (2012) who showed that Japan's prefectural disparities have increased since around 2000. Differences in generational impact and in data range are possible explanations, as Seya et al. (2012) used 1990–2007 data, while we use 2001–2014 data.

[8] There is a potential endogeneity of physical capital and human capital. For example, Toya et al. (2010) addressed human capital endogeneity in estimating its effect on economic growth. Since we investigate prefectural growth difference in one country, the endogeneity problem is less severe than previous studies investigating growth difference between nations such as Toya et al. (2010). However, it should be careful about the interpretation of the coefficient of capital and education.

[9] Panagiotis and Constantinos (2014) used higher education enrollment rates, but we use the ratio of people with university or higher degrees to total population. Hence, we expect our estimated elasticity to be higher.

Table 3 Estimated impacts of average age and multiple generations on the Japanese economy: Base model and robustness check (Dependent variable: Log GDP, $N = 658$)

	Model 1A	Model 1B	Model 2	Model 3	Model 4
	(OLS)	(FE)	(FE)	(FE)	(FE)
Bbb	0.0013	0.0000	0.0012	−0.0070	−0.0079
	(0.0003)**	(0.0001)	(0.0004)**	(0.0056)	(0.0057)
Bb1	0.0086	−0.0003	−0.0032	−0.0197	0.0045
	(0.0016)**	(0.0004)	(0.0024)	(0.0334)	(0.0341)
Gnx	−0.0003	−0.0003	−0.0015	0.0097	0.0098
	(0.0006)	(0.0002)	(0.0006)*	(0.0058)	(0.0059)
Bb2Y	−0.0039	0.0006	0.0017	0.0045	0.0003
	(0.0006)**	(0.0002)**	(0.0004)**	(0.0021)*	(0.0021)
Ytr	0.0019	0.0001	−0.0000	−0.0011	−0.0009
	(0.0004)**	(0.0001)	(0.0001)	(0.0003)**	(0.0003)**
Bbb_Year	0.0000	−0.00002	–	–	–
	(0.0000)	(0.000008)**			
Bb1_Year	−0.0006	0.0001	–	–	–
	(0.0002)**	(0.0000)			
Gnx_Year	0.0001	0.00003	–	–	–
	(0.0001)	(0.00001)**			
Bb2Y_Year	0.0001	−0.0001	–	–	–
	(0.0000)	(0.00001)**			
Ytr_Year	−0.0001	0.00002	–	–	–
	(0.00004)**	(0.000009)*			
avgBbb_Bbb	–	–	−0.00002	0.0002	0.0003
			(0.000008)**	(0.0002)	(0.0002)
avgBb1_Bb1	–	–	0.0001	0.0005	−0.0002
			(0.0000)	(0.0011)	(0.0012)
avgGnx_Gnx	–	–	0.00003	−0.0004	−0.0004
			(0.00001)**	(0.0002)	(0.0002)
avgBb2Y_Bb2Y	–	–	−0.0001	−0.0002	0.0001
			(0.00001)**	(0.0001)	(0.0001)
avgYtr_Ytr	–	–	0.00002	0.0002	0.0002
			(0.000009)*	(0.0001)**	(0.0001)**
avgBbb_2_Bbb	–	–	–	−0.0000	−0.0000
				(0.0000)	(0.0000)
avgBb1_2_Bb1	–	–	–	−0.0000	0.0000
				(0.0000)	(0.0000)
avgGnx_2_Gnx	–	–	–	0.000005	0.000005
				(0.000003)*	(0.000003)*
avgBb2Y_2_Bb2Y	–	–	–	0.0000	−0.0000
				(0.0000)	(0.0000)
avgYtr_2_Ytr	–	–	–	−0.000008	−0.000005
				(0.000002)**	(0.000002)*

Table 3 (continued)

	Model 1A	Model 1B	Model 2	Model 3	Model 4
Capital	0.1984	0.0737	0.0737	0.0644	0.0616
	(0.0177)**	(0.0144)**	(0.0144)**	(0.0151)**	(0.0154)**
AvgAge	0.5213	0.1565	0.1565	0.2040	–
	(0.1584)**	(0.0405)**	(0.0405)**	(0.0496)**	
AvgAge2	−0.0070	−0.0020	−0.0020	−0.0025	–
	(0.0018)**	(0.0004)**	(0.0004)**	(0.0005)**	
Education	1.7858	1.8300	1.8300	1.7173	3.3503
	(0.6268)**	(0.7683)*	(0.7683)*	(0.8057)*	(0.7840)**
Urban	0.1128	0.0085	0.0085	0.0047	0.0026
	(0.0218)**	(0.0094)	(0.0094)	(0.0096)	(0.0099)
R^2	0.95	0.67	0.67	0.68	0.66

