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Hisakazu Kato

An Empirical Analysis of Population and Technological Progress

Population Association of Japan
日本人口学会

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SpringerBriefs in Population Studies

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The world population is expected to expand by 39.4 % to 9.6 billion in 2060 (UN World Population Prospects, revised 2010). Meanwhile, Japan is expected to see its population contract by nearly one-third to 86.7 million, and its proportion of the elderly (65 years of age and over) will account for no less than 39.9 % (National Institute of Population and Social Security Research in Japan, Population Projections for Japan 2012). Japan has entered the post-demographic transitional phase and will be the fastest shrinking country in the world, followed by former Eastern bloc nations, leading other Asian countries that are experiencing drastic changes.

A declining population that is rapidly aging impacts a country's economic growth, labor market, pensions, taxation, health care, and housing. The social structure and geographical distribution in the country will drastically change, and short-term as well as long-term solutions for economic and social consequences of this trend will be required.

This series aims to draw attention to Japan's entering the post-demographic transition phase and to present cutting-edge research in Japanese population studies. It will include compact monographs under the editorial supervision of the Population Association of Japan (PAJ).

The PAJ was established in 1948 and organizes researchers with a wide range of interests in population studies of Japan. The major fields are (1) population structure and aging; (2) migration, urbanization, and distribution; (3) fertility; (4) mortality and morbidity; (5) nuptiality, family, and households; (6) labor force and unemployment; (7) population projection and population policy (including family planning); and (8) historical demography. Since 1978, the PAJ has been publishing the academic journal *Jinkogaku Kenkyu* (The Journal of Population Studies), in which most of the articles are written in Japanese.

Thus, the scope of this series spans the entire field of population issues in Japan, impacts on socioeconomic change, and implications for policy measures. It includes population aging, fertility and family formation, household structures, population health, mortality, human geography and regional population, and comparative studies with other countries.

This series will be of great interest to a wide range of researchers in other countries confronting a post-demographic transition stage, demographers, population geographers, sociologists, economists, political scientists, health researchers, and practitioners across a broad spectrum of social sciences.

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ISSN 2211-3215 ISSN 2211-3223 (electronic)
SpringerBriefs in Population Studies
ISSN 2198-2724 ISSN 2198-2732 (electronic)
Population Studies of Japan
ISBN 978-4-431-54958-1 ISBN 978-4-431-54959-8 (eBook)
DOI 10.1007/978-4-431-54959-8

Library of Congress Control Number: 2015960773

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer Japan KK

Preface

In Japan, we are facing a declining population and an aging society, an unprecedented experience for modern humans. The phenomenon of population decline and aging is found not only in our country but also in other developed nations. Under these circumstances, we face the challenge regarding whether we can maintain sustained economic growth. Historical experience indicates that during the period of rapid economic growth of the 1950s and 1960s, the large younger labor force and their savings spurred the Japanese economy, and the postwar economic miracle was realized consequent of these factors. This was referred to as a "demographic bonus," and the population factors positively contributed to economic growth. However, we are apprehensive of the sustainability of future economic growth by reason of the opposite situation—population decrease and societal aging is a "demographic onus."

For sustainability of economic growth, the pivotal factor is technological progress. Considering the past experience of Japanese economic growth, the most valid factor is technological progress, which is referred to as total factor productivity (TFP) in economic terms. As noted above, the declining population is the most severe problem in Japan, and there is a view that the declining population negatively affects TFP.

There have been numerous prolonged debates regarding the relationship between population and technological progress. From the old Malthusian model to the modern endogenous economic growth models, various theories have been developed in the context of growth theory and the pioneers of economic development research, such as the contribution of Kuznets and Simon to the field. We briefly summarize these discussions and analyze the relationship between population and technological progress empirically in recent years in this study.

This study is organized as follows: Chapter 1 reviews the literature regarding the relationship between population and technological progress and proposes the problem that an empirical study should examine. Chapter 2 discusses the importance of technological progress and economic growth, utilizing the growth accounting method and a simple empirical analysis. In Chap. 3, the study will verify the relationship between the two phenomena through an empirical analysis using Organisation for Economic Cooperation and Development (OECD) data from 1985 to 2012. Utilizing the empirical analysis, the study will confirm that the population scale and the growth rate positively affect multifactor productivity (MFP).

Acknowledgments

I would like to appreciate editors and reviewers of SpringerBriefs in Population Studies, Population Studies of Japan, in particular Prof. Toshihiko Hara (Sapporo City University) and Prof. Kohei Wada (Chuo University). I also would like to thank the members of Population Association of Japan because I learned a lot of knowledge from the activities in Population Association of Japan. In addition, I would like to thank Yutaka Hirachi for editing this book.

Contents

Chapter 1
Population Growth and Technological Progress—From a Historical View

Abstract This chapter focuses on technological progress and its relationship with population growth. Although we begin with the Malthusian theory, it is important to note that Malthus did not understand the importance of technological progress in society at the time. Kremer (Q J Econ 108:681–716, 1993) and other economists have stressed that it is possible to observe a close relationship between population growth and production technology, and Boserup (The conditions of agricultural progress. Aldine Publishing Company, Chicago, 1965) has pointed out that Malthus ignored the positive consequences of population growth in the long run. We define technological progress in an economic sense and emphasize that such progress has become an engine of economic growth for the modern economy. The important question to be posed is, "Does the size of population affect technological progress?" The answer is that a large population will generate many ideas that could bring about rapid technological progress. In addition, technological progress eases the constraints triggered by population growth by increasing the production of economic resources. Furthermore, we discuss the scale effect which means that a larger population would generate a rapid growth of population by mediating technological progress. Next, in developed countries, declining fertility rates have been widely observed and identified as causing population declines in the future. This phenomenon has raised an important point to discuss concerning the relationship between technological progress and population. Lastly, we conclude that the relationship between population size and technological progress encompasses complicated mutually exclusive effects. Specifically, technological progress leads to economic prosperity, which results in reduced fertility and population growth, while population size has a positive effect on technological progress. In the appendices of this chapter, we summarize the Kremer's theoretical model and provide a simple survey of endogenous growth theory including population dynamics.

H. Kato, *An Empirical Analysis of Population and Technological Progress*,
Population Studies of Japan, DOI 10.1007/978-4-431-54959-8_1

1.1 Malthusian Model and Modern Interpretation of Technological Progress

1.1.1 Malthusian Model

We should begin from the Malthusian theory as an introduction to deploy our story because without introducing his theory, it is difficult to explain the importance of technological progress. Thomas Robert Malthus was the first economist (or demographer) to establish a population theory. His famous book, "An Essay on the Principle of Population" in 1798, has continued to exert a great influence on economists and demographers of subsequent generations.

His well-known phrase in "An Essay on the Principle of Population" reads, "Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio" (Malthus 1798, p. 4), which suggests that an increase in population was suppressed in those days. Malthus observed that the human population had grown exponentially, but the subsistence, in other words food production, could not keep up with this population growth. From these facts, he said that population was capable of increasing the geometric progression such as 1, 2, 4, 8, 16, 32, whereas food production (or subsistence) increased only in the arithmetic progression such as 1, 2, 3, 4, 5, 6. Finally, he concluded that the growth of human population was constrained by economic resources.

Although we will not cover anymore detailed contents of Malthus' essay, we want to emphasize that he did not mention the mitigation of the constrained economic resources. Specifically, if food production could grow, not in the arithmetic progression, but rather in the geometric progression with the population increase, there would not be a condition to constrain population growth by food production or economic resources; it is technological progress that allows this condition to be mitigated. At that time, the functions and effects of technological progress in society were not understood by economists, including Malthus.

1.1.2 Modern Interpretation of Malthusian Model

We will now focus more on production structure and its relationship with population growth according to the Malthusian theory. There are two fundamental factors: First, land is in fixed supply and yields diminishing returns to labor. Second is the positive effect of the standard of living (or economic resources) on the population growth. Malthus said that when the population is small and economic resources per capita are large, the growth rate of population is high as a result of "passion" exhibited by both sexes. However, when the population is large and economic resources per capita are small, the growth rate of population is low because of "preventive check" (delayed marriage or reduction in birth rate) and "positive check" (poverty, famine, or war). Because of the lack of technological progress and fixed supply of land, Malthus stressed that population would fluctuate around a constant level. We know that technological progress will improve in production environments, allowing more rapid growth of population in modern society. In other words, when analyzing population growth, it is important to consider its relationships with economic resources and technological progress.

From these discussion points concerning the relationship between population growth and technological progress, Kremer (1993) stressed that it is possible to observe a close relationship between the growth rate of population and the scale of population. As will be discussed later in detail, Kremer (1993) proposed the assumption that population is limited by the available technology such that the growth rate of population is proportional to the growth rate of technology. If we can combine these assumptions, we can infer that the growth rate of population is proportional to the level of population.

In addition, we here discuss Boserup's (1965) criticism of Malthus. Boserup mentioned that Malthus ignored the positive consequences of population growth in the long run. She emphasized that population growth affects agricultural productivity rather than being affected by it, the latter of which is stressed by Malthus. She also said that the assumption of diminishing returns to labor did not hold in the long run and higher population might produce more efficient labor supply.

Although slightly digressing from the main discussion, the ghost of Malthus has also appeared in today's society. Neglecting consideration about the benefits from technological progress might lead to the claim that there is a limit to the growth of humankind. The typical example is "The Limits to Growth" by the Club of Rome. Certainly, it is not possible to ignore resource constraints such as the environment and energy supply, but they are not the fundamental factors that ultimately prevent the growth of humankind. As for food production problems, we should not forget that technological innovation has solved them, e.g., Green Evolution in an agricultural production. Recoverable reserves of crude oil and natural gas are increasing every year. While extreme optimism is not good, ignoring the advances in technological progress does not convey the correct understanding about growth of humankind.

1.1.3 Technological Progress in Economics Sense

First, we define technological progress in an economic sense. Production possibility frontier (PPF) represents a trade-off situation of an economy constrained by fixed economic resources. Figure 1.1 shows the possible combinations of amounts of two commodities that economy can produce using constrained economic resources. The PPF curve shows the maximum amount of production of one commodity for any given amount of production level of the other, given the current state of technological levels. That is, PPF is used to define production efficiency. In general, as more economic resources are allocated to produce one commodity, the cost of an

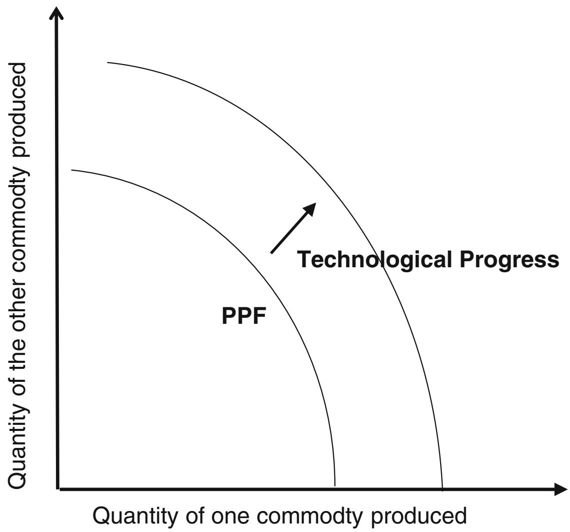

Fig. 1.1 PPF and technological progress

additional unit of that commodity increases gradually. Thus, we can draw a PPF curve as being convex from the origin.

As mentioned above, PPF is drawn assuming the current state of technology. In the long run, technological progress improves an economy's capacity, and the economy can produce more commodities at any given level of economic resources. This phenomenon is described as economic growth. In Fig. 1.1, technological progress is represented by the right shift of the PPF curve. Note that technological progress refers to not only narrow engineering meanings but also all phenomena that increase economic efficiency; consequently, the PPF curve is shifted to the right.

These elements of technological progress had been missing in Malthus' population theory. However, technological progress has become an engine of economic growth in modern economy. Let us organize the relationship between technological progress and population in the next section.

1.2 Population Growth and Level of Population

1.2.1 Scale Effect and Technological Progress

In this section, the first question to be posed is, "Does the size of population affect technological progress?" Kremer (1993) had scrutinized this question using two concepts.

The first key concept is that more population would generate more ideas, and more ideas would accelerate technological progress. Known as the scale effect, Kuznets (1960) and Simon (1977, 1981) first proposed it, while subsequent models of endogenous economic growth theory, such as Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992), improved upon this concept.

Kuzunets (1960) said that “Population growth, under the assumptions stated, would produce an absolutely larger number of geniuses, talented men, and generally gifted contributors to new knowledge–whose native ability would be permitted to mature to effective levels when they join the labor force” (Kuznets 1960, p. 328). In addition, Prettner (2013) said that “the population size of a certain country is crucial for long-run economic performance. Larger countries are able to grow faster because they have more scientists” (Prettner 2013, p. 812).

