APIR Discussion Paper Series No.44
2016/9

Population as a Source of Long−Term Growth: From Malthus to Japan's Postmodern Regime

Hayashi Toshihiko
Director for Research, Asia Pacific Institute of Research

APIR 一般財団法人 アジア太平洋研究所
Asia Pacific Institute of Research

Population as a Source of Long−Term Growth: From Malthus to Japan's Postmodern Regime

Toshihiko Hayashi[1]

Abstract This paper introduces a simple macroeconomic time series model incorporating a key concept of GDP elasticity with respect to population (population elasticity). Using this model, we conducted empirical analyses of 158 countries each covering 25 to 180 years of history. As a result, we found first that the estimated population elasticity demarcated the countries according to regime, showing clearly whether a country was in the 'Malthusian regime', in the 'modern growth regime' or in the 'postmodern regime'. We found that the poorest countries as well as some oil-rich countries were in the Malthusian regime. The modern growth regime prevailed in most European, Asian and American countries in the 20th century. We then predicted long-term real GDP for each country while they stayed in modern growth regimes. Third, we observed that both Germany and Japan went into a postmodern regime after a demographic transformation. Focusing on Japan, we argued that if the nation remained in the modern growth regime, it would face a precipitous decline in GDP. We suggested that Japan must reduce dependence on population as a source of growth in the postmodern era. This lesson might be important for the two thirds of countries in the world that are expected to enter a postmodern regime around the middle of this century. (206 words)

Keywords population elasticity, Malthusian regime, **JEL Classifications** O11・O47・J11

[1] hayashi-t@apir.or.jp
Director for Research, Asia Pacific Institute of Research, Grand Front Osaka C7, 3-1 Ofuka-cho, Kitaku, Osaka 530-0011, Japan

Population as a Source of Long-Term Growth: From Malthus, through Modern Growth, to Japan's Postmodern Regime[2]

Introduction

Relationships between population and GDP have attracted many economists' attention since the time of Thomas Robert Malthus. Galor and Weil (1999) reexamined this relationship and proposed a unified theoretical model to characterize macroeconomic evolutionary stages from the Malthusian regime to the modern growth regime.

According to Galor and Weil, the Malthusian regime is the state of economy in which "technological progress and population growth were glacial by modern standards, and income per capita was roughly constant" (Galor and Weil (1999), p.806). They presented a dynamic theoretical model to illustrate that economies exit from the Malthusian trap and move into the post-Malthusian regime, and then to the modern growth regime.

Later research focused on how accelerated technological progress can foster demographic transitions, such as increases in fertility rates and decreases in mortality rates. Lee (2003) talked about three centuries of fundamental change. Demographers' research also focused on the impacts of GDP, GDP per capita and income on demographic variables, and showed how economic development changes demography.

On the relationship between population and the level of GDP, Huan and Xie (2013) conducted an empirical analysis taking the two-way effects between population growth and per capita GDP growth into consideration. They used a sample of 90 countries covering the period 1980 to 2007 and found that population exerted negative short-term effects on per capita GDP growth, but did not observe any reverse effects from GDP growth on population. Elgin and Tumen (2012) asked an increasingly important question: "Can sustained economic growth and declining population coexist?" They proposed a theoretical dynamic model in the optimal growth theory framework and answered this question in the affirmative. They also conducted empirical analysis to support their theoretical conclusion, analyzing a set of data that consisted of 50 countries and spanned the period from 1960 to 2009. Another important contribution came from Prettner (2013) who looked into population aging in the context of endogenous growth theory.

However, there has not been a comprehensive empirical study that examines the relationship between population and the level of GDP from a historical perspective. The purpose of this study is to do just that. First, we will build a simple auto-regressive model to estimate GDP elasticity with respect to population (population elasticity, for short). We will find that population elasticity gives clear-cut quantitative definitions to the notions of 'Malthus regime', 'modern growth regime' and 'postmodern regime'.

Second, we will predict how each country will fare in terms of GDP and per capita GDP while it stays in the modern growth regime. We will report our predictions for selected countries in this paper.

Third, we will focus on regime transformation from the modern growth regime to the postmodern regime. What brings about this transformation is demographic transformation. Already Germany and Japan are in this

[2] Thanks are due to Mampei Hayashi and James Brady for helpful discussions, Jose O. TiuSonco II and Mizan Bustanul Fuady Bisri for data assistance, and Miles Neale for editorial assistance. Financial assistance provided by the Asia Pacific Institute of Research is gratefully acknowledged.

postmodern regime. We will focus on the Japanese case, and argue that reducing dependence on high population elasticity will be necessary if the country is to maintain its moderately increasing per capita GDP. The lessons that come from Japan's regime transformation should be relevant to those two-thirds of countries that are expected to start losing population around the middle of this century.

Modeling Population and GDP

The Basic Model

A secular change in total population affects the aggregate supply and aggregate demand of the economy, in addition to the political, social and institutional framework. On the demand side, effects will be felt in the overall household consumption level as well as in the composition of consumption expenditures. Along with this, the aging of the population will increase household demand for health care, social security, pension services and other related services. A change in population will also affect fiscal revenues, expenditures, exports and imports in national accounting.

On the supply side, we must recognize that population is the sole reservoir for labor supply, productivity, management skill and new ideas and technologies. Coupled with policy efforts to improve human capital productivity, population can change the overall efficiency of the economy, including that of the private and public sectors. In other words, demographic change can affect the potential GDP of an economy[1].

The method most frequently used to assess contributions of factors of production is growth accounting. Using historical records of GDP, which have been realized by the interplay of aggregate supply and aggregate demand, growth accounting focuses on the contributions of stock of capital and labor input to the level of output. Typically, this approach assumes that the relationship between realized GDP, capital and labor inputs, and technological progress can be described by a Cobb-Douglas function such that

$$y_t = A_t K_t^{\alpha} L_t^{\beta},$$

where y_t stands for real GDP in year t, K_t for capital stock existing at the beginning of year t, and L_t for labor input often measured in terms of work hours. α and β are capital and labor shares, respectively, when perfect competition prevails. When constant returns to scale is assumed, $\alpha + \beta = 1$. A_t represents 'total factor productivity'.

An extrapolative prediction of y can be obtained by calibrating new values for K and L using econometrically estimated relative shares of capital and labor, and total factor productivity. Although this model is heavily used in the literature, it presents economists with the critical difficulty of missing data when used to estimate the long-term structure of the economy. For example, the Penn World Table estimates data on stock of capital only back to 1950. If we wish to apply the Cobb-Douglas formula over 140 years of history for example, the lack of data becomes prohibitive.

However, we have a rich accumulation of data on population. Angus Maddison, in his seminal work (2008), estimated historical population for more than 120 economies, from as far back as 1 AD for some of these. 'UN Population Prospects' gives predictions for 160 economies up to 2100.

We will check if population is an effective predictor in a long-term analytical framework. For that purpose we will modify the Cobb-Douglas function as follows:

$$y_t = X_t P_t^{\beta} y_{t-1}^{\gamma}, \tag{1}$$

where y_{t-1} is substituted for K_t, and P_t for L_t. Since we have a long series of data for y and P, this formulation makes it possible to perform econometric estimations of the parameters.

Equation (1) is not without economic meaning. Consider a simple constant capital-output ratio model, which says $K_t/y_{t-1} = constant$[7]. We can substitute y_{t-1} for K_t, and let X_t subsume the constant capital-output ratio.

We will call β in equation (1) the 'elasticity of GDP with respect to population'. In the short-term production function, the power to labor supply is equal to labor's share in GDP under perfect competition. However, we would like to highlight the multi-channel effects of population on GDP, not just the contribution of labor supply in the production process.

Also, notice that we are now using X_t instead of A_t. We would like to emphasize the importance of *overall* productivity, or the 'X-efficiency', in a sense similar to the concept advanced by Leibenstein (1996).

A Fixed Effect Model

Empirical Model and Data

We will first estimate population elasticity for each economy. For the population data, we will rely on the UN's 'Population Prospects'. Regarding GDP data, we will use the World Bank's 'World Development Indicators' (WDI). In particular, we will use the series that presents GDP in US dollars (constant 2011 prices) converted by purchasing power parity, (NY.GDP.MKTP.PP.KD), over the period of 1990-2014.

In order to obtain a longer historical record, we will rely on the database compiled by Angus Maddison (AM), in which some series of yearly consecutive data go back to 1820. We will append the AM data to the WDI data and build a database of population and real GDP for 155 countries and regions covering 195 years[2].