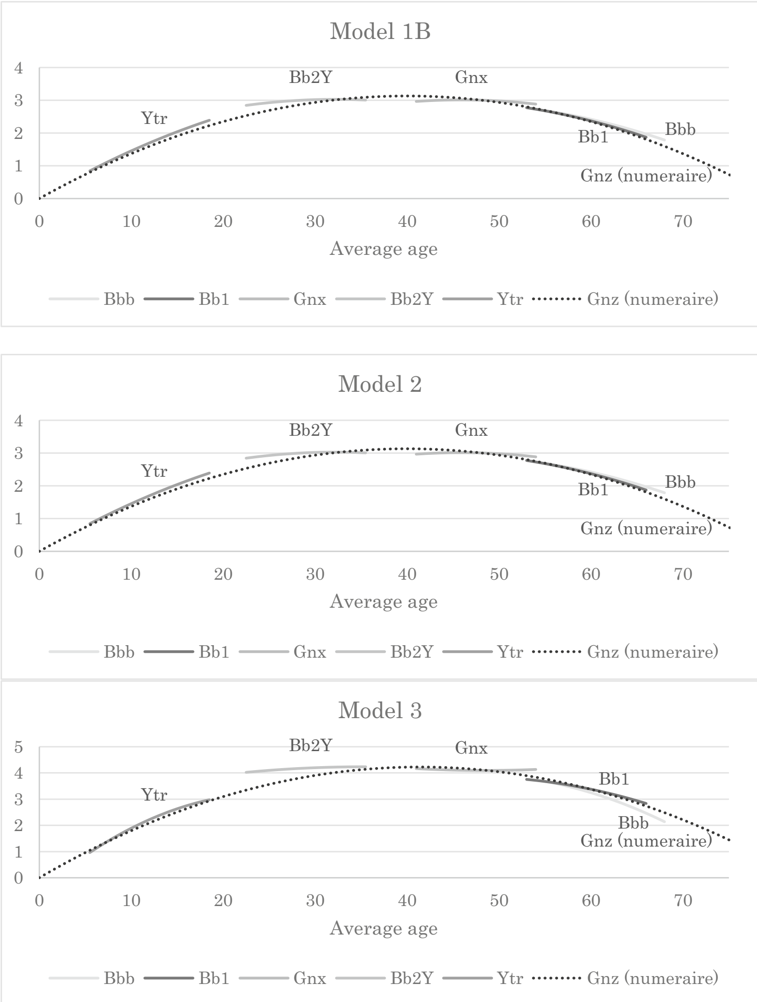
Standard error in the parentheses. Time fixed-effects and constant term are included, but the estimated results are omitted. Robust standard error is used in OLS. * $p < 0.05$; ** $p < 0.01$

Effects of Societal Aging

Now examine the effects of aging based on the FE model (model 1B). The variable Avgage and its square term (Avgage2) capture the effects of overall societal aging on GDP, but not generational aging. Since Gnz is the only generation that is not accounted for in the regression, we attribute the coefficient of Avgage to the effects of aging in general, including the effect of Gnz (our numeraire). The coefficient of Avgage is 0.157 and for Avgage2 is −0.002. Both are significant at 1% level, suggesting that overall societal aging has a positive effect on growth which increases at a diminishing rate, eventually maxing out at age 39 and becoming negative at age 79 (see large inverted U-shape curve of the top graph in Fig. 3). Liu and Westelius (2017) identified 40–49 years as the age range of optimal productivity in Japan. Our peak age of 39 only captures the impact of average age. The coefficients of the average ages of various generations would have to be added to or subtracted from 39, depending on the signs of the coefficient, with the exception of the Gnz generation, the numeraire. Japan's median age was 47.7 in 2019 (Central Intelligence Agency 2019) and continues to increase. In general, population aging begins to suppress economic growth after at age 39 and people start to become a drain on the economy at the age of 79. These findings say nothing about the differential impacts of various generations.