The second concept is that technological progress relieves the constraint imposed in a Malthusian world. That is, technological progress fosters an increase in economic resources or income, and it eases the constraint of population growth. In other words, population can grow when economic resources increase owing to technological progress.

Combining the first and second concepts, a large population would generate many ideas that could bring about rapid technological progress. In addition, this technological progress eases the constraint of population growth by increasing the production of economic resources, namely a larger population shifts the PPF curve to the right (Fig. 1.1). Briefly, population growth is in proportion to the population size, and the scale effect means that a larger population would generate a rapid growth of population by mediating technological progress.

In addition to the above discussion regarding the scale effect, Collins et al. (2013) has an interesting viewpoint on population growth. Collins et al. (2013) added an extra element, which they called innovative potential. Innovative potential produces many ideas that advance the technological frontier. Furthermore, they asserted that as a larger population generates more mutations that increase the innovative potential of the population, population growth is in proportion to both the size and the innovative potential of the population.

In the next section, a simple empirical analysis was performed to confirm the scale effect.

1.2.2 Population and Population Growth (1): World Population

We continue to discuss the relationship between population growth and population. Table 1.1 shows the historical data of population and population growth, which are listed in Kremer (1993).[1] Figure 1.2 plots the growth rate of population against its

[1]Kremer referred from McEvedy and Jones (1978) and so on.

Table 1.1 Population growth: world

Year	POP (millions)	Growth rate (%)
−1,000,000	0.125	0.00030
−300,000	1	0.00044
−25,000	3.34	0.00310
−10,000	4	0.00450
−5000	5	0.03360
−4000	7	0.06930
−3000	14	0.06570
−2000	27	0.06160
−1000	50	0.13860
−500	100	0.13520
−200	150	0.06230
1	170	0.05990
200	190	0.00000
400	190	0.02560
600	200	0.04770
800	220	0.09310
1000	265	0.18860
1100	320	0.11780
1200	360	0.00000
1300	360	−0.02817
1400	350	0.19420
1500	425	0.24870
1600	545	0.00000
1650	545	0.22530
1700	610	0.33160
1750	720	0.44630
1800	900	0.57540
1850	1200	0.39640
1875	1325	0.81640
1900	1625	0.83060
1920	1813	0.91640
1930	1987	1.07720
1940	2213	1.28320
1950	2516	1.82260
1960	3019	2.01510
1970	3693	1.86460
1980	4450	1.81010
1990	5333	–

Source Kremer (1993)

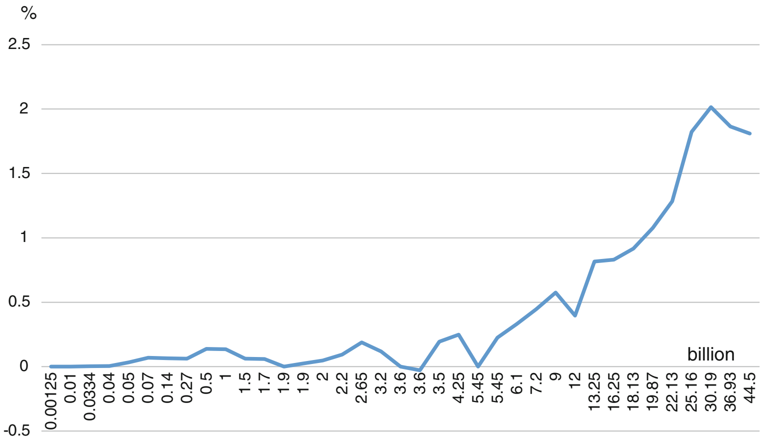

Fig. 1.2 Population and the growth rate in the world. *Source* Kremer (1993)

level from Table 1.1 and shows that the growth rate of population has increased over human history. Since these data were made from historical estimation, measurement error was inevitable. However, since we do not have another choice, we use it to confirm the relationship between them.

Using the data of Table 1.1, we regressed the growth rate of population against the level of population, and the result is Eq. (1.1). POP represents the level of population, and the number of observations is 37.

$$\begin{array}{c} \text{Growth Rate} = -0.0021 + 0.0524 \times \text{POP} \quad \text{adj.}R^2 = 0.914 \\ (0.036)\ (0.003) \end{array} \tag{1.1}$$

The numbers in parentheses, which are described under the formula, are the standard deviations. Therefore, we can conclude that the level of population significantly affects the growth rate of population. From the regression result, the scale effect of population cannot be rejected on the basis of historical data.

However, if we carefully observe Fig. 1.1, it can be said that this relationship would be doubtful when approaching the modern society.[2] In short, while this relationship is satisfied for long-term historical data, another interpretation might be required for understanding it in modern society. We will revisit this problem later.

[2]In the case of regression that excludes the most recent data, the adjusted determinant coefficient rises from 0.914 to 0.938, and the coefficient of POP changes from 0.0524 to 0.0621.

1.2.3 Population and Population Growth (2): Population in Japan

Has scale effect had an impact on the growth rate of population in Japan? Using historical data shown in Table 1.2, we will verify the relationship discussed above.

The sources for Table 1.2 are the National Institute of Population and Social Security Research "Population Statistics" and McEvedy and Jones (1978).[3] Figure 1.3 shows the growth rate of population against its level from Table 1.2, and it can be seen that the relationship between them is slightly weaker than that in the case of world population.

Pursuing the same purpose as that in the above estimation, Eq. (1.2) shows the regression result of the growth rate of population against the level of population. The number of observations in this estimation is 29.

$$\begin{array}{c} \text{Growth Rate} = 0.426 + 0.0048 \ \times \text{POP} \quad \text{adj.}R^2 = 0.121 \\ (0.154)(0.002) \end{array} \tag{1.2}$$

From Eq. (1.2), the level of population has a significantly positive effect on the growth rate of population, and the scale effect also holds in the case of Japanese historical data. Again, it must be acknowledged that the relationship becomes questionable as the time horizon approaches modern society, the same as that in the case of world population.

1.3 Technological Progress and Economic Growth

1.3.1 Doubt About Scale Effect

There are some doubts concerning the scale effect that explains technological progress. For example, the scale effect implies that increases in income, which have occurred simultaneously with technological progress, have the possibility of reducing the incentive for developing new technology. In addition, Jones (1995) indicated that the prediction of scale effect is inconsistent with actual data. More concretely, the assumption that the growth rate of productivity is proportional to the number of scientists and engineers engaged in R&D is not accepted from time-series data.

Though slightly long, it seems beneficial to quote Jones (1999): "In the first wave of such models in the recent growth literature …this scale effect shows up in a particularly troublesome way. The growth rate of the economy is proportional to the

[3]The original data of National Institute of Population and Social Security Research "Population Statistics" are from Kito (2000).

Table 1.2 Population growth: Japan

Year	POP (millions)	Growth rate (%)
200	0.7	0.4
400	1.5	0.5
589	3.9	0.1
725	4.5	0.3
800	5.5	0.1
1150	6.8	0.1
1600	12.3	0.8
1721	31.3	−0.1
1786	30.1	−0.1
1792	29.9	0.0
1850	30.7	0.6
1860	32.5	0.6
1870	34.4	0.8
1900	43.8	1.2
1920	56.0	1.3
1925	59.7	1.5
1930	64.5	1.4
1935	69.3	0.8
1940	71.9	1.5
1950	83.2	1.4
1955	89.3	0.9
1960	93.4	1.0
1965	98.3	1.3
1970	104.7	1.4
1975	111.9	0.9
1980	117.1	0.7
1985	121.0	0.4
1990	123.6	0.3
1995	125.6	0.2
2000	126.9	–

Source National Institute of Population and Social Security Research "Population Statistics," McEvedy and Jones (1978)

total amount of research undertaken in the economy. An increase in the size of the population, other things equal, raises the number of researchers and therefore leads to an increase in the growth rate of per capita income. As pointed out by Jones (1995), this prediction is strongly at odds with 20th century empirical evidence" (Jones 1999, p. 140).

Furthermore, although the scale effect could predict that the growth rate of the population is proportional to the population level from historical data until the 1960s–70s, the explanatory power of prediction has disappeared since the 1970s. While the population growth in developed countries has stagnated, researchers

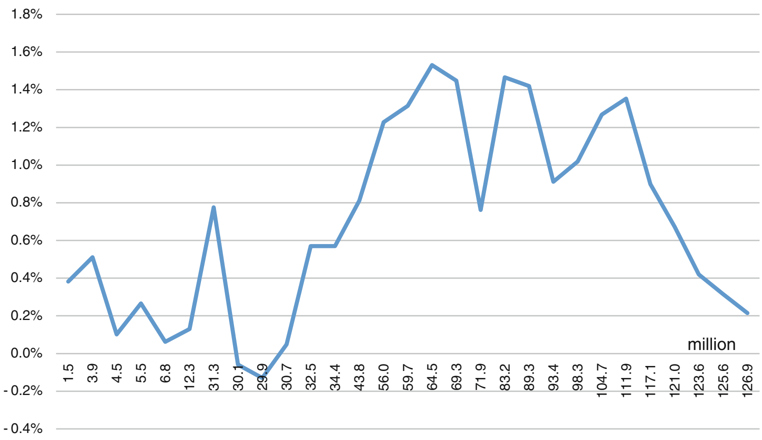

Fig. 1.3 Population and the growth rate in Japan. *Source* National Institute of Population and Social Security Research "Population Statistics", McEvedy and Jones (1978)

engaged in R&D have increased in developed countries in recent decades. Moreover, Collins et al. (2013) said "The population growth rate increased with population size until the global population increased above three billion people in the mid-twentieth century, but then the positive relationship between population size and population growth broke down" (Collins et al. 2013, p. 2).

1.3.2 Technological Progress and Income

Following is a discussion about another cause of technological progress and income growth, which has brought an increase in productivity to R&D. In other words, the scale effect that yields an increase in the number of scientists and researchers who engage in R&D through population growth is not the only cause of technological growth. Because income has been rising with both technological progress and population growth and research productivity also has been increasing with income growth, it is difficult to identify the true cause of technological progress. Jones (1995) indicated that research productivity is dependent on not only population but also income and the level of technology at the time. Furthermore, Kremer (1993) claimed that his generalized model, which allows research productivity to depend on population and the existing level of technology, proves consistent with data if the total technological change increases with population. Hence, we could not isolate the scale effect perfectly.

We should consider another problem concerning the relationship between population density and technological progress. In a country with high population density, we cannot always observe high income and advanced technological progress. In earlier decades, countries with high population density such as China and

India had a high growth rate of population, but income and technological level were low relative to developed countries. According to cross-sectional analysis, the relationship between growth of population and technological progress would be estimated inversely because of low incomes in developing countries.

Furthermore, Young (1993) said that high population density would reduce per capita income, and if research productivity had a close relationship with income, population growth would reduce the speed of technological progress. If this viewpoint were true, the relationship between population and technological progress would be ambiguous.

A more important point that we should consider further is the duration of time analyzed. Kremer (1993) and Jones (1995) discussed their viewpoints from a long-term historical perspective; however, as Izmirlioglu (2008) suggested, if we focus more on short-term analysis, then total factor productivity (TFP) has a more important role in economic growth. In addition, although we focused on total population and its growth, it would also be important to consider its age structure, which is pointed out by Beaudry and Collard (2003). We will discuss more on these points in a later chapter.

In the next section, we will consider a new perspective regarding the complicated relationship among population growth, income, and technological progress.

1.4 Demographic Transition and Economic Growth

1.4.1 Declining Fertility and Income

In developed countries, declining fertility rates have been widely observed and identified as causing population declines in the future. This phenomenon has raised an important point to discuss concerning the relationship between technological progress and population. Studies have verified that the decline in the birth rate is associated with increase in income. We will discuss this in detail later.

Assuming that this inverse relationship is realized in developed countries, and even if the technological progress might increase income through the size effect, prosperity in income would cause a negative impact on technological progress by the declining population. Therefore, in the country or society under declining population, if this negative effect is sufficiently strong, an inverse relationship between population and technological progress could be observed. Furthermore, there is a possibility that technological progress would be stagnated owing to a decline in population caused by fertility decreases.

According to Galor and Weil (1998), the relationship between technological progress and an increase in income has the following two processes. First, it loosens the budget constraint of the household and thus promotes an increase in the resources required for having children. Second, the increased resources might increase the quality of children, and fertility declines as a result. Thus, technological progress and a rapid rise in income might induce a reduction in the speed of population growth. The above logic implies an inverse relationship between population growth and technological progress.

In short, developed countries exhibit two opposite effects on the relationship between population and technological progress; thus, we should identify both effects and determine which is stronger.[4]

1.4.2 Demographic Transition

Before discussing the cause of declining fertility and increasing income, we should briefly review demographic transition. The demographic transition refers to a common phenomenon from high birth and death rates to low birth and death rates in a society or country, as indicated by Notestein (1945) and other demographers, who derived this view on the basis of demographic data over the past 200 years or so.

