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Tamotsu Nakamura · Tomoyuki Tamagawa ·
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Education, Human Capital Investment, and Innovation in the Contemporary Japanese Economy

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Preface

Economics is essentially the study and analysis of economic phenomena to contribute to improving people's wellbeing. However, reflecting on my career as an economist, I believe that modern-day economics has become either merely the study of economics or a sophisticated undertaking intended to explain economic statistics and the relationships among them. Though most economists are aware that the goal is to improve people's welfare through their studies, many of them seldom pursue it further given the pressure of publication. They produce academic articles directly from former articles or conceptualize previous studies by merely analyzing the statistical figures.

In a broader sense, it may be ideal for students to spend twenty years or more engaging with the real economy, and then pursue the study of economics rather than immediately entering academia after graduating from a university. However, this would make it difficult for working graduate students to reach the cutting edge of economics in at least two respects. The first is the length of the absence from their studies. Economics utilizes several analytical methods such as mathematics, which, when not used on a regular basis, can lead to the inability to develop mathematical equations and obtain the results that they try to derive. Furthermore, academic skills such as critical thinking and interpretation also suffer when an individual is away from research for an extended period.

The second reason is that economics has made great progress, at least on the technical side, in the past few decades. New analytical methods have been developed, and the results from research in other fields have been incorporated, allowing graduate students to acquire novel knowledge beyond that acquired as undergraduates. Given the huge gap that exists between undergraduate economics and graduate economics, even regular students who enter graduate school right after university struggle with studies. Furthermore, working graduate students must also bridge the gap in due time.

This volume is the product of the research of three working graduate students who overcame these two difficulties and worked to elucidate the economic phenomena that interest them. Moreover, as I have done in this regard, they had to conquer language barriers to publish their research and make it available to a larger group of readers. Noteworthy is the fact that the four authors of this book share a common interest in the same economic phenomenon and analyze it from their diverse perspectives. In other words, although their primary focus was on the same issue, they have delved further into it from different perspectives given their distinct backgrounds. The common issue is "the current stagnant Japanese economy."

Tomoyuki Tamagawa, a long-time mathematics teacher in junior high school, is now a vice principal. The two of us have collaborated to write Chap. 1 of this book because we believe that the loss of vitality in the Japanese economy is caused by the problem of human capital formation in school education. Class sizes and student–teacher ratios are often at the core of the debate surrounding the factors that affect educational effectiveness. In contrast, based on his experience in the field and focusing on the time constraints that teachers face, Tamagawa and I have clarified that the student–teacher ratio always has a definite effect on educational outcomes. A decrease in this ratio leads to an increase in educational outcomes. However, the effect on class size cannot be simply identified. The study also shows that the relationships between class size and educational outcomes depend crucially on the characteristics of the subject.

In Chap. 2, Shinji Oi has analyzed the relationship between optimal human capital investment and labor market mobility based on his recognition of the importance of vocational training or human capital investment by firms and the necessity for good allocation of human resources. In the past, Japan was thought to have achieved high growth through the development of human resources within firms. Recently, however, labor mobility has been increasing, which is a primary reason for firms to reduce human capital investment, accounting for a loss of competitiveness for the economy as a whole. At the same time, however, increased labor mobility is thought to contribute to efficient allocation of human capital and promote economic growth. By introducing hypothetical "social firms" that take not only their profits but also the productivity of the economy into account, Oi has analyzed the relationship between labor market mobility and optimal human capital investment and has achieved remarkably interesting results.

In Chap. 3, Tokuji Saita, having a distinguished background in the financial industry, has analyzed and pointed out the importance of the "openness" of innovation from a macroeconomic point of view. Traditionally, innovation has been classified into two categories: process innovation and product innovation. However, as he has discussed, while this classification is important at the microeconomic level, the classification of "disruptive innovation" and "sustainable innovation" and the degree of "openness" or "closedness" of innovation are essential when we analyze an economy's productivity and/or growth. Deriving the optimal ratio of investment between disruptive and sustainable innovation using an interesting formal model, he has clarified the importance of the balance of the two types of innovation. The balance is closely related to the openness of innovation, which is, in turn, related to labor mobility. Saita has finally concluded that the closed nature of innovation is one of the main causes of the Japanese economy's stagnation.

Readers might feel that this volume is a little different from general research books. If so, it is not a failure but a success. It is only natural to have a different impression because it is the result of economic analysis performed by people who have seen the reality of education in the field and vocational training inside a firm and who possess an understanding of corporate behavior through financial activities. In other words, if this book gives the same impression as other research books, at least a part of its contribution has been lost.

An increase in the number of people entering the academic world after gaining working experience would greatly contribute to the discipline's development as well as its diversity. Moreover, to make their contributions to academia clear, they must publish their findings in English. It would be a great pleasure for all the authors if this small volume inspires people who have working experience to become interested in academia.