Added Impacts from Generational Aging

Now examine the impacts of generational population on prefectural GDP from the FE model (model 1B). The coefficients show the marginal impacts of an additional one thousand people in a given generation. These are additional shift factors in the relationship between aging and GDP growth. The generational population impact for Bb2Y are statistically significant. The first term is 0.0006 and the cross term is −0.0001, suggesting a positive but diminishing impact of an additional person in the Bb2Y generation. The age range of members of the Bb2Y generation in 2014 was



Note: The top graph is calculated based on model 1B, the middle graph based on model 2, and the bottom graph based on model 3. The large inverted U-shaped curve represents the impact of average age on GDP without accounting for generational impacts. Since Gnz is the numeraire, we attribute this to the impact of overall aging, including the effect of Gnz. The short curves represent the contributions of generations for which parameters where estimated. The difference between the short curves and the large inverted U-shaped curve, which represents additional contribution of each generation, are estimated as the product of the estimated marginal contribution and the mean population of each generation during 2001-2014.

Fig. 3 Estimated contribution of average age and each generation on Japanese economy. Note: The top graph is calculated based on model 1B, the middle graph based on model 2, and the bottom graph based on model 3. The large inverted U-shaped curve represents the impact of average age on GDP without accounting for generational impacts. Since Gnz is the numeraire, we attribute this to the impact of overall aging, including the effect of Gnz. The short curves represent the contributions of generations for which parameters where estimated. The difference between the short curves and the large inverted U-shaped curve, which represents additional contribution of each generation, are estimated as the product of the estimated marginal contribution and the mean population of each generation during 2001–2014

between 28 and 43. Their declining impact in their prime age range is worrisome. These generations are highly educated and grew up in an information and material-rich society. This may have contributed positively to their past productivity. However, due to the Japanese asset bubble burst in 1990s and a long period of stagnation and recession, part of this generation had a hard time finding jobs. Ono (2010) found that in the 1990s, new graduates were significantly less likely to be hired as standard workers than in previous periods, which caused increased nonstandard employment and job mobility. Genda et al. (2010) found that this generation met recession at their career entry points, and faced lower employment and earnings. Our results suggest that they experienced difficulty in increasing their skills due to the challenged economy.

While the coefficients of the Bbb, Gnx and Ytr populations are not statistically significant, their interaction terms with the time trend are significant. The Bbb interaction term with year is negative, but very small. The Gnx and Ytr interaction terms with the time trend are positive, but it is also very small. For the Bbb generation, their age in 2014 was more than 67. The vast majority of them are beyond retirement age and most probably are now beyond the age at which this study estimated negative productivity to set in (age 79).

For the Gnx generation, the result simply suggests that their impact is not different from others, with the exception of the Bb2Y generation. The Gnx generation, aged between 44 and 64 in 2014, are high spenders and are asset-rich. Both of which positively affect the economy. However, their decreasing labor participation rate, due to their age, negatively affects growth. For the Ytr generation, the result suggests that the conservativeness of the Ytr generation may have had an adverse effect on growth, while their ascent to working age may have had a positive effect (they aged between 10 and 27 in 2014). The asset bubble burst, long deflation and recession in Japan also affected their careers, albeit less severely than the Bb2Y generation (Ohta et al. 2008).

The coefficient of the Bb1 is not statistically significant. It suggests that their impacts on growth is not uniquely different from Gnz. Their high spender characteristics may be canceled out by their decreasing labor participation rate.

Robustness Check

In model 1B, the generational populations are crossed with the time trend. As a robustness check, in model 2, they are crossed with the average age of each generation to allow exploration whether the aging of a given generation has a positive or negative impact, in addition to the aging results from the societal average age. The coefficients of the standard variables are not different from model 1B. However, some of the coefficients of generational populations are more statistically significant. In model 2, the coefficient of the Gnx populations turns out to be significant and negative, suggesting smaller impact than the Gnz generation. The population of the Bbb generation are positive and significant. The results suggest that the Bb2Y generation is the most productive generation in terms of contribution to GDP growth, compared with others, while Gnx is the least productive.