This theory describes the population change since the advent of modernized society by utilizing the effects of death and birth rate declines (Fig. 1.4). After the first stage of high birth and death rates, the death rate had begun to decline due to the improvement of sanitary conditions or medical technology; then, population growth had started by high birth rate. To develop the economy and increase the prosperity of life, the birth rate had begun to decline, and the speed of population growth rate began to gradually decline. However, the birth rate remained higher than the death rate, so the population continued to grow. This is referred to as the third stage in Fig. 1.4. When the birth rate is reduced to approximately the same level as the death rate, population growth would stop and population would fluctuate around a constant level. The classic demographic transition model explains the long-term historical population situation above.

Van de Kaa (1987) and others further proposed the idea of the second demographic transition. This idea described that industrialized countries were facing a new stage in their demographic history, whereby the birth rate continued to decline after the third stage of the classic demographic transition model.

Although there are many literatures about the demographic transition and the second demographic transition, such as Kirk (1996) or Lee (2003), note the continued decline of the birth rate in developed countries after the third stage in the classic demographic transition. Next, we will explain population economics that focuses on the relationship between fertility and economic growth.

[4]Collins et al. (2013) pointed out that even if population growth rate has been positively associated with population size, the relationship has been deteriorating at the stage where the total population of the world has over 30 million people. The era in which the amount of population is over 30 million is after the Second World War and also the period in which large disparity began to occur among world nations.

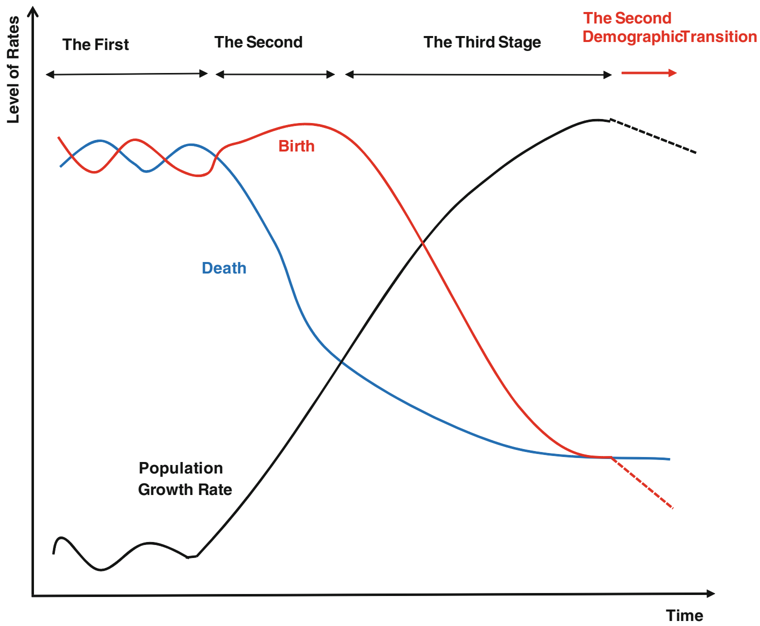

Fig. 1.4 Demographic transition

1.4.3 Declining Fertility and Economic Growth

The relationship between declining fertility and economic growth (or development) is examined mainly in population economics. To study this issue, we turn to three distinguished economists who are the pioneers in this field: Leibenstein, Easterlin, and Becker.

Leibenstein (1957) proposed three utilities obtained from children: (1) labor utility (to utilize children as a labor force), (2) pension utility (to utilize children as income guarantor after parent's retirement), and (3) consumption utility (to care about children and love them). Of these three, labor and pension utilities have been diminished because of economic development, and only consumption utility remains in the developed countries. This is the reason for fertility decline following economic development.

Easterlin (1969) advocated a "relative income hypothesis" as a condition for married couples with children. The hypothesis explains that the parent's living standards and economic conditions experienced in their childhood affects their decision for having children in the future. In a mature economy, parents might hesitate to have children according to Easterlin's hypothesis, and he explained that this was the cause of declining fertility in developed countries.

Becker (1965) devised a "quality–quantity model" to explain the following facts: (1) as income per capita increases, fertility declines in developed countries;

(2) parents with high income have a tendency to have fewer children than those with low income in developed countries. The quality–quantity model explains that the demand for the quality of children increases with increases in household income; however, this demand rises with spending for education of children. By this logic, parents reduce their demand for the quantity of the children so that the total expense for children is constant.

By the 1980s, economic growth theory had entered a new era. Until the 1970s, technological progress and population growth were treated as exogenous factors for economic growth analysis. However, new growth theory considered them as endogenous factors and engines for economic growth. Becker and Barro (1988) and Barro and Becker (1989) constructed a new theory, studying the relationship between economic growth and population as part of the endogenous growth theory. With the attempt of understanding endogenous technological progress by Lucas (1988), economic growth theory has entered a new phase.

In any case, to verify the relationship between population and technological progress, apart from simple scale effects, it should be necessary to control more complex situations.

1.5 Remarks

The relationship between population size and technological progress encompasses complicated mutually exclusive effects. Specifically, technological progress yields economic prosperity, resulting in reduced fertility and population growth, while population size has a positive effect on technological progress. In addition, already mentioned, compared with other countries, the speed of technological progress in large populated countries such as China and India is not fast. Considering these factors, it is necessary to limit the range of the target to be analyzed for empirically clarifying the relationship between population size and technological progress. Therefore, in a later chapter, we attempt to determine the relationship between them, limited to developed countries after the 1980s, and treat TFP (details will be described later) as the proxy variable of the technological level.

As Kremer (1993) indicated, the simple scale effect, which means that large population scale promotes technological progress and increases population growth as a result, was applicable until the 1950s. However, it should be necessary to limit the time range and target countries to analyze the scale effect in the current era. In addition, as Izmirlioglu (2008) pointed out, since it is difficult to evaluate the role of TFP over a long-term period, short-term analysis is required. New growth theory treats technological progress as an endogenous factor, and the viewpoint that technological progress is an engine of economic growth has not been lost in the theory; however, the analytical strategy about the relationship between population and technological progress should be modified slightly.

Appendix 1: Kremer's Theoretical Model

Various theoretical interpretations concerning the relationship between population and technological progress have been argued about since Malthus (1798). In this appendix, we summarize three such models and show the assumptions for an analysis on the relationship between population and technological progress induced from each model.[5]

(1) **Malthusian Model**
The Malthusian model conducts a scenario whereby land is in short supply relative to other production factors from increasing population and decreasing output per capita to a resulting steady-state level. We can define the production function as Eq. (1.3) such that Y is output, P is population, and T is amount of land.

$$Y = AP^{\alpha}T^{1-\alpha} \tag{1.3}$$

In the case where the amount of land is normalized to unity and y is the constant output per capita at steady state, we have Eq. (1.4), which shows the relationship between output per capita and population at the steady state.

$$\bar{p} = \left(\frac{\bar{y}}{A}\right)^{\frac{1}{\alpha-1}} \tag{1.4}$$

For the condition $\alpha < 1$, a direct relationship between population and technology is obtained from Eq. (1.4). As for this direct relationship, (Kuznets 1960) and Simon (1977) discussed that as much as the amount of population increased, there were so many potential innovators, such that technological progress was stimulated. Eliminating the condition that the output per capita converges to a constant steady-state level in the Malthusian model, assuming the relationship between population and technological progress $\frac{\dot{A}}{A} = gP$, where g is a parameter, we get Eq. (1.5).

$$\frac{\dot{P}}{P} = \frac{1}{1-\alpha}\frac{\dot{A}}{A} = \frac{g}{1-\alpha}P \tag{1.5}$$

If this is the case and Kuznets (1960) and others' assumptions are correct, then we can find a direct relationship between the scale and the growth rate of population from Eq. (1.5).

Proposition 1 *From Eq. (1.5), there is a direct relationship between the scale and the growth rate of population.*

[5] Referring Kremer (1993), Barro and Sala-i-Martin (2003).

(2) **Population Relationships with Technology and Output**
Although the direct relationship between population and technological progress conducts a direct relationship between population and output, per capita income is relatively low in the developing countries with large population in the real world. This fact casts doubt on the direct relationship between population and technological progress. Then, assuming that parameter g is the function of output per capita, i.e.,

$$g = ky^{\delta}, k, \quad \delta > 0$$

we have Eq. (1.6).

$$\frac{\dot{A}}{A} = ky\delta P = kA^{\delta}P^{\delta(\alpha-1)+1} \tag{1.6}$$

From Eq. (1.6), when δ is the less than $\frac{1}{1-\alpha}$, the larger population causes the more rapid growth of technological progress. However, when δ is larger than $\frac{1}{1-\alpha}$, the above conclusion is reversed. Therefore, the relationship between population and technological progress is dependent on those values of parameters.

On the other hand, the growth rate of technological progress is the function of the technological level itself; Eq. (1.7) is given by

$$\dot{A} = gPA^{\varphi} \tag{1.7}$$

When $\varphi = 1$, the growth rate of technological progress has a direct relationship with population P. In addition, the relationship between output per capita at a steady-state level and the scale or the growth rate of population is shown by Eq. (1.8), which is calculated from Eq. (1.7) using Eq. (1.5).

$$\frac{\dot{P}}{P} = \frac{1}{1-\alpha} gP^{1-(1-\alpha)(1-\varphi)}\bar{y}^{\varphi-1} \tag{1.8}$$

Proposition 2 *When $\varphi = 1$ in Eq. (1.7), there is a direct relationship between the scale of population and the growth rate of technological progress.*

(3) **Relationship between Population Growth and Technology**
Kuznets (1960) discussed that more population brought about more intellectual interactions, and this promoted the specialty and efficiency of the human capital such that the growth rate of technological progress was increased. Similar to Kuznets (1960), Aghion and Howitt (1992), Grossman and Helpman (1991), and others argued that the population increase with an expansion of the economical scale encouraged outputs of R&D and spurred technological progress as a result. On the contrary, they also pointed out that the large population situation caused duplications of technology, which led to inefficiency in its development.

Barro and Sala-i-Martin (2003), Jones (1995), and others presumed Eq. (1.9), which is more generalized than Eq. (1.7).

$$\dot{A} = gP^{\phi}A^{\varphi} \tag{1.9}$$

Furthermore, defining the growth rate of population as $\frac{\dot{P}}{P} = n$, Eq. (1.10) is obtained.

$$\frac{\dot{A}}{A} = \frac{\phi n}{1 - \varphi} \tag{1.10}$$

From Eq. (1.10), we have $\frac{\partial}{\partial t}\left(\frac{\dot{A}}{A}\right) = (\varphi - 1)(gP^{\phi}A^{\varphi-1})^2$. When $\varphi > 1$, then the growth rate of technological progress would rise rapidly with increasing level of technology. However, such situations have not been observed in developed nations through postwar periods, so Barro and Sala-i-Martin (1992) imposed the condition $\varphi \leq 1$. In this case, the growth rate of technological progress has a direct relationship with that of population.

Proposition 3 *From Eq.* (1.10), *there is a direct relationship between the growth rate of technological progress and that of population.*

Appendix 2: Endogenous Growth and Population Literature

Demography, which was founded by Malthus (1798), had an estranged relationship with economics in the long term, as economics had considered population as a simple exogenous variable. Hence, there was a large gap between the two academic disciplines for a long time. More concretely, population had been handled as a given condition, and it was not a subject of analysis in either the optimum growth model by Ramsey (1928) or the neo-classical growth model by Solow (Solow 1956).

However, the study about fertility by Becker (1965) and the optimum population growth rate by Samuelson (1976) have since established a new relationship between demography and economics, and economics has commenced analysis regarding population dynamics. However, the relationship between economic growth and population or that between economic growth and technological progress was not one of interdependence, but rather population and technological progress were considered as exogenous variables.

These relationships have changed greatly with the emergence of endogenous economic growth theories by Romer (1986) and Lucas (1988), which treated technological progress itself as an endogenous variable of economic growth. Furthermore, Becker and Barro (1988) presented a model wherein fertility and

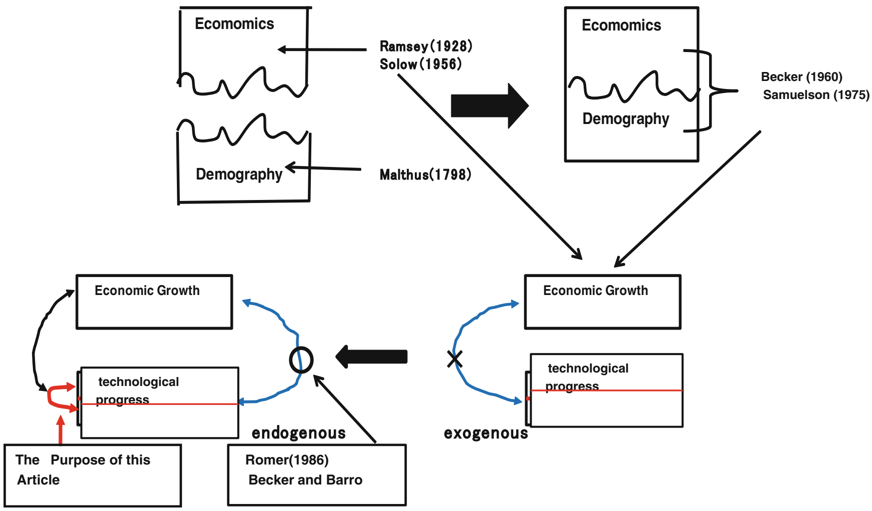

Fig. 1.5 Endogenous growth and population literature

economic growth were determined simultaneously. Population and technological progress, which had been treated as exogenous variables of economic growth, were to be analyzed as endogenous variables from these studies. Yet, problems remained concerning the relationship between population and technological progress. In studies of economic growth to date, it has been rare to analyze the relationship between them. Thus, studies exploring the relationship between population and technological progress have continued from the Malthusian era, as shown by the analysis of this chapter. Indeed, the purpose of this book is exploring this exact relationship between population and technological progress (Fig. 1.5).