Kobe, Japan Tamotsu Nakamura
Kobe, Japan Tomoyuki Tamagawa
Ayauta, Japan Shinji Oi
Nara, Japan Tokuji Saita

Acknowledgments

Many professors have offered their helpful advice and encouragement in the process leading to the publication of this volume. Among them, that from Professors Masahiko Ashiya, Kenichi Hashimoto, Yunfang Hu, and Kazufumi Yugami has greatly assisted in significantly improving the content. We would like to take this opportunity to express our sincere gratitude.

The financial support of Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (18K01569) is gratefully acknowledged. The authors would also like to thank the Kobe University Center for Social Systems Innovation for their financial assistance.

Last, but not the least, we thank Professors Shigeyuki Hamori and Yunfang Hu of Kobe University, the editors of the Kobe University Social Science Research Series, who have encouraged us to publish our findings as one of the series.

Kobe, Japan — Tamotsu Nakamura

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Tamotsu Nakamura has been Executive Vice President of Kobe University since 2021 and has served as Professor of Economics since 2003. He is Adjunct Professor of Economics at Xiamen University in China. He was also Visiting Professor of Economics at the University of British Columbia in Canada. He received his Ph.D. from Kobe University. His research interests include macroeconomic dynamics and income inequalities. He has published many papers in refereed journals, such as the *Journal of Economic Inequality*, *Journal of Economic Behavior and Organization*, *Metroeconomica*, and *Sustainability*.

Tomoyuki Tamagawa has served as Vice Principal at Tsukuda Junior High School in Osaka, Japan, since 2021. He has about ten years of experience as a junior high school mathematics teacher. He received his B.A. and M.A. in economics from Kobe University. He is now a Ph.D. student at Kobe University. His main research interests include the economic effects of education and human capital investment.

Shinji Oi has worked for more than 35 years at a Japanese broadcasting station and possesses extensive experience in human resource development. He received his B.A. and M.A. in economics from Kobe University. He also obtained his M.S. from Okayama University of Science. He is now a Ph.D. student at Kobe University. His research focuses on economic growth through human resource development and labor mobility.

Tokuji Saita is well versed not only in the realities and practices in the financial industry but also in the financial system as a whole. He worked as a front-line banker for Sumitomo Mitsui Banking Corporation for about 30 years and then insurance agency Ginsen Corporation as a managing executive officer. He received his B.A. and M.A. in economics from Kobe University. He is now a Ph.D. student at Kobe University. His main research interests are economic growth and innovation.

Chapter 1
Relationship Between Educational Attainment and Class Size: Effects of Teacher Resource Allocation

Tamotsu Nakamura and Tomoyuki Tamagawa

Abstract Analyzing the determinants of educational attainment, with class size being one of the most important among them, is crucial in investigating the accumulation of human capital and economic growth. However, we have not yet reached a clear conclusion regarding the relationship between class size and educational attainment. Some empirical studies show a positive correlation, while others find the correlation negative. In this chapter, we analyze the direct and indirect impacts of class size on educational attainment through the allocation of teachers' efforts. We focus on the relationship between class size and teachers' working hours to construct a formal model that endogenizes the time spent outside of class to prepare teaching materials and the time spent preparing for classes. The empirical results reveal that the relationship between class size and educational attainment can be U-shaped, inverted U-shaped, upward sloping, or downward sloping. This suggests the existence of the optimal class size as well as the most inappropriate class size. In addition, the analysis points out that grade levels and the characteristics of each subject are as important as class size in achieving the maximum educational attainment, given limited educational resources.

Keywords Educational attainment · Teacher resource allocation · Class size · Pupil–teacher ratios

1.1 Introduction

Class size is believed to greatly impact educational attainment. This relationship has been of great interest not only in economics but also in pedagogy and educational psychology.

Class size is crucial for managing students in a class through its effect on their emotional and behavioral faculties. Finn, Pannozzo, and Achilles (2003) summarize the empirical results of 10 previous studies on the relationship between class size and student antisocial behavior. Project STAR, which was conducted in the state of Tennessee with 11,600 students and 1,330 teachers, was an experimental economic study focusing on the relationship between class size and educational attainment. Using the data from the experimental study, Krueger (1999) shows that students

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assigned to smaller classes obtain higher scores. Krueger and Whitmore (2001) also investigate the impact of Project STAR on subsequent college entrance examinations and report that those who were assigned to smaller classes were 2.7% more likely to take the ACT or SAT than their counterparts. Moreover, the Black students assigned to small classes were 5.9% more likely than their counterparts to take the tests. Thus, irrespective of race and gender, the smaller the class size, the better the educational attainment, indicating the effectiveness of small class sizes.[1]

Hanushek (1999) focuses on pupil–teacher ratios to reexamine 276 empirical studies. The results reveal that 14% of them show a positive relationship between pupil–teacher ratios and academic attainment, while 14% show a negative relationship, and 72% show no relationship. Thus, the effectiveness of pupil–teacher ratios cannot be satisfactorily detected. Although much focus has been placed on research regarding class size or pupil–teacher ratios, including Project STAR, no clear conclusion has been reached regarding their impact on educational attainment. Many people think that there is a negative correlation between class size and educational attainment. In reality, various types of correlations have been observed.