As a starting point, we will employ a hypothesis that the X-efficiency is fixed over time for each economy. This is tantamount to assuming that X-efficiency is a historically determined, economy-specific productivity concept rooted deeply in the fundamental fabrics of the natural environment, culture and ethnicity of economies.

For empirical analyses, we will use a log transformed version of equation (1) such that

$$ln\, y_{jt} = C_j + \beta_j lnP_{jt} + \gamma_j lny_{jt-1} ,$$

where j is a running index of economies. This is simply an auto-regressive model with the exogenous variable P_{jt}. Hence, we will run AR regressions for each economy for the period in which data are available[3]. Results of these regressions are summarized in the Appendix.

Population Elasticity and per capita GDP

Since

$$ln(rate\ of\ change\ in\ per\ capita\ GDP)_{jt} = ln\dot{y}_{jt} - ln\dot{P}_{jt} = (\beta_j - 1)ln\dot{P}_{jt}\ ,$$

the rate of change in per capita GDP is $(\beta_j - 1)$ times the rate of change in population. Using this formula, we can classify countries according to their population elasticity value and rate of population change as in Table 1.

Table 1: Population elasticity and growth regimes

Regime	β	Population growth
Malthus	<1	+
Modern growth	>1	+
Postmodern growth	<1	-

The Malthusian regime is characterized by a population elasticity of less than unity and positive population growth. In countries in this regime, population is increasing and per capita GDP is decreasing. The modern growth regime emerges when both population and per capita GDP start to increase.

After the modern growth regime, population growth turns negative mainly because the fertility rate falls below the mortality rate, and perhaps immigration plays a less important role in labor supply in the host country. If a country's population elasticity remains high in the face of declining population, per capita GDP will fall as a result. In the postmodern regime, an economy strives to reduce population elasticity while its population keeps declining, and it may end up with a mildly increasing per capita GDP if successful. This cycle may repeat itself in future, although we have yet to observe such a phenomenon.

Three Development Regimes

The Malthusian Regime

First, let us look at our results for the economies that are in the Malthusian regime. We classified economies that that showed Malthusian characteristics more than 25 times during the observation period as being in the regime. 13 economies fit our classification, showing these characteristics more than 25 times. We excluded from our classification 23 additional countries that showed the characteristics less than 25 times. Most of the Malthusian regime countries are concentrated in Africa, the Caribbean and Central America. They belong to the low-income country group according to the World Bank's classification. These low income countries seem to typify countries in the Malthusian regime. As an example, below is the scatter plot of *ln(htpop)* and *ln(htgdppc)* for Haiti[4].

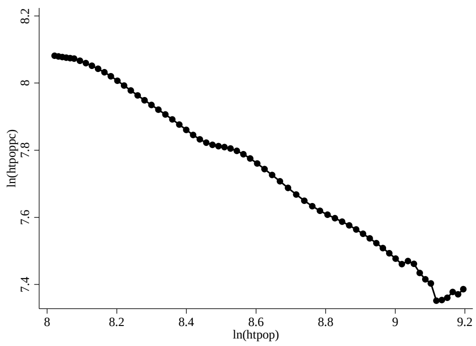

Figure 1: Haiti, 1945-2014, $\beta = 0.40$

Throughout the 70 years between 1945 and 2014, the Haitian population kept increasing without a break, whereas its per capita GDP fell persistently. The four dots at the south east corner correspond to the earthquake of 2010, which claimed 160,000 lives, and the post-disaster recovery. A serious question for Haiti is whether it can sustain the growth movement that started after the large-scale disaster.

Another example is the Central African Republic. This country experienced a chronic decline in per capita GDP after declaring independence from France in 1960, while its population kept increasing. Since its independence the country has been plagued with political instability. The sharp drop that appears at the right-hand-most corner of the plot was caused by the political turmoil in 2013.

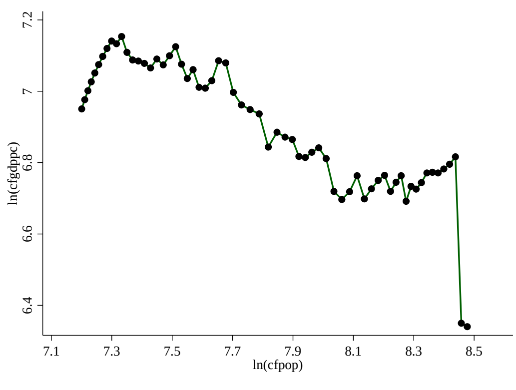

Figure 2: Central African Republic, 1950-2014, $\beta = 0.60$

In addition, we found another category of countries with a population elasticity of less than unity. The countries in this category are Kuwait, Qatar and the United Arab Emirates. These are oil-rich economies with a per capita GDP exceeding 50 thousand current dollars each.

From 1950 to 2014, the UAE population increased 2.7 fold, Kuwait's population increased 17.9 fold and in Qatar, population increased 9.8 fold. In all these economies, population growth out-paced growth in real GDP[5]. These findings illuminate yet another dimension of the 'resource curse' paradox[6]. Figure 3 and Figure 4 depict the scatter diagrams of Kuwait and Qatar. Kuwait had a downward sloping scatter diagram for most of the 1950-2014 period. The ragged pattern that appears toward the right end is due to the military invasion by Iraq that started in 1990.

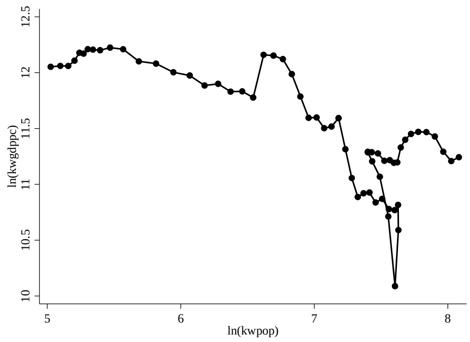

Figure 3: Kuwait, 1950-2013, β=0.60

Qatar was in the Malthusian regime between 1970 and 1993. During that period, it was an oil-producing economy and its revenues were monopolized by the ruling monarch. In 1995, the son of the Emir overthrew his father in a bloodless coup, and since then it started on a modern growth path, changing its focus from oil and natural gas to tourism and education.

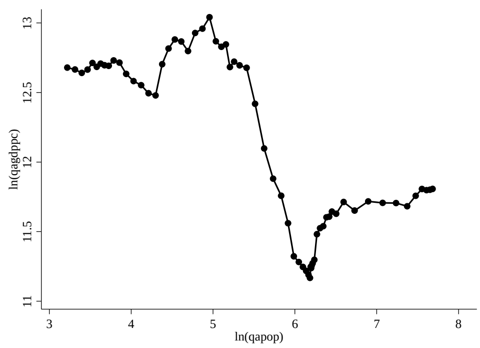

Figure 4: Qatar, 1950-2014, β=0.75

We may also note in passing that Russia showed an entirely different pattern. For Russia, GDP data is available only for 1990-2014, or 25 samples. Our AR estimation yielded a negative estimate for population elasticity.

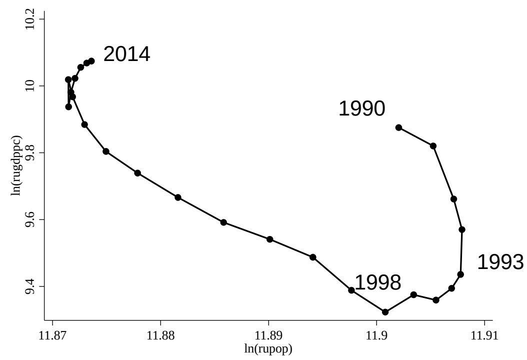

Figure 5: Russia, 1990-2014, β=-15.25

Figure 5 illustrates this. This scatter plot seems to show a negative correlation between ln(rupop) and ln(rugdppc), a characteristic of a country in the Malthusian regime. However, the chronological order of events is different from previous cases. Russia's population peaked off in 1993, and it has been declining ever since. In other words, the plot line has moved from the lower right to the upper left in recent years.

In 1998, Russia experienced a financial crisis in the immediate aftermath of its transition from planned economy to market economy. GDP and per capita GDP started to increase after this crisis had subsided. However, population kept declining during the recovery. We have recorded too few instances of relevant conditions to reach a conclusion on whether the Russian case suggests the existence of a Malthusian regime in reverse or a postmodern growth regime.