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Chapter 2
Population, Economic Growth, and TFP in Developed Countries

Abstract In this chapter, we investigate the relationship between population size and economic growth using growth accounting and empirical studies. We begin with an explanation of the production function and growth theory. Although economic growth can be achieved by increasing the amounts of either labor or capital in the production function, it can also be realized through increased efficiency or, in other words, by improving how factors are used together. This improved efficiency, which contributes to an increase in GDP, is closely related to technological progress. Since it is generally difficult to estimate technological progress in the macroeconomy, we need to identify indicators that capture technological progress for our empirical research. We will demonstrate the significance of total factor productivity (TFP), which is a proxy variable for technological progress, by using the results of growth accounting in the OECD countries. The OECD (2013) has published growth accounting data for selected countries from 1985 to 2010. From this report, we find that the average economic growth rate was 2.58 %, and the average contribution ratio of multifactor productivity (MFP) was 45.5 %. In other words, almost half the economic growth came from the contribution of MFP. After reviewing the traditional growth theory, we present our empirical results on the relationship between population growth and economic growth. Our empirical tests confirm that the relationship between economic growth and population growth is negative, as proposed in the Solow growth model. However, theoretically, population growth should spur technological progress, as discussed in the previous chapter. We therefore conduct more direct empirical tests on the relationship between population growth and technological progress in the next chapter.

The previous chapter summarized historical views of the relationship between population and technological progress and concluded that technological progress has resulted in rapid economic growth. In this chapter, we investigate the relationship between population and economic growth using growth accounting and empirical studies. We begin with an explanation of the production function and growth theory. Further, we will demonstrate the significance of TFP, which is a proxy variable for technological progress, utilizing the results of growth accounting in Organization for Economic Cooperation and Development (OECD) countries.

H. Kato, *An Empirical Analysis of Population and Technological Progress*,
Population Studies of Japan, DOI 10.1007/978-4-431-54959-8_2

Finally, we will review the traditional growth theory and present the empirical results of the relationship between population and economic growth.

2.1 Economic Growth and Growth Accounting

2.1.1 Economic Growth and Production Factors

Economic growth is defined as the increase in value added to an economy in a year, in a quarter, or in a certain period. In the System of National Accounts (SNA), the economic growth rate is measured by the growth rate of gross domestic product (GDP), which is the key economic indicator for the total economy. From the point of view estimating GDP, three approaches from the demand side, supply side, and income are used. The demand-side approach defines GDP as the total expenditure on final goods and services consumed or invested by economic agents in the economy. On the other hand, the supply-side approach uses the level of production by the industries and the government. From a theoretical viewpoint, GDP estimations using the demand-side and supply-side approaches are balanced in an equilibrium economy.

The economic growth rate is defined as the percentage rate of increase in GDP, or:

GDP growth rate at the current period = increase of GDP at the current period/GDP at the last period (%).

Because modern economic activity is often accompanied by a business cycle that involves short-term changes in expenditures, the supply-side approach is used for long-term observation of economic growth or to establish a GDP trend. The supply-side approach generally uses the concept of the production function. The production function will be explained in greater detail below.

For simplicity, the basic production process will be discussed. In that regard, we assume that there is only one kind of output produced using different types of production factors. Since GDP is an indicator of output, we can translate this to the economy as a whole, and we also assume two factors of production: capital and labor. Then, the production process can be shown by this simple equation (2.1):

$$\text{GDP} = F(\text{Capital}, \text{Labor}) \quad \text{or} \quad Y = F(K, L), \tag{2.1}$$

where Y is GDP, K is capital, and L is labor.

Though economic growth can be achieved by increasing either the amount of labor or the capital in the production function, there is a limit to the contribution of a single factor for an increase in GDP, due to the law of diminishing marginal productivity. Marginal productivity refers to the additional output gained by adding one unit of factor of production when other factors are held constant, and it gradually decreases as the amount of that factor increases.

In reality, it is not ordinary for only one factor to increase when other factors do not change; we therefore need to analyze economic growth with all factor changes taken into account. GDP can be increased by increasing the labor and capital inputs used in production; however, economic growth can also be realized through increased efficiency, in other words, by improving how factors are used together. This improving efficiency, which contributes to an increase in GDP, is referred to as total factor productivity (TFP), also called multifactor productivity (MFP), and is closely related to technological progress. Thus, we often allow TFP to act as a proxy variable for technological progress. Because it is difficult to measure efficiency gains or TFP directly from observation data, we estimate TFP as a residual that is the part of economic growth that cannot be explained through capital increases or labor increases. Considering TFP, we can write the production function as follows:

$$Y = AF(K, L), \tag{2.2}$$

where A denotes TFP or the level of technology. Note, in economics, "technology" is used in a broad sense and is not limited to engineering technology. As mentioned above, technology means general gains in efficiency or productivity, and it is this that acts as the engine of long-term economic development.

2.1.2 *The Cobb–Douglas Production Function and Growth Accounting*

We illustrate the discussion above using the Cobb–Douglas production function. The Cobb–Douglas production function is formulated as follows:

$$Y(t) = A(t)K(t)^{\alpha}L(t)^{1-\alpha}. \tag{2.3}$$

All variables are a function of time t. The parameter α is the share of income received by the owners of capital, and the share of the income received by labor and the share is $1 - \alpha$. We can call this parameter α as the share of capital cost, because it is the share of cost paid to capital in producing GDP.

Taking the logarithm of both sides, we then have

$$\ln Y(t) = \ln A(t) + \alpha \ln K(t) + (1 - \alpha) \ln L(t),$$

and differentiating the above equation by time t,

$$\frac{\Delta Y(t)}{Y(t)} = \frac{\Delta A(t)}{A(t)} + \alpha \frac{\Delta K(t)}{K(t)} + (1 - \alpha) \frac{\Delta L(t)}{L(t)}. \tag{2.4}$$

This is the basic equation of growth accounting. In other words, this equation shows that the GDP growth rate is decomposed to the rate of change of capital and labor and to the rate of TFP growth, which is computed as residual. The contribution of capital (labor) to GDP growth is the speed of growth of capital (labor) multiplied by the share of capital (labor) in GDP.

Though the parameter value α is stable and is similar in developed countries (known as stylized facts in the field of economic growth theory), we can more accurately calculate the share of capital cost using SNA data or other data sources. In addition, many researchers or institutes try to calculate growth accounting. Next, the growth accounting calculation employed by the OECD will be described.

2.2 Growth Accounting in OECD Countries

2.2.1 Data of Technological Progress by OECD

Since it is generally difficult to estimate technological progress in the macroeconomy, we need to identify indicators that capture technological progress for our empirical research. In addition, for the most part, the indicators should be common across developed countries in order to make a comparison. One indicator is published by the OECD as MFP. Briefly, MFP growth represents the unexplained portion of an increase in GDP growth which cannot be accounted for through growth in labor or capital input. The OECD (2001) stated that MFP growth is a proxy indicator of technological progress, and it is the increase in GDP growth that is not embodied in the amounts of either capital or labor. However, it is interpreted in a somewhat larger sense. The OECD (2008) said "MFP growth comes from more efficient use of labor and capital inputs, for example through improvements in the management of production processes, organizational change or more generally, innovation" (OECD 2008, p. 24). In addition, resource constraints of MFP data hamper efforts to precisely measure labor and capital input and this in turn affects MFP.

The OECD published an online MFP database that can be downloaded from "Growth in GDP per capita, productivity and ULC."[1] This database contains the results of measurements of the MFP growth rate for 20 OECD countries, from 1995 to 2012.[2] It should be noted that some fiscal years are missing from the data, and some new countries became OECD members during the period covered by the data; for these reasons, the data do not represent a balanced panel data set for all 20 countries.

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[1]http://stats.oecd.org/Index.aspx?QueryId=54566.

[2]The level of MFP is standardized as 100 in 2005. An old database contained MFP growth rates for 19 OECD countries for the period 1985–2007. In addition, MFP is formulated for the purpose of international comparison, and OECD statistical data cannot necessarily be considered the optimal basis for calculating MFP for individual nations.

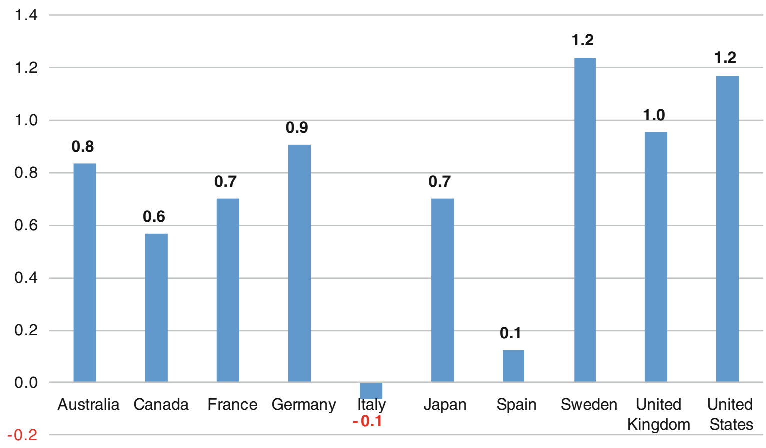


Fig. 2.1 Average growth rate of MFP (1995–2012, %). *Source* OECD database "Growth in GDP per capita, productivity and ULC"

With regard to calculating MFP, it is defined as the difference between the rate of change in output (Q) and the rate of change in input (X). Equation (2.5) provides the definition as follows:

$$\ln\left(\frac{\mathrm{MFP}_t}{\mathrm{MFP}_{t-1}}\right) = \ln\left(\frac{Q_t}{Q_{t-1}}\right) - \ln\left(\frac{X_t}{X_{t-1}}\right). \tag{2.5}$$

Note, output (Q) is the real gross domestic product in the OECD National Accounts, and input (X) is labor and seven categories of capital stock. The difference between MFP and standard TFP lies in this use of seven categories of capital stock.[3]

Figure 2.1 shows MFP growth, on average, from 1995 to 2012 for 10 major nations (Australia, Canada, France, Germany, Italy, Japan, Spain, Sweden, the UK, and the USA). It reveals that Sweden displayed the highest rate of increase in MFP at 1.2 %, followed by the USA at 1.2 %, almost the same as Sweden, the UK at 1.0 %, and Germany at 0.9 %. In contrast to those countries, Italy had the lowest rate of MFP increase at −0.1 %, and Spain's rate of increase was 0.1 %. With respect to Japan, the MFP growth rate was 0.7 %, on average, from 1995 to 2012.

2.2.2 Growth Accounting in OECD Countries

Technological progress is the most fundamental source of human progress. In addition, it is also the most important engine of economic growth. In the previous

[3]See Schreyer (2003) or Wölfl and Hajkova (2007) for more details.

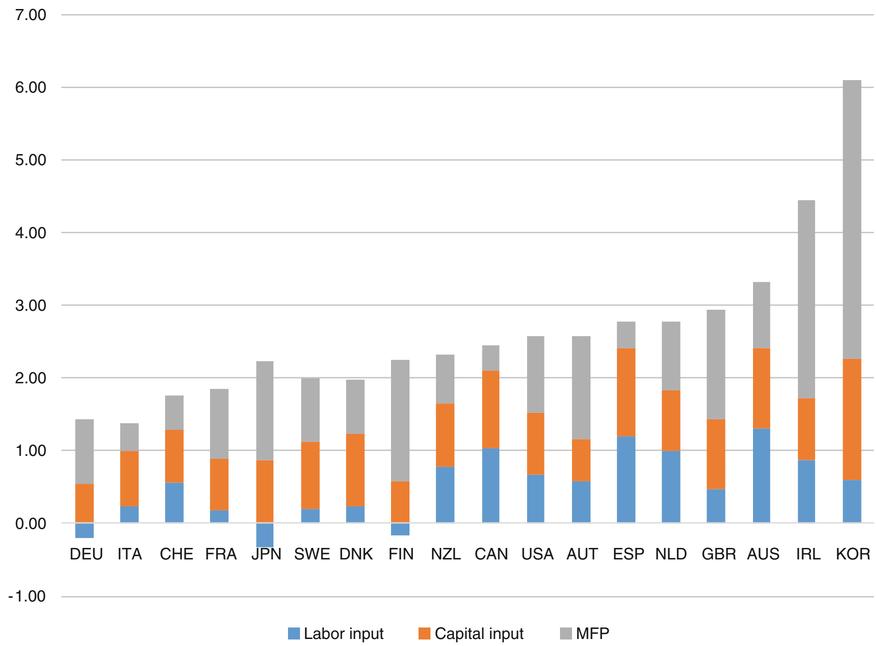


Fig. 2.2 Growth accounting in OECD countries (1985–2010). *Data* OECD (2013)

section, the growth accounting method was explained. Considering TFP (or MFP) is the proxy variable of technological progress, we will now examine how TFP contributed to economic growth in developed countries, using growth accounting by the OECD (2013).