Figure 3 represents the estimated impact of societal and generational aging. The top panel is based on model 1B. The middle panel is based on model 2. As mentioned above, the large inverted U-shape curve represents societal aging of the numeraire (Gnz). The smaller curves represent generational contributions. The differences between the large curve and the small curves represent additional contributions of generations at specific ages, which are estimated as the product of the marginal contribution and the mean generational population during 2001–2014.

The Ytr generation has growing marginal impacts over time by the overall societal aging impact and their positive generation-specific impact. The Bb2Y generation seem to have stable contribution though they are in the prime age range. Since they are in their twenties and thirties, child rearing and nursing care for parents may offset the growing impact of societal aging. The Gnx generation also seem to have stable contribution. Their additional growing marginal impacts over time complements the overall societal aging impact. The Bb1 generation has declining marginal impacts over time by the overall societal aging impact. The Bbb generations have declining population marginal impact which can be explained by their losing savings, physical strength, and so on.

Exploring Non-linearity

Since there seems to be nonlinear relationships between overall average age and its impact on economic growth, we can expect nonlinear relationships between the average age of each generation and its population impact. To test such a relationship, we estimate models 3 and 4 which assume quadratic relationships between generations' impact and average age of each generation. Results appear in the fourth and fifth column of Table 3 (model 3 and model 4). The interaction term of average age square and population for each generation are included in model 3. In model 4, the average age of the overall population and its square term are excluded because they are highly correlated with average age of each generation.

The bottom graph in Fig. 3 graphically presents the implied relationships between marginal impact of population and average age for each generation based on model 3. Note that we do not draw graph based on model 4 since it omits Avgage and Avgage2. We skip the details of the parameter estimates and simply presents the graphical implications in Fig. 3. One can observe that not all generations are equal in marginal impact as we demonstrated before.

Endogeneity of the Population of each Generation

The population of each generation may be affected by GDP growth rate. For example, a prefecture with high economic growth rate may demand more labor, thereby increasing working-age population. If such endogeneity problem exists, this would make our estimate spurious. To ensure that there is no endogeneity problem, one could regress the population of each generation on the log of GDP. We confirmed that population is not endogenous to GDP (the results are not reported in this paper). We take this analysis further by conducting simple Granger causality tests on the relationship between GDP and the population of each generation rather than estimate the impacts of GDP on population of each generation. Our results, which are also not reported in a table in this paper, show that none of the generational populations are Granger caused by the log of prefectural GDP. These imply that prefectures that are experiencing growth do not cause in-migration of people. Therefore, we conclude that endogeneity problems are not concerned in our model.

Conclusion

Previous studies on the impact of population aging on the economy of Japan treated the aging variable as a mean or median measure derived from the age distribution of the population. However, population aging has several nuances and affects the economy in different ways. In this study, we explain the growth patterns in Japan during the short 2001–2014 period by estimating the heterogeneous impacts of multiple generations on prefecture GDP. We found that in addition to average population aging, the distribution of generations also affects economic growth.

As the average age of the base generation (Gnz) increases, we found that the Japanese growth rate increases, but at decreasing rate. It peaks at age of 39 years. This peak, however, does not account for the effect of specific generations. Each generation adds an extra boost to economic growth due to their characteristics. The generation with the most extra boost is the Bb2Y, at least for the period of our study, followed by the Gnx generation and then the Bb1 generation. The population impacts of the Bb2Y and Bbb generations are declining over time. On the other hand, the impacts of the Gnx and Ytr generations is increasing.

Considering the growing life expectancy and low fertility rates in Japan, the results suggest that population aging will cause future economic declines. Eggleston and Fuchs (2012) suggested that to respond to this demographic challenge, public policy should encourage higher labor force participation among the elderly, improve productivity, with an emphasis on human capital, increase savings, investment and capital formation. We further add enhancing the productivity of the younger generations through, for example, workforce development policies, could enhance future growth. Policies supporting childcare, education, and nursing can also help the growth contributions of working-age people by improving their labor force participation and productivity.

There are several limitations to this study. First, since the study period is only 14 years (2001–2014), the dynamics of the contribution of multiple generations may not be fully captured. Second, to maintain the similarity of characteristics within generation, the lengths of periods corresponding to each generation are still different from each other in this study, making it difficult to compare the marginal impacts of multiple generations at the same ages. Third, the sources of the generational difference are not evaluated.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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