The Modern Growth Paradigm

In modern growth economies, population increases and per capita GDP rises simultaneously. Most of today's high-income and middle-income economies followed this pattern. Figure 6 and 7 illustrate two typical scatter plots: the United States from 1870 to 2014, and China from 1820 to 2014.

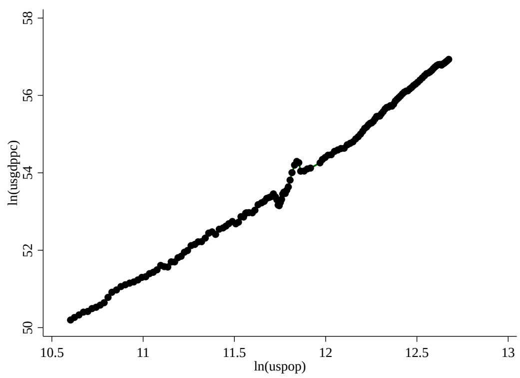

Figure 6: United States, 1870-2014, β=2.23

The United States maintained growth in per capita GDP almost uninterruptedly for 144 years, with the exception of the World War II period. The war caused a sudden drop in the ratio of log of per capita GDP to log of population, and a steep bounce-back in its immediate aftermath. The effect of WWII is visible in the middle of the scatter diagram.

What is prominent for China is that its growth in per capita GDP accelerated from around 1980, a rise that is attributed to the launch of the 'open door policy' by Deng Xiaopin in 1978. China has become the second richest country in the world in terms of GDP converted to US dollars at market rate of exchange, and its behavior affects, for better or for worse, the performance of many other national economies today.

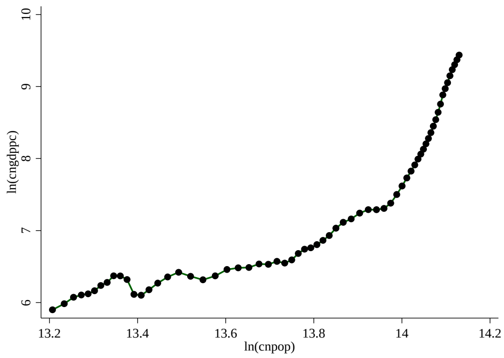

Figure 7: China, 1950-2014, β=3.72

In fact, a majority of economies in the world entered into the modern growth regime in the 20th century, and upward rising scatter plots became a historical paradigm. How long does this paradigm last? We hypothesize that an individual economy's modern growth regime will last until the year in which a secular decline in the population of said economy begins. We will now turn to long-term forecasts of GDP for countries and regions in the modern growth regime.

Long-Term Forecasts for Countries within the Modern Growth Regime

G7 Countries, China and India

We tried to forecast future GDP to 2100 for countries for which we have obtained reasonably good estimates of population elasticity[7]. Figure 8 illustrates the predicted GDP trajectories of the United States, Canada, United Kingdom, France, Italy, Germany and Japan (G7), and China and India. Notice that China, Japan, Germany, India and Italy are shown by truncated lines ending in varying years. This is because we predicted that the modern growth regime would end at the point where the line ends for these countries. The United States, the United Kingdom, France and Canada would keep their momentum as modern growth regime countries.

From Figure 8, we can make some interesting observations. First, although predicted GDP will have a confidence band, we predict the United States will stay on top of the world throughout the 21st century. Second, we predict that China will catch up with the United States around 2020, but will not supersede it before China's population starts to decline in 2028. Third, we predict that India's GDP will keep growing until 2068, but will stay below those of the United States and China. Fourth, we predict that France will grow faster than the United Kingdom and Canada.

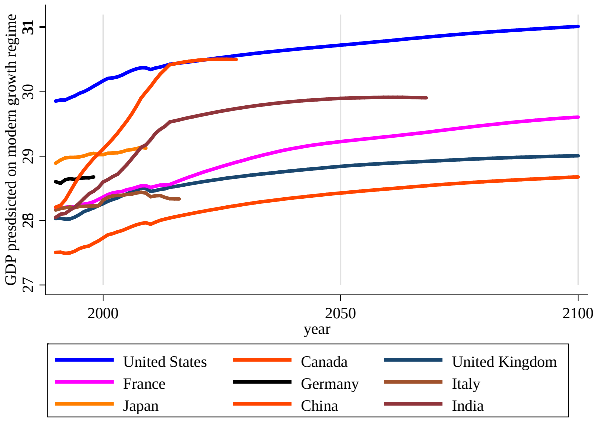

Figure 8: G7 Countries, China and India

On the other hand, the futures of China, India, Japan, Germany and Italy are difficult to predict. These countries will see their population peak before or within this century (China in 2028, India 2068, Japan 2009, Germany 1998 and Italy 2016), and will fall into the postmodern regime afterwards. Naturally, each economy will undergo a transformation to adapt to the phase in which the population declines. We cannot say with any confidence how these economies can achieve growth in the postmodern regime. We will come back to this point when we discuss the case of Japan in the next section.

Figure 9 illustrates how the nine countries will fare in terms of per capita GDP. Along the vertical axis, we are now measuring natural log of per capita GDP in international dollars at 2011 prices. As in Figure 8, truncated lines indicate that those countries will undergo a regime change somewhere in the early 21st century. Based on the results shown in Figure 9, we can classify the G7 countries, China and India into three groups. The first group consists of the United States, Canada, France and the United Kingdom. These countries will steadily improve their per capita GDP following modern growth paths. Most prominently, France will supersede the United States around 2030 in terms of per capita GDP.

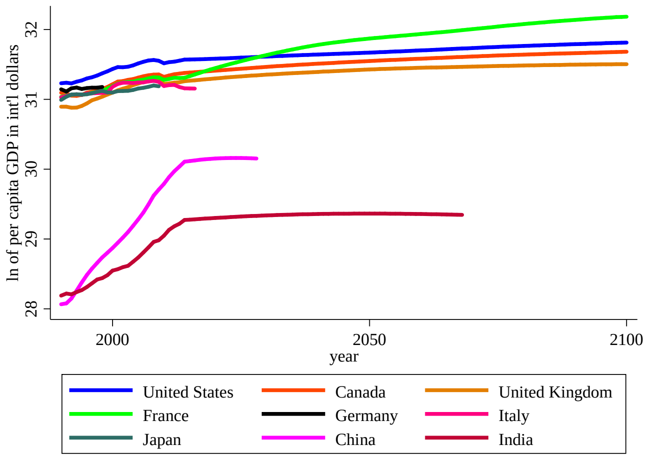

Figure 9: Per capita GDP of the G7, China and India

Germany, Japan and Italy form the second group. Their per capita GDPs are more or less similar to the first group of the most advanced counties at the start of the 21st century. However, how this second group will perform in terms of per capita GDP will depend on how they enter into the postmodern regime. The third group, which includes China and India, will not be able to achieve the level of income that is currently attained in advanced economies. This observation raises two important questions for these countries: will they be able to escape from the middle-income trap and achieve sustained growth, and will they be able to construct a system of welfare institutions before they face population decline?

Selected Asian Countries

South East Asia is one of the fast growing regions today. In fact, all countries in the region have escaped from low-income status and entered into the middle-income country group.[8] However, some countries in the region, led by Thailand, Indonesia, Singapore, Hong Kong, Cambodia and Laos, will fall into the postmodern regime. Until that happens, the countries depicted in Figure 10 will keep growing in GDP.

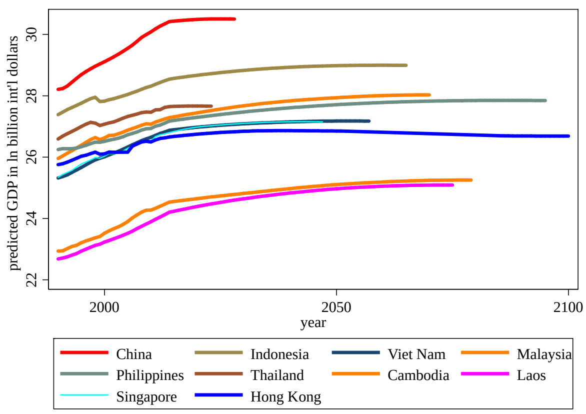

Figure 10: GDP of Asian Countries

In terms of per capita GDP, Asian countries will keep their diversity. Singapore and Hong Kong will stay on top, and Malaysia will follow. Thailand, China, Indonesia, the Philippines, Laos and Viet Nam will increase their per capita income as a second group. For Cambodia and Myanmar (not shown in Figure 10), it will take considerable time before their living standards catch up with those of the other Asian countries.