The OECD (2013) has published growth accounting data for selected countries from 1985 to 2010. In these calculations, the contribution of labor (capital) to GDP growth is measured as the growth of labor (capital) input, multiplied by the share of labor (capital) in GDP. Figure 2.2 shows the contribution degree of capital, labor, and MFP to GDP growth rate.[4] Eighteen OECD countries were selected.[5]

From the figure, we can see the importance of MFP and capital to the GDP growth rate in almost all of the countries; however, labor input was important for only a few countries from 1985 to 2010. For example, Japan, Finland, and Germany experienced negative GDP contributions from labor inputs.

South Korea recorded the highest economic growth in this period among the 18 countries, with an average economic growth rate of 6.10 %. The contribution

[4]Although, in the original OECD (2013) publication, the contribution of capital to GDP is broken down into Information and Communication Technologies (ICT) capital and non-ICT capital, we combined the two kinds of capital for convenience.

[5]Germany, Italy, Czech Republic, France, Japan, Sweden, Denmark, Finland, New Zealand, Canada, USA, Austria, Spain, Netherland, United Kingdom, Australia, Ireland, and South Korea.

ratio of MFP to GDP growth was 62.8 % in Korea; meanwhile, the contribution ratio of labor input was only 9.8 %. On the contrary, Germany's economic growth rate from 1985 to 2010 was the lowest of the 18 countries, with an average growth rate of only 1.22 %. Interestingly, South Korea's contribution of MFP to GDP growth is larger than capital and labor input. The contribution ratio of MFP was 72.6 %, the second-highest value among the 18 countries.

For all countries, we find that the average economic growth rate was 2.58 %, and the average contribution ratio of MFP was 45.5 %. In other words, almost half of the economic growth came from the contribution of MFP. Among the 18 countries, Finland had the highest contribution ratio of MFP, 80.2 %, because its GDP growth rate was 2.08 % and the growth rate of MFP was 1.67 %. Conversely, the contribution ratio of MFP to GDP growth was low in both Spain and Canada, with ratios of 13.1 and 14.1 %, respectively.

As for Japan, the average GDP growth rate was 1.91 %, making it the fifth-lowest country, and the growth rate of labor was −0.32 %. This was because of the decreased size of the labor force in the mid-1990s. The growth rate of MFP was 1.36 % from 1985 to 2010, and the contribution ratio to GDP growth was 71.0 %, the third-highest value of the 18 countries.

2.2.3 Some Problems Related to Technological Progress Indicators

(1) **Productivity and TFP**

Based on current research, it can be said that the contribution of MFP or technological progress to economic growth, through the analysis of growth accounting, is large. However, there are other relevant indicators. Productivity also means the degree of efficiency of production; therefore, it may also be an indicator of technological progress.

The term "productivity" is used frequently in the context of economics; however, it is difficult to define because its significance varies. Generally, productivity is defined as the ratio of an amount of output or GDP to one unit of input. In addition, a growth rate of labor productivity is calculated as:

$$\text{Growth rate of Labor Productivity} = \text{Growth Rate of}(\text{GDP}/\text{Labor input}).$$

In general, labor productivity is interpreted as single-factor productivity (SFP), and TFP is defined as the total factor or multifactor productivity. Hence, if labor is selected as an input production factor, we can then measure labor productivity. If we choose capital as an input factor, then capital productivity is calculated. Furthermore, MFP is defined as the productivity of combined input factors, which are labor, capital, and intermediate inputs (e.g., raw materials, energy). Thus, we can say that a variety of definitions of productivity are possible, depending on what

Table 2.1 Overview of main productivity measures

Type of output measure	Type of input measure			
	Labor	Capital	Capital and labor	Capital, labor, and intermediate inputs (energy, materials, services)
Gross output	Labor productivity (based on gross output)	Capital productivity (based on gross output)	Capital–labor MFP (based on gross output)	KLEMS multifactor productivity
Value added	Labor productivity (based on value added)	Capital productivity (based on value added)	Capital–labor MFP (based on value added)	–
	Single-factor productivity measures		Multifactor productivity (MFP) measures	

Source OECD (2001, p. 13)

inputs are used as the indices for productivity measurements. Incidentally, labor productivity is the most representative index.

Note, the definition of productivity will differ depending on what type of output we choose (e.g., a value-added basis of GDP or a production basis which incorporates intermediate goods and services).

Table 2.1 depicts the main productivity measures from the OECD (2001). The OECD (2001) offered an explanation of the productivity definition. As for labor productivity, based on value added, it is defined as the quantity index of value added, divided by the quantity index of labor input. Capital–labor MFP, based on value added, is defined as the quantity index of value added divided by the quantity index of combined labor and capital input, and so on. A more detailed definition of MFP will be explained below.[6]

(2) **Independence between TFP and Labor**
From the above discussions, it can be said that TFP or MFP is a proxy index of technological progress and has an important role in growth accounting. As such, measuring TFP is an indispensable procedure for the analysis of economic growth. On the other hand, both labor and capital are also essential in establishing growth factors. In this case, how are capital and labor related to technological progress? Assuming the production function, described as Eq. 1.1, we presume that technological progress is independent of the labor force (and capital). Mainly, because TFP is defined as the efficiency gain of production in total, technological progress should be interpreted as an exogenous shock. However, is there actually an independent relationship between labor (capital) input and TFP in the economy?

[6]The OECD (2001) said that "conceptually, capital-labor productivity is not, in general, an accurate measure of technical change…" and MFP "reflects the combined effects of disembodied technical change, economies of scale, efficiency change, variations in capacity utilization and measurement errors" (p. 16).

Examining this point, two possibilities can be considered. Firstly, a labor-augmenting technological progress exists. Using the production function form, we can describe this as follows:

$$Y = F(K, AL).$$

This labor-augmenting technological progress serves to enhance the efficiency of labor, and in this case, it is difficult to calculate the pure contribution of technological progress to GDP growth.

Secondly, there is a fundamental theory that some significant relationship exists between technological progress and labor input. This is the main theme of this study. The purpose of this study is to explore the relationship between TFP and population. If the population size (or labor input) is one of the causes of the speed of technological progress, then both factors are not independent in the production function. This study will examine this relationship in detail below.

2.3 Population and Economic Growth

2.3.1 Population and Economic Growth

As described above, technological progress is the most important factor for economic growth. However, we cannot directly measure technological progress through the use of indicators; therefore, TFP is utilized as a proxy variable. An advantage of using TFP as a proxy variable is that it is easy to decompose its contribution by growth accounting. Firstly, we will review the Solow growth model, which is the simplest theory used to describe economic growth.

Assuming the specific production function of homogeneous of degree one as follows:

$$Y = F(K, L) \Rightarrow Y = K^{\alpha} L^{1-\alpha},$$

then it transforms per capita.

$$\frac{Y}{L} = \left(\frac{K}{L}\right)^{\alpha} \left(\frac{L}{L}\right)^{1-\alpha} = \left(\frac{K}{L}\right)^{\alpha},$$

where Y is GDP, K is capital stock, and L is labor or population. Also it defines the capital–labor ratio as $k = \frac{K}{L}$ and per capita GDP as $y = \frac{Y}{L}$. We can describe the production function in terms of per capita.

$$y = k^{\alpha}$$

The transition equation of capital stock is as follows:

$$K_t - K_{t-1} = I_t$$

I is investment, and in equilibrium in economy, S is defined as saving, as follows:

$$S = I.$$

We can rewrite this as follows:

$$S = sY.$$

Next, considering the dynamic change of the capital–labor ratio, we can show that

$$\frac{\dot{k}}{k} = \frac{\dot{K}}{K} - \frac{\dot{L}}{L},$$

and assume the labor growth rate is constant n. The next equation is derived as follows:

$$\frac{\dot{k}}{k} = \frac{sY}{K} - n = s\frac{Y/L}{K/L} - n = s\frac{y}{k} - n \rightarrow \dot{k} = sy - nk$$

This equation shows the Solow growth model and implicates the relationship between GDP and labor (or population). In a steady state, by considering the production function in terms of per capita, it is easy to derive Eq. (2.6). Note, * means the value in a steady state.

$$y^* = \left[\frac{s}{n}\right]^{\frac{\alpha}{1-\alpha}} \tag{2.6}$$

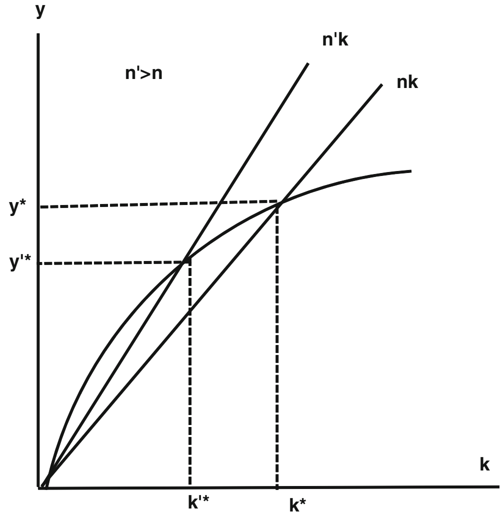
Equation (2.6) shows that the level of GDP per capita decreases as the rate of population growth increases. From this logic, it is concluded that an increased population generates lower levels of per capita income in a steady state. Figure 2.3 illustrates this conclusion.

2.3.2 *The Results of Empirical Studies (1)*

The relationship between economic growth and population will now be examined, based on empirical studies. Firstly, we will explore the relationship between the population growth rate and the economic growth rate for countries in the long term.

To collect as much data as possible, for both developed and developing countries, we utilized the “World Bank Open Data.” The selected variables are real GDP in domestic currencies and population figures from 1960, 1985, and 2010.

Fig. 2.3 The Solow growth model



From these data, the average growth rate can be easily calculated. Therefore, we prepared three different average growth rates, namely from 1960 to 1985, 1985 to 2010, and 1960 to 2010. The data included 91 countries.

Figure 2.4 shows the simple relationship between the population growth rate and the economic growth rate. The *X*-axis denotes the population growth rate and the *Y*-axis denotes the economic growth rate from 1960 to 2010. The correlation coefficient of the two variables was −0.207, a weak negative relation was observed, and we could not obtain strong evidence supporting the conclusion of the Solow growth model.

The conclusion of the Solow growth model is derived using a per capita variable. Therefore, a per capita growth rate should be used instead of a macroeconomic

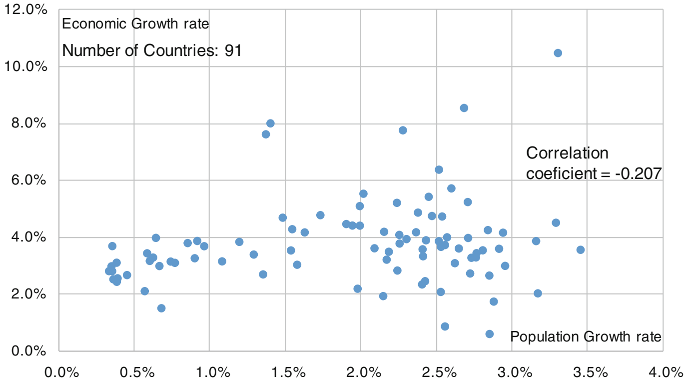


Fig. 2.4 Economic growth and population increase: 1960–2010. *Data* from The World Bank's Open Data

growth rate. Per capita growth rate is calculated using the figure obtained from the macroeconomic growth rate minus the population growth rate.

Figure 2.5a shows the relationship between the per capita growth rate (measured at the *X*-axis) and the population growth rate (measured at the *Y*-axis) from 1960 to 2010.