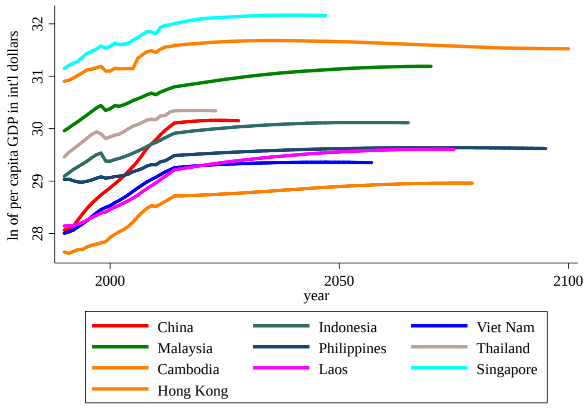

Figure 11: Per Capita GDP of Asian Countries

Selected African Countries

In Africa, South Africa is the largest economy. However, our prediction shows that South Africa's GDP will more or less stabilize before entering into the postmodern phase, and Republic of Tanzania and Equatorial Guinea will catch up with South Africa toward the latter half of this century, as Figure 12 illustrates.

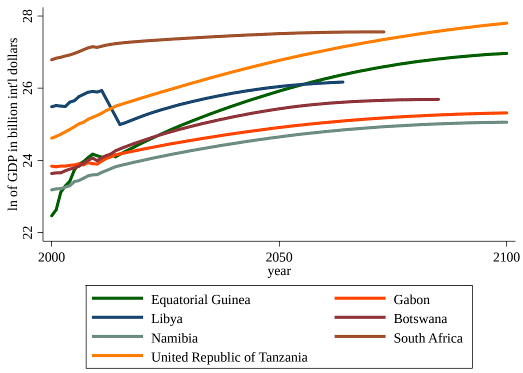

Figure 12: Selected African Countries

In terms of per capita GDP, there is expected to be a big change in country rankings. Equatorial Guinea will be the richest among seven countries, as illustrated in Figure 13. Botswana and Gabon will lift their per capita income steadily; Libya will be among the four countries that supersede South Africa if the state of civil war subsides. Tanzania will threaten the supremacy of South Africa in GDP, but will stay far below South Africa in per capita GDP.

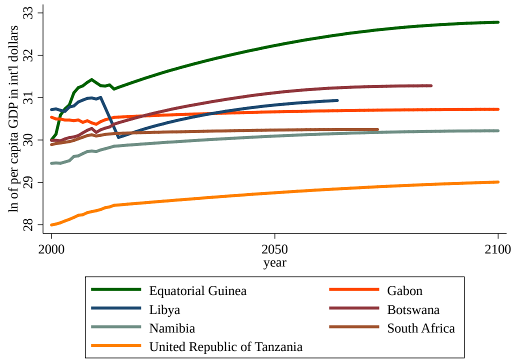

Figure 13: Per Capita GDP of Selected African Countries

The Richest and Poorest Countries Today

There will be a change in the order of the richest countries in the world in the near future. We chose to forecast the future growth of eleven countries that were richest in terms of per capita GDP in the World Bank ranking in 2014. The most notable change is that the rankings of oil-rich countries like Qatar, the United Arab Emirates and Kuwait will decrease. After 2060 they will not be the richest countries in the world any more. As Figure 14 illustrates, it will be Switzerland and Norway that come to the top. They will also be the fastest growing economies throughout the 21st century.

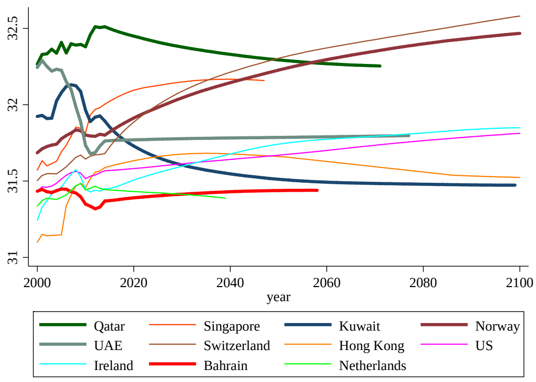

Figure 14: Today's Richest Economies

Likewise, the poorest countries of today will diverge in economic development. Liberia will escape from its poorest country status, but the standard of living in Niger, Madagascar, Malawi and Democratic Republic of Congo will decrease still further. In all these countries in Africa, population will keep increasing.

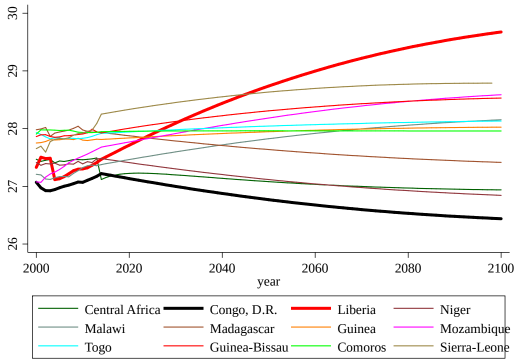

Figure 15: Today's Poorest Economies

Postmodern Regime

Germany and Japan

Some economies, after reaching a certain level of development, started losing their population in the late 20th and the early 21st centuries due to many socio-economic factors, including a higher value of time, the proliferation of higher education, changes in people's preferences and changes in social norms related to family and marriage. Two countries attract our attention in this respect: Germany and Japan.

Germany had a growing population and a gradually increasing per capita GDP until 1998. After 1998, as Figure 16 shows, Germany's population started to decrease. However, Germany's per capita GDP kept rising until 2013 with a brief decline in 2009, which was the year of the worldwide Great Recession. It may be hypothesized that Germany entered the postmodern growth regime after 1998.

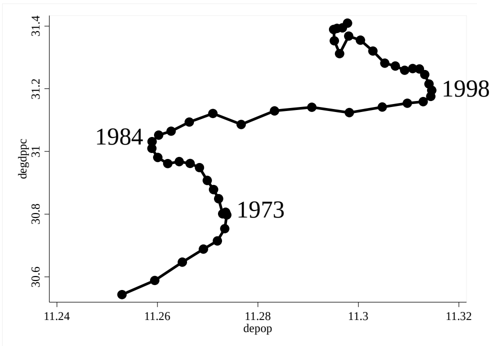

Figure 16: Germany, 1967-2014; $\beta = 4.59$ over 1850-2013

Japan offers yet another example of an emerging postmodern growth regime. It followed the modern growth regime until 2009, when a switch to the postmodern growth regime seems to have taken place. Again, the drop appearing in the north-east corner of the graph corresponds to the Great Recession of 2009, the downturn that followed a period of financial turmoil symbolized by the Lehman Brothers' demise.

Will postmodern growth be sustainable? Will there be a reversal of the trend in which a population decline is followed by a fall in per capita GDP in years to come?

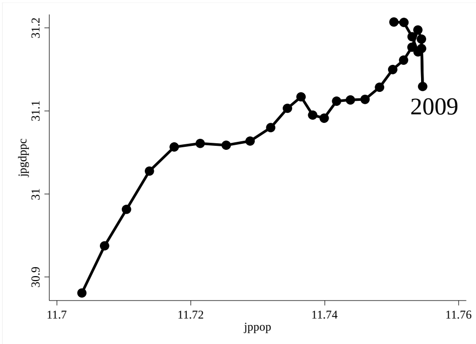

Figure 17: Japan, 1988-2014; $\beta = 3.82$ over 1870-2014

Two-Thirds of Economies Will Follow

From here we will focus on Japan's case. Before going into detail, we should confirm that the postmodern regime is not an anomaly confined to Germany and Japan. In fact, almost all economies in the world experienced population growth throughout the 20th century, with the exception of Russia and Germany. However in the 21st century, 157 economies, or 67.4% of countries and regions listed in the UN Population Prospects, will reach a population peak and experience a subsequent continuous population decline toward 2100. If population increase was prevalent throughout the world in the 20th century, population decline will be a new normalcy in the 21st century.[9]

Table 2 lists selected economies that show a higher rate of population decline. Russia, Ukraine, Romania and Poland are projected to face the largest rate of decline as a country. Asian economies such as Thailand, Japan, Korea and Nepal will face a rate of decline in the order of -0.05% per annum. Latin American economies like Mexico, Brazil and Chile are no exception. Their population is forecasted to decline at -0.3% from the middle of the century.