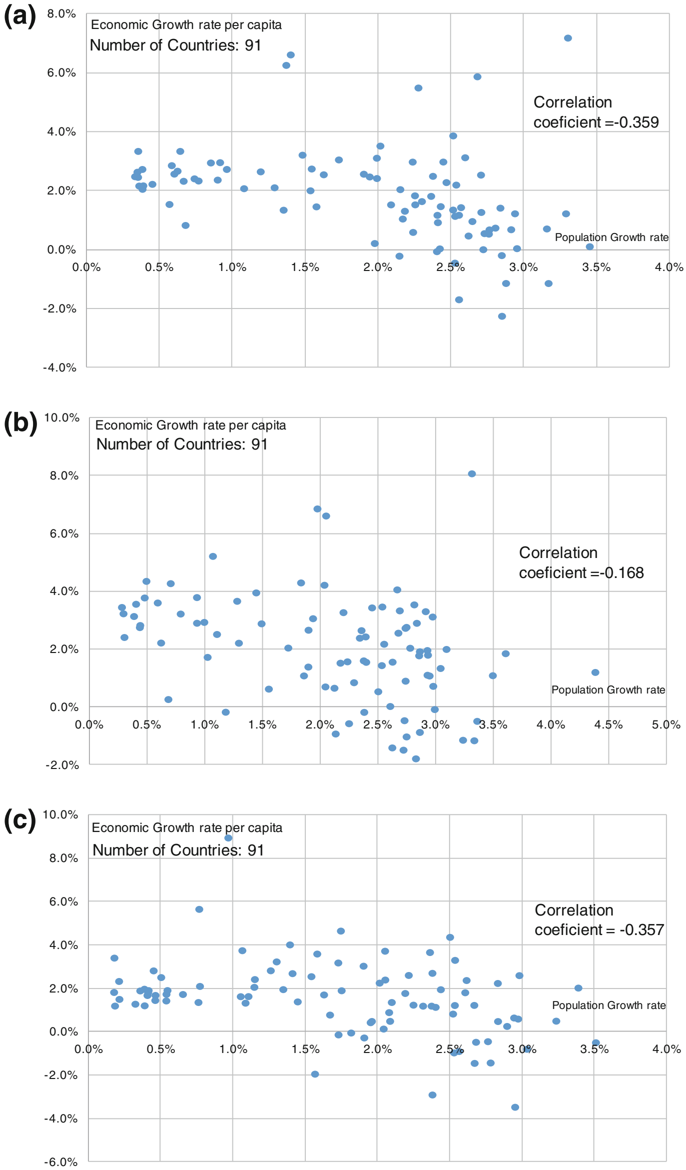


Fig. 2.5 Economic growth per capita and population increase. **a** 1960–2010, **b** 1960–1985, **c** 1985–2010. *Data* from The World Bank's Open Data

The correlation coefficient of the data in Fig. 2.5a is estimated as −0.359, which is slightly stronger than the data in Fig. 2.4. Furthermore, we divided the sample data period into two periods, from 1960 to 1985 and 1985 to 2010, and again estimated the correlation coefficient between them. Figure 2.5b is the result of the first half of the period (1960–1985), and a somewhat weaker relationship seems to exist between the variables during this period than during the period as a whole (1960–2010). The correlation coefficient is −0.168, which is almost half of the estimated value in the total period. However, in the latter half of the period (1985–2010), the correlation coefficient between the two growth rates is stronger than during the first half. The coefficient is −0.357.

These empirical studies confirm that the relationship between economic growth and population growth is negative, as proposed in the Solow growth model. However, the statistical significance of the relationship is somewhat ambiguous because the estimated correlation coefficients of absolute value are small.

One of the reasons for this weak relationship is that it included countries at different stages of development. It may be necessary to separate developed and developing countries. Therefore, in the next section, only developed countries are analyzed to verify the relationship between population and economic growth.

2.3.3 The Results of Empirical Studies (2)

Before investigating the relationship between population and economic growth, it is helpful to review the study conducted by Beaudry and Collard (2003). They attempted to estimate the relationship using three different types of economic performance, specifically growth in output per adult, growth in output per worker, and the change in employment per adult. Their data were from the period 1960–1997, encompassing 18 developed countries. They observed that around the first half of the 1970s the relationship between economic growth and population growth changed drastically. Beaudry and Collard (2003) set the growth rates in GDP per capita (or per adult, an adult defined as being between 15 and 64 years of age) as dependent variables, and these were regressed on the growth rate of population and the initial (log) level of GDP per capita in the initial year, which represented a convergence hypothesis in economic growth.

Beaudry and Collard (2003) discovered that population or the adult growth rate exerted only a small and insignificant effect on economic performance over the period 1960–1974. Additionally, they found strong evidence of convergence, which is consistent with the standard economic growth theory. On the other hand, the effect of population growth had a stronger negative effect on economic growth during the period 1975–1997. By referring to Beaudry and Collard's (2003) work, we will investigate an extended period of data for OECD countries.

Using OECD data for 24 countries from 1970 to 2010, we estimated regression equations to verify the relationship between population and economic growth. Dependent variables are the economic growth rate per capita, denoted as $\%\Delta(Y/P)$, and per adult (15–64-year-old), denoted as %Δ(*Y*/*A*), respectively. As for the independent variables, we prepared a population growth rate (Pop Gr), an adult growth rate (Adult Gr), an initial log level of GDP per capita in the initial year [Initial(*Y*/*P*)], and an aging ratio (AGE). Note the aging ratio selected data in the mid-year of each period. Furthermore, we divided the sample period into two terms, from 1970 to 1990 and from 1990 to 2010; we therefore prepared three different sample periods, including the total period.

Table 2.2 shows the results of the above regressions. Panel A is the result of the full sample period, and estimated parameters of both the population growth rate and the adult growth rate are negative, but not significant to economic growth. It should

Table 2.2 Population and economic growth in OECD countries

Dep. var.	%Δ(*Y*/*P*)	%Δ(*Y*/*P*)	%Δ(*Y*/*A*)	%Δ(*Y*/*A*)
Panel A: 1970–2010				
Pop Gr	−0.355 (0.328)	−0.882 (0.740)		
Adult Gr			−0.508 (0.251)**	−0.955 (0.592)
Initial (*Y*/*P*)	−0.015 (0.003)***	−0.012 (0.004)***	−0.014 (0.003)***	−0.012 (0.004)***
Age		−0.109 (0.137)		−0.118 (0.141)
R^2	0.523	0.538	0.453	0.471
Panel B: 1970–1990				
Pop Gr	−0.882 (0.326)**	−2.718 (0.694)***		
Adult Gr			−0.748 (0.270)**	−1.591 (0.629)**
Initial (*Y*/*P*)	−0.022 (0.004)***	−0.010 (0.006)*	−0.020 (0.005)***	−0.016 (0.005)***
Age		−0.507 (0.175)***		−0.282 (0.191)
R^2	0.579	0.703	0.486	0.536
Panel C: 1990–2010				
Pop Gr	0.221 (0.412)	−0.756 (0.609)		
Adult Gr			0.068 (0.300)	−0.537 (0.508)
Initial (*Y*/*P*)	−0.009 (0.004)*	0.002 (0.007)	−0.005 (0.005)	0.002 (0.006)
Age		−0.209 (0.101)*		−0.162 (0.111)
R^2	0.171	0.316	0.062	0.152

Data OECD "OECD Data Base"
Calculation by author
* means significant at 10%, ** means significant at 5%, and *** means singnificant at 1%

be concluded that population growth has not affected economic growth in the past 40 years. For reference, the initial level of GDP per capita strongly affects economic growth negatively, so it could be referred to as the hypothesis of convergence which standard economic growth theory described.

From the results of Panel B, in contrast to panels A or C, the population growth rate had a negative and significant effect on economic growth, and the aging ratio also negatively affected economic growth. However, in the more recent sample, Panel C, there was no significant relationship between the dependent and the independent variables. It is interesting that the results of these regressions are not consistent with the results of Beaudry and Collard (2003).

After reviewing the traditional growth theory, we present our empirical results on the relationship between population growth and economic growth. Our empirical tests confirm that the relationship between economic growth and population growth is negative, as proposed in the Solow growth model. However, theoretically, population growth should spur technological progress, as discussed in the previous chapter. We therefore conduct more direct empirical tests on the relationship between population growth and technological progress in the next chapter.

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Chapter 3
Theoretical and Empirical Analysis of Population and Technological Progress

Abstract This chapter confirms the relationship between population growth and technological progress using theoretical and empirical studies. First, we look at some theories of technological progress in terms of population scale and growth. Many economists have asserted that a larger population induces more innovation, new technology, ideas, and so on. This view implies that the growth rate of technological progress declines as population decreases in Japan or other developed countries in the near future. Second, we devise a simple model to analyze the effect of population scale on technological progress. This model forms the basis of the empirical study discussed below. As for the implications of this model, the effect of population scale on technological progress is theoretically ambiguous. Since the conclusions depend on the assumption of the model, only an empirical study can confirm the implications of the model. In addition, according to the traditional Keynesian perspective, population numbers are an important factor in economic performance. In this view, a reduced population size leads to a decline in economic growth. This lower economic growth introduces the possibility of reduced investments in technology. Lastly, we test whether there is a positive relationship between population and technological progress using OECD panel data from 1985 to 2012 for 20 countries. We use the pooled regression and the random-effect models. From these empirical results, we derive a positive relationship between population growth and MFP using panel data analysis, thus supporting our assumption that the relationship between population growth and technological progress is positive.

Many developed countries are facing a present or future population decrease. Does this mean that a fall in economic growth is linked to the decreasing speed of technological progress? This is the main theme of this chapter, and we will offer conclusions using theoretical and empirical studies.

First, some technological progress theories are considered in terms of population scale and growth. "Genius hypothesis" or intellectual interaction theories will be analyzed. A discussion regarding the relationship between technological progress and population is also included below. In addition, in regard to the demand side, we also review whether the population scale is important for maintaining the current consumption market.

H. Kato, *An Empirical Analysis of Population and Technological Progress*,
Population Studies of Japan, DOI 10.1007/978-4-431-54959-8_3

Second, we devise a simple model to analyze the effect of population scale on technological progress. This model forms the basis of the empirical study discussed below. As for the implications of this model, the effect of population scale on technological progress is theoretically ambiguous. Since the conclusions depend on the assumption of the model, only an empirical study can confirm the implications of the model.

Lastly, we will show the results of the empirical study to confirm the relationship between population scale, population growth, aging, and technological progress or MFP. Using OECD data from 1985 to 2012 for 20 countries, we obtained a positive relationship between population and MFP by panel data analysis.

3.1 Perspective of Technological Progress and Population Decreasing

3.1.1 Population Scale and Technological Progress

As discussed in Chap. 1, population increase has affected technological progress. Kremer (1993) and others said that a larger population would generate more innovation, new technology, ideas, and so on. Hence, technological progress had been inspired by them. Furthermore, in economics, technological progress (TFP or MFP) has been an engine of economic growth. From the point of view of the production function approach, which is well explained for long-term economic growth, technological progress is one of the most important factors determining the economy's potential. Of course, the labor force, which reflects the total population, is also an important factor for economic growth; however, as seen in Chap. 2, technological progress has had a greater impact on economic growth in recent decades.

However, there is a controversial problem regarding the relationship between economic growth and fertility or birth rates. Although there was a high fertility level in the case of developing economies, a total fertility rate (TFR) in excess of 2.0, this figure has been decreasing in developed economies. In Japan and other developed countries, decreasing birth rates are the main cause of population reduction and an aging. From the view of scale effect of population to technological progress, a decline in the birth rate would have an indirect effect of slowing down technological progress. On the other hand, developed countries, such as the USA, the UK, or France, have maintained their TFR around 2.0 and they are not concerned with a declining population. This mechanism about determination of fertility rates is very difficult to solve.

Figure 3.1 shows the relationship discussed above. Population increase has a scale effect on technological progress, and technological progress is the strongest engine of economic growth. However, the relationship between economic growth and a population increase through the fertility rate is somewhat ambiguous.

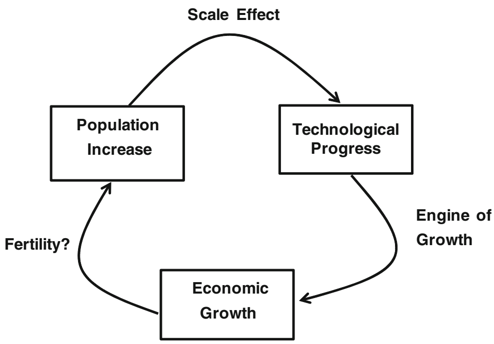

Fig. 3.1 Population and technological progress

With an increase in population, and all other things being equal, it follows that there will be an increase in the number of researchers and innovators. It can therefore be said that the growth rate of the economy is proportional to the total amount of research conducted in society. However, Collins et al. (2013) proposed an interesting view on this point. They wrote that "a complementary driver of technological progress is evolution of the human potential to innovate. As a larger population generates more mutations, population growth will increase the rate at which new traits may emerge. If mutations that increase innovative potential raise the fitness of the host, these genes will spread in the population, enhance technological progress and provide an economic basis for further population growth" (Collins et al. 2013, p. 1). This interesting point of view is broader than an economic discussion.

3.1.2 Technological Progress Perspective and Decreasing Population

In some developed countries, including Japan, if there is a positive relationship between population and technological progress (or productivity improvement), it is anticipated that the growth rate of technological progress will decline as population decreases in the near future. Japan is a country where the scale and speed of population decrease are at its largest and most rapid, relative to other developed nations. Therefore, Japan's declining growth rate of technological progress will be a serious impediment to sustaining its economic growth.[1]

[1]According to "Population Projections for Japan (January 2012)" by the National Institute of Population and Social Security Research, Japan's average annual population growth rate between 2010 and 2060 will be −0.78 %. In addition, according to "World Population Prospects: The 2012 Revision" by the UN, Germany's average annual population growth rate between 2010 and 2100 will be −0.42 %, −11 % in Italy, and −0.20 % in Korea.

Due to the critical nature of Japan's declining population and technological progress, discussions began in the mid-1990s, and various studies have been reported. Those studies will be summarized as follows. The Economic Planning Agency (1995) found that the relationship between the labor force and technological progress or productivity could be grouped into three effects. Firstly, there is the forfeiture effect of scale economy, where the collective power of economic activity declines because of the decreasing growth rate of the labor force. Secondly, there is the forfeiture effect of creative power caused by the decreasing labor force and progressive aging of society. Thirdly, there is the labor-saving effect caused by rising scarcity of the labor force relative to other production factors; therefore, this effect promotes technological progress. If the degree of the third effect is larger than that of the first and second effects, the decreasing labor force promotes technological progress. However, if the opposite is true, then the decreasing labor force is the cause of the decline in technological progress. An empirical study conducted by the Economic Planning Agency (1995) estimated the relationship using cross-country data. The Agency concluded that the growth rate of productivity increased by a decrease in the growth rate of the labor force.

Following this study, many similar studies were published. Yashiro (1999) measured the negative correlation between the growth rate of the labor force and of TFP using data from 1980 to 1991 covering eight advanced countries. The Ministry of Labor (2000) showed the negative and significant coefficient of correlation between the growth rate of the labor force and of TFP using average data from 1975 to 1994 in 10 advanced countries, including Japan. Furthermore, the Cabinet Office (2003) confirmed the negative relationship by regressing the growth rate of TFP on the growth rate of employees by pooling data from the OECD's database covering the period from 1981 to 2000.

Oguro and Morisita (2008) used a panel data set of G5 countries and empirically analyzed in detail the relationship between the scale of the population and technological progress, theoretically and mathematically. However, they found a positive relationship. Unlike the other studies, it regarded the scale of the population itself, not the growth rate of the labor force, as an explanation variable.

As for the relationship between population and economic growth, there is another point of view of demand. It can be said that economic growth in the short term is dependent on effective demand, such as consumption, investment, or government expenditure. According to this traditional Keynesian perspective, population numbers are an important factor in economic performance. In this view, a reduced population size leads to a decline in economic growth. This lower economic growth introduces the possibility of reduced investments in technology.

In addition, there is a relationship between the economy of accumulation, or the economy of scope, and the scale of population. As population increases, and more consumers enter the market, the possibility of generating new or niche markets will increase through the diversity of consumer demand. Similarly, population size supports economic growth through the development of new markets. Furthermore, we consider that the development of new or niche markets generates a positive impact on technological progress.

3.2 The Theoretical Setting for an Empirical Analysis

To examine the relationship between the scale of population and the growth rate of TFP, we formalize the hypothesis presented by Kuznets (1960) and others, discussed above. Here, we introduce the underlying theoretical model for an empirical analysis.[2]

L means labor force and a part of which, L_A, is engaged in technological development and another part of which, L_Y, works in general production. Hence, we have the following:

$$L = L_A + L_Y. \tag{3.1}$$

Next, pursuant to this hypothesis, the ratio of workers engaged in technological development to total workers is constant, and its ratio represents γ_A, and then

$$\gamma_A = L_A/L,$$

and it determines the number of workers who are in general production as

$$L_Y = (1 - \gamma_A)L.$$

We have the simple production function that

$$Y = AL_Y,$$

where Y is income and A means productivity. The income per capita is described as follows:

$$y = A(1 - \gamma_A). \tag{3.2}$$

With regard to technological progress, we assume its rate, $\dot{A}/A$, as follows. The technological progress rate is determined by both input of labor and the "cost" of technological development. The cost of technological development describes μ, and then, Eq. (3.3) is established.

$$\frac{\dot{A}}{A} = \frac{L_A^\beta}{\mu} = \frac{L^\beta \gamma_A^\beta}{\mu}, \tag{3.3}$$

where β is a constant for representing effectiveness and direction of labor input.

In a case where $\beta > 0$, then as the labor force engaged in technological development increases, the rate of technological progress accelerates. However, where $\beta < 0$, the opposite situation is true. Furthermore, in the case that the aging will

[2]This model is in reference to Jones (2005).

promote in the society and the younger population who have creative ability will decrease, then μ will rise and the growth rate of technological progress will fall in relation.

Assuming that γ_A is constant, the reduced equation for the following empirical test is,

$$\frac{\dot{A}}{A} = F(L \text{ or } P, \mu, X), \tag{3.4}$$

where P means population, which determines the size of labor, and X means other factors that affect technological progress.

On the other hand, it can be considered that γ_A is function of labor, L.

$$\gamma_A = \gamma_A(L)$$

A constant γ_A ratio means that an increase in labor or population is the reason for an increase in labor engaged in technological development, thereby facilitating technological progress.

However, can we say that the ratio γ_A is constant? What would happen if an increase in labor did not add more workers engaged in technological development? In other words, if such workers have a certain special innate ability, then there is the possibility that an increase in the rate of workers engaged in technological development would be less than the growth rate of the total labor or population. If this proposition were correct, we could not exclude the possibility that a population increase would result in reducing the ratio, γ_A. In that case, the relationship between labor or a population increase and technological progress would be negative.

The above inference can be described as follows. Because $L_A = \gamma_A(L) \times L$, then

$$\frac{\mathrm{d}L_A}{\mathrm{d}L} = \gamma'_A L + \gamma_A.$$

If $\gamma'_A < 0$, then

$$\frac{\mathrm{d}L_A}{\mathrm{d}L} > \text{or} < 0.$$

Considering $L_Y = L - L_A = (1 - \gamma_A(L))L$, then we get

$$\frac{\dot{A}}{A} = F(L_A, \mu) \rightarrow \frac{\partial F}{\partial L} = \frac{\partial F}{\partial L_A}\frac{\mathrm{d}L_A}{\mathrm{d}L} > \text{or} < 0, \quad \frac{\partial F}{\partial \mu} < 0.$$

There is a possibility that an increase in labor provides a more labor-intensive production system, which results in a decline in labor productivity. The decline in labor productivity might mean that there is a negative relationship between labor and technological progress. In any case, by regressing the rate of technological progress on population or labor, we should hypothesize the relationship between them from the estimated coefficients. In an empirical study, we should consider other factors that affect technological progress. For example, the diffusion of technology and introduction of new technology from other areas or countries would promote the growth rate of technological progress or productivity. Considering this diffusion effect, we should employ an explanation variable which proxies this effect in an empirical analysis. In the following part of this section, we will verify the above discussions.

3.3 Preparation for Empirical Analysis

3.3.1 Outline of Data

MFP data are published by the OECD as a proxy indicator for technological progress (a concept introduced in Chap. 2 is used in this empirical analysis as an objective variable). These data are from "MFP based on Harmonized Price Indices for ICT Capital Goods, Capital Input, Cost Shares, Total Factor Input" published by the OECD in 2007. This database includes MFP data for 20 member nations of the OECD from 1985 to 2012; we can therefore use this as panel data. However, this database is unbalanced, as it lacks data from some nations.

MFP is defined as the difference between the rate of change of output (Q) and the rate of change of input (X), as shown in Eq. (3.5).

$$\ln\left(\frac{\mathrm{MFP}_t}{\mathrm{MFP}_{t-1}}\right) = \ln\left(\frac{Q_t}{Q_{t-1}}\right) - \ln\left(\frac{X_t}{X_{t-1}}\right) \tag{3.5}$$

Output (Q) is measured as GDP at constant prices for the entire economy from the OECD Annual National Accounts, and input (X) is composed of labor force and seven kinds of capital stock, weighted by cost share. The difference with ordinary TFP is that MFP adopts the multikinds of capital stock.

For analyzing MFP, we also use an aging ratio (ratio of population 65 and older to the total population), obtained from the OECD's "Labour Force Statistics." In the following analysis, the value of the scale of population is transformed into a logarithmic value.

Figure 3.2 shows the transition in MFP of seven major countries, such as Canada, France, Germany, Italy, Japan, the UK, and the USA. As for the average value of MFP in the sample period, Japan had the highest value (1.26 %, 1985–2012) of the seven countries, followed by the UK (1.13 %, 1985–2011), the USA (1.08 %, 1985–2012), and so on. Canada recorded the lowest value (0.38 %, 1985–2012), and Italy's value was 0.42 % (1985–2007).

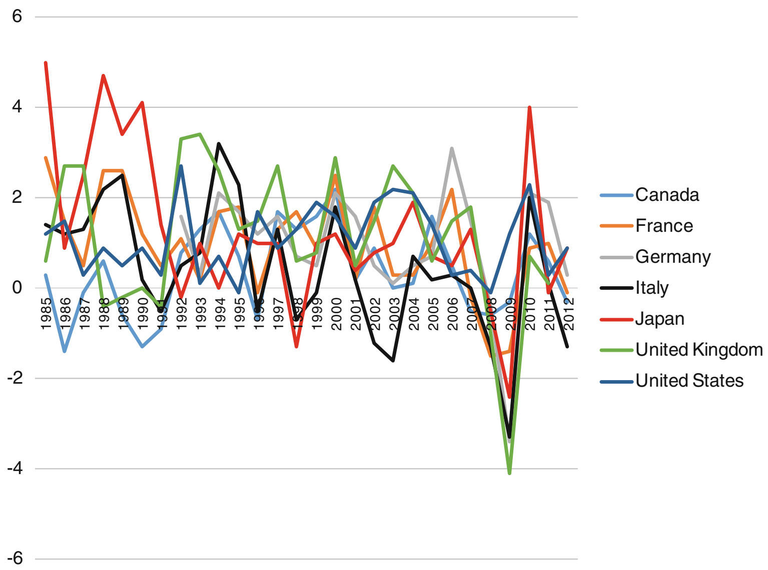

Fig. 3.2 Transition in MFP for major countries. *Data* OECD database

3.3.2 Estimation by Panel Data Analysis

In the panel data analysis, assumptions concerning the cross section (20 OECD countries) and time series (1985–2012) are needed. In the international comparison analysis, it is necessary to consider the heterogeneity of each country, that is, a cross section. In such a case, there are three estimation methods.

The first is a method of pooling panel data, assuming that heterogeneity does not exist in the cross section, and this is called the pooling model (common constant term model). Y is a dependent variable, X is an independent variable, the cross section is indicated by subscript i and time by subscript t, and u is a disturbance term. The pooling model is shown by Eq. (3.6).

$$Y_{it} = \alpha + \beta X_{it} + u_{it} \tag{3.6}$$

The second method is a fixed-effect model, which absorbs heterogeneity with dummy variables. For Eq. (3.6) of the pooling model, it was assumed that the constant term was common in the cross section. However, the heterogeneity in the cross section is indicated by the dummy variable of each unit in the fixed-effect model. The fixed-effect model is shown by Eq. (3.7).

$$Y_{it} = \alpha_i + \beta X_{it} + u_{it} \tag{3.7}$$

The third method is a random-effect model. It is assumed that the heterogeneity of the cross section is included in part of the disturbance term as shown by Eq. (3.8). Because the disturbance term contains a peculiar cross section term, heteroskedasticity should be assumed in the model. Therefore, the method of generalized least square (GLS) is used for the estimation.

$$Y_{it} = \alpha + \beta X_{it} + (v_i + u_{it}) \tag{3.8}$$

The model's application judgment is roughly as follows. Concerning the selection of the pooling model and the fixed-effect model, it judges it by the F test, in terms of whether the dummy variable of each country is significant and effective. Moreover, the Hausman test is used for selecting the fixed-effect model and the random-effect model. The null hypothesis of the Hausman test is that the random-effect model is appropriate. This test statistic follows the chi-square distribution, and the null hypothesis is rejected when the value is large and the fixed-effect model will be selected.

3.4 Estimation Results

3.4.1 General Case

We will confirm whether there is a positive relationship between population and technological progress from historical data of OECD countries.

Table 3.1 shows the results of panel regression when the dependent variable is the growth rate of MFP for 20 OECD member nations. Explanation variables include the scale of population, aging ratio, indicator for economic openness, and the population growth rate. Those variables are adopted by the theoretical setting in Sect. 3.2 and the assumptions in the above discussions. The aging ratio means the development of technology. As for the indicator for economic openness with other countries, we adopt a ratio of the total amount of exports and imports to GDP as the proxy variable. In addition, the financial crisis dummy was set as 1 in 2008 and 2009, and set as 0 in other years.