Table 2: Rate of Population Decline

Economy	*Peak (Year)*	*Rate of Decline (%)*
Romania	19,511 (2015)	-0.70
Thailand	68,673 (2023)	-0.65
Poland	38,812 (2015)	-0.64
Ukraine	44,824 (2015)	-0.62
Iran	92,261 (2048)	-0.54
Nepal	36,458 (2058)	-0.49
Korea	57,715 (2035)	-0.48
Japan*	127,341 (2008)	-0.46

Russia	148,436 (1993)	-0.22
Germany	82,010 (1998)	-0.02

Note: Rate of decline is calculated for the period from the peak to 2100 for each economy.

A Closer Look at Japan

So far we have used UN data and Maddison data for population, and World Economic Indicators and Maddison data for real GDP. The main reason we chose these GDP figures was because we wanted to construct real GDP series that are internationally comparable. We also made this choice to avoid the 'double conversion' problem posed by exchange rate conversion and constant prices conversion.

However, because we used that very method, our GDP data contained purchasing power parity conversion, which is unnecessary for individual countries. Thus, we will use another set of data for our next investigation: historically estimated and contemporarily compiled government statistics on Japan's real GDP, expressed in terms of local currency. Furthermore, we will use another source of population data independently estimated by a Japanese government-affiliated research institute.

IPSS Data on Japan's Population

In 'UN Population Prospects: 2015 Revision', Japan's population in 2100 is estimated at 83.175 million, down from the figure of 127.341 million estimated in the 2009 edition. Japan's National Institute for Population and Social Security Research (IPSS, 2014) estimated that the Japanese population would be 49.591 million in 2100, with a peak of 128.057 million in 2010. Numbers differ between the two forecasts due to a difference in assumptions regarding fertility rate and mortality rate. But declines like 35% or 61% over a 90-year period are unprecedented in world history. We will call this change in Japan's population the 'great demographic transformation'[10]. Regarding the historical statistics on Japan's population, we will use in this section the official statistics of the government and the population forecasts made by IPSS.

The government statistics were first recorded by the Bank of Japan (1960). They start from 1872 and are connected to the current data compiled by the Ministry of Internal Affairs and Communications. Population forecasts are provided by the IPSS based on assumptions regarding prospective birthrates and mortality rates. We will use the historical data up to 2013 and IPSS's forecasts based on a medium birthrate and medium mortality rate for 2014 to 2100[11]. We will call the combined long-term population series *jppop4*.

A caveat is in order. The two series, namely AM+UN (which we used in the sections above) and *jppop4*, coincide for most of the historical period 1872 to 2013, but they diverge considerably in terms of future forecasts. *jppop4* gives a more pessimistic forecast than AM+UN, and the gap widens increasingly toward 2100.

The GDP Data

In recent years, the Cabinet Office has compiled official statistics for real GDP. Its postwar series starts from 1955 and comes in three sub-series with different base years. We first constructed a chained series using the sub-series with 2005 prices.

Historical data on real GDP are fragmented. Hitotsubashi University dedicated decades to estimating historical series on basic economic data including real GDP going back to 1878. The Ohkawa estimate is the earliest and the most definitive estimate for the period 1878 to 1942 (Ohkawa, K, 1957). The Economic Planning Agency published GNP series together with the GNP deflator in billion yen units from 1930 to 1964. We chained these historical series and the postwar data to construct *jpgdp4* in billion yen at 2005 prices, creating a set of data that covers the period 1878 to 2013[12].

A Model with Time Trend

So far, we have been using equation (1) with the assumption that the X-efficiency is specific to the country concerned and is time invariant. However, in this section we assume that the X-efficiency is composed of a constant and a time trend. The equation to be estimated becomes

$$lny_t = constant + \alpha t + \beta lnP_t + \gamma lny_{t-1} + \varepsilon_t \,. \quad (2)$$

Using this model, we can clarify the characteristics of Japan's growth pattern in the prewar period (1878-1944), the postwar period (1945-2015) and the modern growth period (1878-2009). The next table summarizes our results.

Table 3: Estimates of Prewar, Postwar and Modern Growth Data

	(1) Prewar	(2) Postwar	(3) Modern growth
	lnjpgdp4	*lnjpgdp4*	*lnjpgdp4*
	1878-1944	1945-2015	1878-2010
year	0.036**	0.007	0.006
	(3.12)	(1.03)	(0.65)
lnjppop4	0.578	4.643***	3.541***
	(0.56)	(21.79)	(6.18)
_cons	-66.032***	-55.173***	-41.403**
	(-6.00)	(-4.48)	(-2.68)
ARMA			
L.ar	0.522***	0.959***	0.952***
	(4.06)	(25.78)	(29.69)
sigma			
_cons	0.084***	0.042***	0.078***
	(13.70)	(17.09)	(20.64)
N	67	71	133
BIC	-120.47	-224.82	-273.24

Notes: 1. *z* statistics in parentheses
2. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Comparing the results for prewar and postwar periods, we notice that the growth rate of X-efficiency was much greater in the prewar period than in the postwar period, and in contrast, population elasticity was much higher in the postwar growth than in the prewar period. Simply put, the prewar modernization and growth of the Japanese economy largely originated from fast growth in X-efficiency. On the other hand, Japan's postwar growth, including the legendary high growth epoch of 1950-1973, was enabled by the nation's high population elasticity. Throughout the 133 years Japan spent in the modern growth regime, which included wars, social transformations, political turmoil and technological progress, the annual growth rate of X-efficiency was 0.6% and population elasticity was 3.5.

GDP Prediction Based on Past Trends

A great concern in academia as well as in policy circles is how the Japanese economy will fare when population declines chronically. In policy discussions, many economists and institutions offer long-term forecasts of GDP. The OECD (2014) provides the most comprehensive long-term forecasts for member countries, including Japan. One of their concerns in relation to long-term forecasts of macroeconomic performance was population aging rather than the level of population itself.

They pay attention to the possibility that the working age population will decrease by 7% in the OECD from 2010 to 2060, whereas the total population of the OECD will increase by 17%[3]. We argue that total population matters more when it comes to long-term projections, especially for a country like Japan which is already witnessing a declining population.

In order to see what the future will entail for a Japan with a declining population, we predicted GDP based on long-term estimates of the two parameters α and β listed in the column (3) in Table 3. This is a prediction based on the assumption that the structure of the economy, which has remained the same for the past 133 years, will be unchanged for another 90 years.

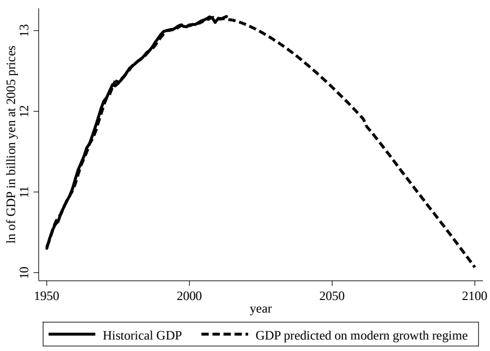

Figure 18: Japan's Historical GDP and its Predicted Path

Our prediction shows a clear downward trend in Japan's future GDP. The average annual rate of decline comes to almost 3% from 2010 to 2100, or a drop from 512 trillion yen in 2010 to 257 trillion yen in 2100. However, this prediction ignores the fact that the Japanese economy has been in the postmodern era since 2010. A once-in-130-year demographic transformation is taking place. Whatever evolution Japan witnessed in the long period in which population trended upwards will not be repeated in reverse in a new phase in which secular population declines. What we need is not predictions based on past trends but simulations of what the future might entail. We need to ask ourselves whether the simulated future path is feasible or realizable.

Some Simulations

To clarify this point, we ran some simulations. We considered alternative targets for GDP prospects. First, we assumed that GDP would grow at the rate *n%* after 2015. We tried 0% growth (lnjpgdp40) and 1% growth (lnjpgdp41) as examples. Second, we examined what is needed to sustain 0% growth in per capita GDP (lnjpgdp400) and 1% growth in per capita GDP after 2015 (lnjpgdp401). The time paths corresponding to the four different scenarios are represented in Figure 19. All scenarios are expressed in terms of ln of GDP in billion yen at 2005 prices.

As is clear from Figure 19, the 1% GDP growth path is the most ambitious target compared to our predictions based on the past 133 years of modern growth history[13]. The 1% per capita growth trajectory behaves similarly to the 0% GDP growth path, which is natural since the rate of decline in population is approximately 1% per year.