The estimation methods are the pooling regression model and the random-effect model.[3] MFP was regressed on population by the pooling model in case (A-1) and by the random-effect model in case (A-2). The estimated parameters for population in the logarithm were 0.014 and −0.016, respectively. Those are not significant, so that the above discussion regarding the positive relationship between them was not supported. In addition, in cases (B-1) and (B-2), those are added as a variable of the aging ratio. Thus, the estimated parameters for population were 0.043 and 0.051,

[3]Because the scale of population of the sampled countries varied greatly, it was difficult to absorb the difference or to measure the cross section effect by dummy variable, so we did not adopt the fixed-effect model and instead utilized the GLS method.

Table 3.1 Estimation result of effect of population on MFP—OECD 20 countries

Case	(A-1)	(A-2)	(B-1)	(B-2)	(C-1)	(C-2)	(C-3)	(C-4)	(D-1)	(D-2)	(D-3)	(D-4)
Model	Pooling	Random	Pooling	Random	Pooling	Random	Pooling	Random	Pooling	Random	Pooling	Random
Constant	1.081 (1.88)	1.363 (0.849)	3.491*** (5.74)	3.053** (2.21)	2.011** (2.504)	1.872 (1.190)	2.268** (2.54)	1.282 (0.713)	3.362*** (4.00)	2.378 (1.63)	3.936*** (4.30)	1.626 (0.974)
Population (in logarithm)	0.014 (0.250)	−0.016 (−0.097)	0.043 (0.804)	0.051 (0.385)	0.152** (2.30)	0.151 (1.02)	0.141* (1.95)	0.230 (1.37)	0.137** (2.09)	0.159 (1.18)	0.131* (1.85)	0.262* (1.70)
Aging ratio			−0.1879*** (−8.58)	−0.163*** (−4.94)	−0.191*** (−8.77)	−0.181*** (−5.18)	−0.214*** (−8.71)	−0.233*** (−5.63)	−0.245*** (−10.1)	−0.203*** (−5.77)	−0.287*** (−10.6)	−0.257*** (−6.22)
Openness					0.638*** (−2.80)	0.635 (1.577)	0.878*** (3.36)	1.429*** (3.04)	0.655*** (2.90)	0.785** (2.04)	0.939*** (3.67)	1.727*** (3.81)
Inc. rate of population									−72.02*** (−5.10)	−60.4*** (−3.88)	−94.1*** (−6.08)	−86.5*** (−5.15)
Financial crisis dummy	−2.529*** (−9.52)	−2.512*** (−10.87)	−2.214*** (−8.79)	−2.252*** (−9.60)	−2.289*** (−9.10)	−2.302*** (−9.73)			−2.133*** (−8.57)	−2.223*** (−9.42)		
Estimation period	1985–2012	1985–2012	1985–2012	1985–2012	1985–2012	1985–2012	1985–2007	1985–2007	1986–2012	1986–2012	1986–2007	1986–2007
Hausman test	–	0.125	–	0.931	–	0.964	–	0.308	–	0.674	–	0.161
R^2	0.143	0.179	0.246	0.212	0.255	0.214	0.157	0.065	0.290	0.234	0.224	0.113
S.E.	1.615	1.406	1.515	1.386	1.505	1.384	1.467	1.287	1.475	1.346	1.413	1.257
Number of samples	534	534	534	534	534	534	439	439	519	519	424	424

(1) Dependent variable is MFP
(2) *t*-value in parenthesis, *** means 1 % significant, ** means 5 % significant, and * means 10 % significant
(3) Database is unbalanced panel data including missing values

respectively; however, those are also insignificant, and the assumption was not accepted. As for the estimated parameters of aging, these were established as −0.188 and −0.163, respectively, and were statistically significant. From these values, we can conclude that aging has a negative effect on MFP.

In regard to the determinant factors of MFP, there is the possibility that it is not sufficient to control the model because important variables are lacking. We then added the variable that represents economic openness as an explanatory variable.[4] In case (C-1), this was estimated by pooling regression. The parameter value of population was 0.152, a positive value and statistically significant. In case (C-2), this was estimated by the random-effect model and the parameter of population was 0.151, also a positive value. However, the *t*-value of this parameter was small and was not significant. In cases (C-3) and (C-4), which do not include the financial crisis dummy, the estimated parameter values of population were positive, 0.141 and 0.230, respectively; however, they were insignificant. In case (C-4), the estimated parameter of aging ratio was −0.233, economic openness was 1.429, and both were significant.

In cases (D-1) and (D-2), including the growth rate of population as the explanatory variable, it showed that there was a positive relationship between the growth rate of population and that of technological progress. The estimated parameters of the growth rate of population were −72.0 in case (D-1) and −60.4 in case (D-2). Finally, in cases (D-3) and (D-4), excluding the financial crisis dummy, the estimated parameters for population were 0.131 and 0.262, respectively, and both positive and statistically significant at 10 %. In addition, the parameters of the growth rate of population were −94.1 and −86.5, respectively. From these results, the above discussion about the positive relationship between population and technological progress is supported.

3.4.2 Ten Large Countries

We selected 10 large countries of economic scale from 20 OECD member countries Canada, France, Germany, Italy, Japan, Spain, Sweden, Switzerland, the UK, and the USA, and analyzed them using the same method as the above section.[5]

Table 3.2 shows the results. In cases (A-1) and (A-2), the explanatory variable was the scale of the population only, and the estimated value of the parameter was not statistically significant, as in Table 3.1. The estimated method of case (A-1) was the pooling model, and the parameter of the population was 0.089. In case (A-2), the estimated method was the random-effect model and the parameter of population was −0.075.

[4]We considered the ratio of gross investment to GDP, but meaningful results were not obtained.

[5]Those countries were selected not only by their economic scale, but also by whether there was lacked value or not.

Table 3.2 Estimation result of effect of population on MFP—OECD large 10 countries

Case	(A-1)	(A-2)	(B-1)	(B-2)	(C-1)	(C-2)	(C-3)	(C-4)	(D-1)	(D-2)	(D-3)	(D-4)	(D-5)	(D-6)
Model	Pooling	Random	Pooling	Random	Pooling	Random	Pooling	Random	Pooling	Random	Fixed	Pooling	Random	Fixed
Constant	0.295 (0.21)	2.093 (0.422)	0.741 (0.589)	−0.158 (−0.04)	−2.418 (1.64)	−2.628 (−0.69)	−2.715* (1.69)	−4.247 (−1.06)	0.672 (0.417)	0.639 (0.415)	−6.100 (−0.369)	1.193 (0.712)	−0.494 (−0.233)	14.10 (0.68)
Population (in logarithm)	0.089 (0.683)	−0.075 (−0.166)	0.320*** (2.74)	0.370 (1.128)	0.536*** (4.24)	0.575 (1.64)	0.576*** (4.29)	0.747** (2.03)	0.370*** (2.86)	0.371*** (2.99)	0.905 (0.592)	0.380*** (2.85)	0.471*** (2.61)	−0.924 (-0.481)
Aging ratio			−0.212*** (−9.12)	−0.187*** (−5.40)	−0.219*** (−9.62)	−0.234*** (−5.76)	−0.243*** (−9.73)	−0.307*** (−6.72)	−0.263*** (−10.5)	−0.263*** (−10.92)	−0.217*** (−3.94)	−0.306*** (−11.5)	−0.287*** (−9.05)	−0.333*** (−5.21)
Openness					1.845*** (3.92)	1.846** (2.26)	2.236*** (3.95)	3.405*** (3.49)	1.466*** (3.11)	1.472*** (3.27)	1.367 (1.23)	1.785*** (3.29)	2.341*** (3.56)	4.743*** (3.33)
Inc. rate of population									−71.50*** (−4.11)	−70.85*** (−4.27)	−26.9 (−1.26)	−104.3*** (−5.47)	−78.0*** (−3.81)	−43.9* (−1.73)
Financial crisis dummy	−2.115*** (−5.90)	−2.100*** (−7.11)	−1.671*** (−5.25)	−1.740*** (−5.96)	−1.814*** (−5.89)	−1.814*** (−6.20)			−1.622*** (−5.28)	−1.624*** (−5.56)	−1.793*** (−5.56)			
Estimation period	1985–2012	1985–2012	1985–2012	1985–2012	1985–2012	1985–2012	1985–2007	1985–2007	1986–2012	1986–2012	1986–2012	1986–2007	1986–2007	1986–2007
Hausman test	–	0.578	–	0.591	–	0.993	–	0.402	–	0.000	–	–	0.002	–
R^2	0.109	0.155	0.317	0.232	0.352	0.243	0.320	0.159	0.388	0.386	0.447	0.403	0.269	0.486
S.E.	1.544	1.261	1.350	1.214	1.316	1.203	1.249	1.089	1.274	1.273	1.212	1.165	1.114	1.080
Number of samples	272	272	272	272	272	272	223	223	263	263	263	214	214	214

(1) Dependent variable is MFP
(2) *t*-value in parenthesis, *** means 1 % significant, ** means 5 % significant, and * means 10 % significant
(3) Database is unbalanced panel data including missing values

In cases (B-1) and (B-2), the aging ratio was added as an explanatory variable, and the estimated parameters of the population were 0.320 and 0.370, respectively. The result by the pooling model case in (B-1) was significant; however, the random-effect case in (B-2) was not significant. Additionally, the parameters of the aging ratio were −0.212 and −0.187, respectively, and were significant.

In cases (C-1) and (C-2), the variable of economic openness and financial crisis dummy were added to the model. The estimated parameters of population were both positive; however, in case (C-2), using the random-effect model, the estimated parameter was not significant. As for other explanatory variables, the parameters of aging ratio were negatively significant and those of economic openness were positively significant, which were consistent with the assumptions. Also, the financial crisis dummy was also negatively significant.

Cases (C-3) and (C-4) excluded the financial crisis dummy from the model in cases (C-1) and (C-2). The estimated parameters of population were 0.576 and 0.747, respectively. Both parameters were positive and statistically significant, and this empirical result is consistent with the above discussion about the relationship between population and technological progress. In case (C-4), with the random-effect model, the estimated parameter of the aging ratio was −0.307, which was negatively significant; however, the parameter for economic openness was 3.405, both positive and significant.

Next, in cases (D-1) to (D-6), the variable of growth rate of the population was added as an explanatory factor. The estimated parameter of population was 0.370 in case (D-1) and 0.371 in case (D-2). Both were positively significant and consistent with the hypothesis. However, in case (D-3), which is by fixed-effect model, the estimated parameter of population was positive, but not significantly. As for the estimated parameter of growth rate of population, it was −71.5 in case (D-1) and −70.9 in case (D-2). Both were negatively significant, which is also consistent with our assumption. The estimated parameters of aging ratio were −0.263 and −0.263, respectively, in cases (D-1) and (D-2). Cases (D-4) and (D-5) excluded the financial crisis dummy from cases (D-1) and (D-2); however, we obtained almost the same results and confirmed the positive relationship between MFP and population scale or growth rate of population. Those results are supported by the above discussions.

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Conclusions and Remaining Problems

The purpose of this study was to investigate the relationship between population and technological progress, both theoretically and empirically. Firstly, in Chap. 1, we summarized and introduced a variety of views on the relationship between population and technological progress and considered various possibilities for a positive relationship, referring to previous studies. However, there are other theoretical models related to this field; it is therefore necessary to revisit these in order to further explore the relationship.

Next, we confirmed that technological progress is the main factor of economic growth, and calculated the contribution of MFP to the annual economic growth rate using the growth accounting method in OECD countries. In addition, we considered the simple empirical results of the relationship between economic growth and population scales. In Chap. 2, we observed the negative relationship between economic growth and population growth, which is prospected from the Solow growth model. However, the statistical significance of the relationship in the empirical analysis is somewhat ambiguous because the estimated correlation coefficients of absolute value are small.

In Chap. 3, we considered the effect of population decrease on technological progress, and formulated a hypothesis to explain it. However, those depend on the hypothesis, not on empirical or theoretical view. After setting the theoretical model, we attempted to estimate the relationship between MFP and population. Of course, it is obvious that technological progress is dependent not only on the scale or growth of population but also on other factors. We considered the effect of economic openness or the aging of society on MFP in the model. In some cases, we confirmed that the estimated parameter of population is positive and statistically significant to MFP; therefore, the empirical result in Chap. 3 is almost consistent with the above hypothesis regarding the relationship between population and technological progress.

We should note that it is insufficient to analyze the relationship between technological progress and population in this study. Therefore, in the future, we should improve the remaining problems that we could consider.

H. Kato, *An Empirical Analysis of Population and Technological Progress*,
Population Studies of Japan, DOI 10.1007/978-4-431-54959-8