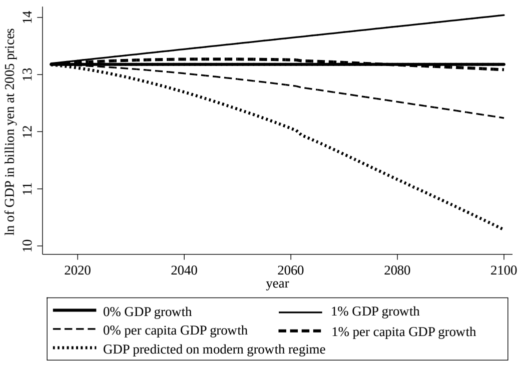

Figure 19: Predicted and Simulated Growth of Japan's GDP

We next examined what combination of α and β would be able to bring about these paths. To find these, we have only to run the same ARIMA regression on the simulated GDP series. Table 4 summarizes the results of these regressions.

Table 4: Estimation Results for Simulated Paths

	(1)	(2)	(3)	(4)	(5)	(6)
	lnjpgdp4	lnjpgdp40	lnjpgdp41	lnjpgdp400	lnjpgdp401	lnjpgdp402
	1878-2010	2010-2100	2010-2100	2010-2100	2010-2100	2010-2100
year	0.006	0.002*	0.010***	0.002	0.010***	0.016***
	(0.65)	(2.08)	(94.13)	(1.79)	(111.00)	(7.53)
lnjppop4	3.541***	0.150	0.010	1.191***	0.980***	0.680***

	(6.18)	(1.73)	(0.84)	(11.22)	(103.33)	(3.79)
_cons	-41.403**	7.684**	-7.219***	-5.564	-17.880***	-26.670***
	(-2.68)	(2.80)	(-20.57)	(-1.45)	(-62.70)	(-4.46)
ARMA						
L.ar	0.952***	0.939***	0.162*	0.957***	0.255***	0.972***
	(29.69)	(31.02)	(2.41)	(32.88)	(4.46)	(21.88)
sigma						
_cons	0.078***	0.002***	0.001***	0.002***	0.002***	0.003***
	(20.64)	(22.65)	(24.31)	(18.99)	(25.49)	(7.75)
N	133	91	91	91	91	91
BIC	-273.24	-828.10	-914.55	-822.37	-889.65	-772.50

Notes: 1. *z* statistics in parentheses
2. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We can infer by comparison the plausibility of attaining each scenario. The 1% GDP growth scenario looks to be close to impossible. For such a scenario to materialize, the annual rate of X-efficiency increase would have to be more than triple the historical trend, and population elasticity would have to be halved from the historical trend or cut by 64% from the postwar trend.

Would it then be feasible to sustain GDP at the 2015 level? Again, to achieve this, the growth rate of X-efficiency would have to be tripled, and population elasticity would need to be lowered considerably. Such a drastic change is historically unprecedented and would seemingly be extremely hard to come by.

Then, what about keeping per capita GDP on a 0% growth path? Among the four scenarios, this looks to be the most realistic one. Indeed α would have to be triple the postwar historical trend, and $\beta = 1.19$ would still be considerably lower than the 133 year trend.

In any case, a decline, not growth, looks inevitable for a Japanese economy with a declining population. The most realistic choices seem to be either to keep the pace of overall change at the postwar historical level and accept a 0.47% annual decline in per capita GDP (and a 3% annual decline in GDP), or accelerate social change to steer to a 2% increase in per capita GDP.

We can summarize our findings as follows:

1) Japan's GDP elasticity with respect to population was so high in the postwar period that most of the nation's growth, including the historic high-growth epoch, can in fact be accounted for by population increase alone. In this sense the 'population bonus hypothesis' applies to the Japanese experience.
2) Such being the case, when Japanese population started to decline after 2010, a negative effect set in on Japan's GDP as the postwar regime remained intact. Population became an onus on the economy. This will become conspicuous after 2018.
3) However, from the Meiji era to the Heisei era, the growth of the Japanese economy was dependent less on elasticity with respect to total population and more on growth in X-efficiency. We may call the structure of the economy pertaining to these 133 years of history (encompassing political transformations, industrial revolutions, wars, technological progress, and changes in the composition of output) the *basso continuo* of

the Japanese economy.

4) Playing this *basso continuo* into the future would only serve to set Japan's GDP on a downward path, with the nation's population declining. Even if Japan does sustain 1% growth in per capita GDP, considerable efforts will have to be expended transforming social infrastructure and enhancing aggregate supply and demand to maintain the nation's GDP growth.

Concluding Remarks

In this paper, we introduced a key concept of GDP elasticity with respect to population, or 'population elasticity' for short. In order to estimate empirically the degree of elasticity for individual economies, we proposed using a simple ARIMA model to avoid the spurious correlation that would result from an OLS model and to incorporate the sequential dynamism built in to the population and GDP nexus. Using this model, we estimated population elasticity for 158 countries over a historical period from the earliest point recorded in the AM dataset until 2014.

Based on our estimates of elasticity, we classified economies as being in one of three developmental stages: the Malthusian regime, the modern growth regime or the postmodern regime. One of the important findings we made in the classification process was that some high-income, oil-rich economies were in the Malthusian regime until 2014.

Next, we used the aforementioned ARIMA model to make estimates of future population elasticity up until 2100, which yielded interesting non-linear predictions for individual economies. We showed that the United States, Canada, the United Kingdom and France would continue on a modern growth trajectory to 2100. We also showed predicted GDP and per capita GDP for selected countries, with our predictions extending to the year when each country enters the postmodern regime. In Germany, Italy and Japan, the postmodern regime has already started. This led to our next investigation.

In this investigation, we focused on the case of Japan as a forerunner. We used domestic data for GDP and population to avoid complications arising from currency conversion. We also employed a hypothesis that X-efficiency growth consists of a time trend and an intrinsic constant. Even with this change, our post-estimation prediction suggested that a decline in GDP was imminent for Japan.

Finally, we turned to an analysis of certain scenarios. We suggested various scenarios of growth in Japan's postmodern regime, and investigated what combination of parameters would bring those scenarios into reality. We found that the scenario of 0% GDP growth and 1% growth in per capita GDP looked most plausible.

Although there are only a few years of data from countries in the postmodern regime that we can observe, statistical inference based on old regimes would be grossly misleading. A method similar to the one we used in our scenario analysis must be developed for each country before two-thirds of countries fall into the postmodern regime.

References

Auty, R.M. (1993), *Development in Mineral Economies: The Resource Curse Thesis*, London, Routledge.

Barro, R.J. and X.I. Sala-i-Martin (2004), *Economic Growth,* 2nd ed., MIT Press.

Bloom, D. E., D. Canning, and S. Sevilla (2001), "Economic Growth and the Demographic Transition," NBER Working Paper No.8685, December.

___________________________________ (2003), *The Demographic Dividend: A New Perspective on the Economic Consequences of Population Change,* RAND Corporation.

Braconier, H., G. Nicoletti and B. Westmore (2014), "Policy Challenges for the Next 50 Years," OECD Economic Policy Paper, July, No.9.

Cabinet Office of the Government of Japan (2015), "*Chūchōki no Keizai Zaisei ni kansuru Shisan* (A Tentative Estimate for the Economy and Public Finance in a Medium- to Long-Term)", February 12.

Center for International Comparisons at the University of Pennsylvania (2015), *Penn World Table* 8.1.

Economist Intelligence Unit (2015), *Long-term Macroeconomic Forecasts: Key Trends to 2050*.

Elgin, C. and S. Tumen (2012), "Can sustained economic growth and declining population coexist?' *Economic Modelling,* 29(5), September, 1899-1908.

Fernando Gabriel Im and David Rosenblatt (2013), "Middle-Income Traps," World Bank, Policy Research Working Paper, 6594.

Fogel, R. W. (1994), "Economic Growth, Population Theory, and Physiology: The Bearing of Long-term Processes on the Making of Economic Policy," *American Economic Review*, 84(3), 369-395, June.

Frankel, J. A. (2010), "The Natural Resource Curse: A Survey," Working Paper 15836, National Bureau of Economics, downloaded January 21, 2016 from http://www.nber.org/paper/w15836.

Galor O. and D. N. Weil (2000), "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90(4): 806-828.

Hayashi, T. (2010), "The High-Growth Epoch," in *Political Economy of Japan: Growth, Challenges and Prospects for a Well-Being Nation*, Hōsōdaigaku Kyōiku Shinkōkai, 29-50.

Howitt, P. (2007), "Innovation, Competition and Growth: A Schumpeterian Perspective on Canada's Economy," C. D. Howe Institute Commentary, No.246, April.

Huan, T-H and Z. Xie (2013), "Population and economic growth: a simultaneous equation perspective," *Applied Economics,* 45, 3820-3826.

IMF (2012), World Economic Outlook Database, June 24. (http://www.imf.org/external/pubs/ft/weo/2011/02/weodata/index.aspx)

Lee, R. (2003), "The Demographic Transition: Three Centuries of Fundamental Change," *Journal of Economic Perspectives,* Volume 17, Number 4, Fall, 167-190.

Leibenstein, H. (1996), "Allocative Efficiency vs. X-Efficiency," *American Economic Review,* 56(3): 392-415.

Maddison, A. (2008), *Contours of the World Economy 1-2030 AD: Essays in Macroeconomic History*, Oxford University Press.

Malthus, Thomas Robert (1798), An *Essay on the Principle of Population*,

Mitsubishi Research Institute (2013), "*Naigai Keizai no Chū-Chōki Tembo* (A Medium to Long-Term Perspective for Japan and the World, 2013-2030", April.

National Institute for Social Security and Population Research (IPSS) (2014), "Japan's Population Prospects."

Japan Economic Research Center (2014), "Chō-Chōki Keizai Yosoku 2013-2050 (A Very Long-Term Economic Forecast: Global Long-Term Forecasts and Three Future Scenarios for Japan), February.

OECD (2012), *Looking to 2060: Long-term global growth prospects*, November

OECD (2014), *Economic Outlook No.95- May 2014- Long-term baseline projections*, (Date Accessed: 12/05/2015). Available at https://stats.oecd.org/Index.aspx?DataSetCode=EO95_LTB

Prettner, K. (2013), "Population aging and economic growth," *Journal of Population Economics*, April, 26(2), 811-834.

PricewaterhouseCoopers (2015), *The World in 2050: Will the shift in global economic power continue?*

United Nations, Department of Economic and Social Affairs (2016), *World Population Prospects, the 2015 Revision*. (http://esa.un.org/wpp/Excel-Data/population.htm)

University of Groningen (2015), *Maddison Project Database,* (Date Accessed : 12/03/2015). Available at http://www.ggdc.net/maddison/maddison-project/home.htm

The World Bank, *World Development Indicators* (Date Accessed: 12/03/2015)

Appendix: AR Regression Results

Eastern Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Burundi	bi	1.16***	0.96***	-188.65	65	1950-2014
Comoros	km	0.98***	0.94***	-153.83	65	1950-2014
Djibouti	dj	0.69***	0.97***	-167.83	65	1950-2014
Ethiopia	et	1.43***	0.98***	-208.34	65	1950-2014
Kenya	ke	1.30***	0.86***	-221.01	65	1950-2014
Madagascar	mg	0.66***	0.93***	-223.70	65	1950-2014
Malawi	mw	1.47***	0.92***	-196.91	65	1950-2014
Mauritius	mu	2.44**	0.99***	-181.97	65	1950-2014
Mozambique	mz	1.64***	0.97***	-169.68	65	1950-2014
Rwanda	rw	1.50***	0.79***	-101.07	65	1950-2014
Seychelles	sc	2.56***	0.86***	-195.26	65	1950-2014
Somalia*	so	0.75***	0.72***	-129.43	59	1950-2008
Uganda	ug	1.29***	0.98***	-205.85	65	1950-2014
United Republic of Tanzania	tz	1.34***	0.97***	-255.01	65	1950-2014
Zambia	zm	1.21**	0.96***	-183.01	65	1950-2014
Zimbabwe	zw	1.22*	0.97***	-155.40	65	1950-2014
Middle Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Angola*	ao	0.88	0.95***	-64.85	59	1952-2008
Cameroon	cm	1.27***	0.96***	-222.35	65	1950-2014
Central African Republic	cf	0.60***	0.88***	-155.07	65	1950-2014
Chad	td	1.26***	0.94***	-132.96	65	1950-2014
Democratic Republic of the Congo	cd	0.51*	0.97***	-165.19	65	1950-2014
Equatorial Guinea	gq	2.82***	0.99***	-33.48	65	1950-2014
Gabon	ga	1.16*	0.96***	-111.61	65	1950-2014
Sao Tome and Principe	st	1.66***	0.96***	-146.93	65	1950-2014
Northern Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Algeria	dz	1.69***	0.88***	-164.69	65	1950-2014
Egypt	eg	2.18***	0.64***	-118.13	65	1950-2014
Libya	ly	1.52	0.97***	-13.20	65	1950-2014
Morocco	ma	1.67	0.98***	-220.36	65	1950-2014
Sudan	sd	1.14***	0.93***	-175.29	65	1950-2014
Tunisia	tn	2.49***	0.90***	-212.59	65	1950-2014
Southern Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Botswana	bw	2.74***	0.95***	-186.65	65	1950-2014
Lesotho	ls	2.69***	0.81***	-176.85	65	1950-2014
Namibia	na	1.49***	0.96***	-226.27	65	1950-2014
South Africa	za	1.46***	0.97***	-290.40	65	1950-2014
Swaziland	sz	1.87***	0.97***	-192.61	65	1950-2014
Western Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period

Benin	bj	1.35***	0.82***	-259.47	65	1950-2014
Burkina Faso	bf	1.70***	0.98***	-233.40	65	1950-2014
Cape Verde	cv	3.13***	0.97***	-171.88	65	1950-2013
Cape d'Ivoire	ci	1.06***	0.98***	-200.09	65	1950-2013
Gambia	gm	1.16***	0.94***	-157.01	64	1950-2013
Ghana	gh	0.33	0.97***	-190.73	64	1950-2013
Guinea	gn	1.22***	0.99***	-262.67	65	1950-2014
Guinea-Bissau	gw	1.46**	0.97***	-141.66	65	1950-2014
Liberia	lr	2.29***	0.99***	-63.28	65	1950-2014
Mali	ml	1.73***	0.89***	-194.04	65	1950-2014
Western Africa	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Mauritania	mr	1.21***	0.91***	-176.47	65	1950-2014
Niger	ne	0.74**	0.94***	-179.31	65	1950-2014
Nigeria	ng	1.67***	0.92***	-144.90	65	1950-2014
Senegal	sn	1.04***	0.87***	-238.82	65	1950-2014
Sierra Leone	sl	1.63***	0.96***	-178.72	65	1950-2014
Togo	tg	1.14***	0.97***	-180.90	65	1950-2014
Eastern Asia	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
China	cn	3.72**	0.99***	-150.38	65	1950-2014
China, Hong Kong SAR	hk	2.39***	0.99***	-189.31	65	1950-2014
Dem. People's Republic of Korea*	kp	1.85**	0.98***	-106.14	59	1950-2008
Japan	jp	3.82***	0.98***	-335.15	144	1870-2014
Mongolia	mn	2.34	0.98***	-219.33	65	1950-2014
Republic of Korea	kr	0.96	0.998***	-153.30	104	1911-2014
Central Asia	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Kazakhstan	kz	4.13	0.97***	-51.21	25	1990-2014
Kyrgyzstan	kg	1.28	0.94***	-40.00	25	1990-2014
Tajikistan	tj	0.31	0.96***	-19.90	25	1950-1974
Turkmenistan	tm	1.23	0.97***	-29.33	25	1950-1974
Uzbekistan	uz	2.27	0.94***	-58.63	25	1990-2014
Southern Asia	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Afghanistan	af	1.23***	0.91***	-150.25	65	1950-2014
Bangladesh	bd	1.47	0.99***	-213.59	65	1950-2014
India	in	1.62***	0.996***	-415.57	131	1884-2014
Iran (Islamic Republic of)	ir	1.68***	0.96***	-144.06	65	1950-2014
Nepal	np	1.85***	0.97***	-268.34	65	1950-2014
Pakistan	pk	1.85***	0.83***	-297.59	65	1950-2014
Sri Lanka	lk	1.51***	0.996***	-466.01	145	1870-2014
South-Eastern Asia	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Brunei Darussalam	Br	0.80***	0.72**	-112.01	25	1990-2014
Cambodia	kh	2.16***	0.94***	-144.47	65	1950-2014

Indonesia	id	2.28***	0.97***	-208.19	66	1949-2014
Lao People's Democratic Republic	la	1.88**	0.99***	-273.67	65	1950-2014
Malaysia	my	2.34***	0.93***	-203.35	68	1947-2014
Myanmar*	mm	2.34	0.98***	-147.01	59	1950-2008
Philippines	ph	1.61***	0.98***	-184.40	69	1946-2014
Singapore	sg	1.27***	0.99***	-185.78	65	1950-2014
Thailand	th	2.82***	0.99***	-219.23	65	1950-2014
Viet Nam	vn	1.96*	0.99***2	-191.20	65	1950-2014
Western Asia	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Armenia	am	0.83	0.95***	-13.01	25	1950-2014
Azerbaijan	az	2.74	0.95***	-13.06	25	1990-2014
Bahrain	bh	1.25***	0.98***	-218.53	65	1950-2014
Georgia	ge	0.53	0.93***	-6.24	25	1990-2014
Iraq	iq	1.30***	0.91***	-20.48	65	1950-2014
Israel	il	2.18***	0.82***	-218.33	65	1950-2014
Jordan	jo	1.35***	0.90***	-144.02	65	1950-2014
Kuwait	kw	0.60***	0.88***	-53.86	65	1950-2014
Lebanon	lb	1.38***	0.85***	-128.94	65	1950-2014
Oman	om	1.71***	0.98***	-82.67	65	1950-2014
Qatar	qa	0.75**	0.97***	-106.04	65	1950-2014
Saudi Arabia	sa	1.53***	0.98***	-170.24	65	1950-2014
Syrian Arab Republic	sy	1.66***	0.74***	-120.79	59	1820-2009
Turkey	tr	2.33***	0.85***	-238.25	92	1922-2014
United Arab Emirates	ae	0.81***	0.97***	-142.67	65	1950-2014
Yemen	ye	1.43***	0.98***	-195.23	64	1950-2013
Eastern Europe	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Belarus	by	-10.30	0.94***	-54.84	25	1990-2014
Bulgaria	bg	2.77	1.00***	-174.09	65	1950-2014
Czech Republic	cz	5.43	0.96***	-26.64	24	1990-2013
Hungary	hu	2.77	1.00***	-198.38	69	1946-2014
Poland	pl	2.92**	0.99***	-216.45	65	1950-2014
Republic of Moldova	md	1.40	0.94***	-20.71	25	1950-2014
Romania	ro	2.56*	1.00***	-182.00	65	1950-2014
Russian Federation	ru	-15.25	0.96***	-56.47	25	1990-2014
Slovakia	sk	1.85	0.98***	-53.92	25	1990-2014
Ukraine	ua	0.32	0.94***	-32.11	25	1990-2014
Northern Europe	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Denmark	dk	2.63*	0.99***	-723.89	195	1820-2014
Estonia	ee	-0.54	0.95***	-41.54	25	1990-2014
Finland	fi	2.00***	0.999***	-467.42	155	1860-2014
Ireland	ie	2.50***	0.999***	-333.06	94	1921-2014
Latvia	lv	-0.87	0.90***	-26.85	25	1990-2014

Lithuania	lt	-2.14	0.88***	-38.07	25	1990-2014
Norway	no	2.89***	0.996***	-664.86	185	1830-2014
Sweden	se	3.00***	0.997***	-717.18	195	1820-2014
United Kingdom	gb	2.21***	0.999***	-747.43	185	1830-2014
Southern Europe	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Albania	al	1.80	0.99***	-148.18	65	1950-2014
Bosnia and Herzegovina	ba	0.24	0.95**	1.60	25	1990-2014
Croatia	hr	-1.42	0.88***	-49.68	24	1991-2014
Greece	gr	3.97***	0.95***	-161.61	102	1913-2014
Italy	it	4.07***	0.99***	-444.99	154	1861-2014
Portugal	pt	2.61***	1.00***	-497.57	150	1865-2014
Serbia	rs	-7.87	0.93***	-14.01	19	1990-2008
Slovenia	si	1.63**	0.96***	-178.72	65	1950-2014
Spain	es	3.30***	0.98***	-533.53	165	1850-2014
TFYR Macedonia	mk	7.61***	0.93***	-95.45	25	1990-2014
Western Europe	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Austria	at	3.97*	0.99***	-268.38	145	1870-2014
Belgium	be	3.23***	0.99***	-601.43	169	1846-2014
France	fr	5.45***	0.95***	-570.21	195	1820-2014
Germany	de	4.59***	0.99***	-399.19	164	1850-2014
Netherlands	nl	2.23***	0.98***	-530.62	195	1820-2014
Switzerland	ch	3.38***	0.88***	-495.06	165	1850-2014
Caribbean	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Cuba	cu	1.72***	0.89***	-152.92	85	1929-2013
Dominican Republic	do	1.67***	0.88***	-204.90	65	1950-2014
Grenada	gd	1.33	4.50	-190.73	64	1950-2013
Haiti	ht	0.40***	0.98***	-384.82	70	1945-2014
Jamaica	jm	2.68***	5.67	-209.46	65	1950-2014
Puerto Rico	pr	4.13***	0.97***	-241.64	64	1950-2013
Trinidad and Tobago	tt	3.03***	0.97***4.92	-187.22	65	1950-2014
Central America	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Costa Rica	cr	1.76***	0.88***	-252.42	95	1920-2014
El Salvador	sv	0.88***	0.998***	-318.44	95	1920-2014
Guatemala	gt	1.50***	0.86***	-225.25	95	1920-2013
Honduras	hn	0.89***	0.998***	-343.54	95	1920-2014
Mexico	mx	1.77***	0.90***	-410.27	115	1900-2014
Nicaragua	ni	1.27*	0.53***	-40.56	30	1920-1949
Panama	pa	2.01***	0.96***	-222.73	70	1945-2014
South America	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Argentina*	ar	1.59***	0.90***	-313.74	109	1900-2008

Bolivia (Plurinational State of)	bo	1.50***	0.95***	-246.57	70	1945-2014
Brazil	br	1.78***	0.98***	-477.96	145	1870-2014
Chile	cl	1.95***	0.94***	-505.46	195	1820-2014
Colombia	co	1.84***	0.96***	-487.88	115	1900-2014
Ecuador	ec	1.76***	0.93***	-278.70	75	1939-2013
Paraguay	py	1.46***	0.96***	-226.52	76	1939-2014
Peru	pe	1.97***	0.98***	-361.81	119	1896-2014
Uruguay	uy	1.54***	0.97***	-323.67	145	1870-2014
Venezuela (Bolivarian Republic of)	ve	1.58***	0.99***	-238.74	115	1900-2014
Northern America	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Canada	ca	2.16***	0.93***	-434.28	145	1870-2014
United States of America	us	2.23***	0.96***	-422.39	145	1870-2014
Australia/New Zealand	Code	Elasticity (β)	L..1 (γ)	BIC	N	Period
Australia	au	1.71***	0.98***	-502.45	195	1820-2014
New Zealand	nz	1.55***	0.98***	-432.86	144	1870-2013

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

[1] In policy discourse, population decline is often taken to be synonymous to working-age population decline and a shortage of labor, which may be supplanted by such technology as artificial intelligence and robots. This argument focuses only on supply-side effects and fail to recognize the importance of the demand-side effects.

[2] Our database can be accessed at http://www.apir.or.jp/database

[3] If we ran a simple OLS regression with GDP as a dependent variable and population as an independent variable, we would obtain a very high coefficient of determination. However, the very small Durbin-Watson statistics would suggest that the observed correlation is just spurious. The AR model was conceived to avoid this statistical problem.

[4] We use the two-letter country code supplied by the International Standardization Organization.

[5] Other OPEC economies had elasticity greater than 1.

[6] The term ‘resource curse’ normally refers to the paradox that relatively resource-rich economies tend to grow more slowly than resource-poor economies. See Auty (1993) and Frankel (2010).

[7] GDP data for the 12 countries that belonged to the former Soviet Union is available only from 1990 in the World Bank database. In 1991, the Soviet Union was formally dissolved into these 12 countries, one of which was the Russian Federation. The 12 countries show a common characteristic of decreasing population and increasing GDP. However, the small number of samples hinders any meaningful statistical analysis.

[8] World Bank List of Economies (July 2016).

[9] However, the world total population keeps rising toward 2100.

[10] In the literature, this term usually means a modal shift in population growth from stagnation to acceleration, or the reverse of this. See, for example, Bloom, Canningand Sevilla (2001).

[11] Actually, the IPSS’s population forecast extends to 2110.

[12] No data is available for 1945. We bridged 1944 data and 1946 data for the 1945 estimate.

[13] The Japanese government simulates that 1% growth in GDP is necessary for their fiscal rebalancing target in 2020.