Turning to the analysis in Japan, Akabayashi and Nakamura (2014) analyze the relationship between class size and educational attainment using data from Japan's National Assessment of Academic Ability (NAAA) and the Yokohama City Achievement Test (YCAT) for 2008 and 2009. The analysis reveals that the Japanese language test scores of 6th-grade students yielded the most significant negative correlation. Senoh, Hojo, Shinozaki, and Sano (2014) also conduct an analysis using data from Japan's NAAA for 2009, reaching a similar conclusion to that of Akabayashi and Nakamura (2014): namely, a negative correlation between class size and educational attainment. Thus, data from both studies show a positive effect of reduced class size on educational attainment among 6th-grade Japanese language test scores. However, both studies show a less significant correlation for 6th-grade mathematics or 9th-grade Japanese language and mathematics. Although it may be thought that a negative correlation exists between class size and educational attainment, this has not always been found to be the case.

Let us examine the relationship between class sizes and educational attainment in various countries. Figure 1.1 shows the relationship between average PISA test scores in 2018 in OECD countries and the average class size in junior high schools, including both public and private schools. Japan is indicated by a red dot in the graphs for all subjects. Since Japan is considered an outlier, excluding its data, the test scores decrease as class size increases beyond a certain point, as the dotted curves show. However, the relationships between class size and test scores are not necessarily the same for all class size areas. For example, in the case of mathematics scores, the relationship between class size and test scores is upward sloping in the 16–19 range and downward sloping in the 20 + range. In other words, maximum attainment is achieved in the 17–20 range. Thus, no clear evidence exists for the monotonic relationship between class size and educational attainment.

[1] See, for example, Angrist and Lavy (1999), who analyze Israel's class size rules to estimate the effect on educational achievement.

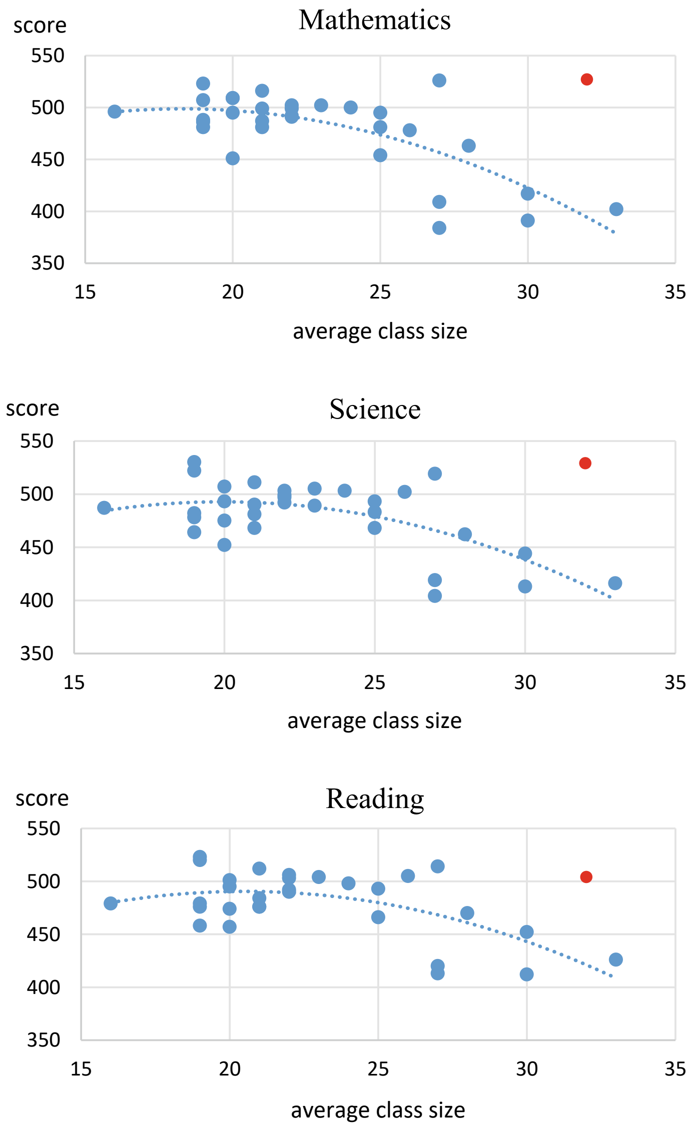

Fig. 1.1 PISA test score and class size 2018. Created from https://data.oecd.org/pisa/reading-attainment-pisa.html. OECD (2020), Education at a Glance 2020*: OECD Indicators*, OECD Publishing, Paris, (https://doi.org/10.1787/69096873-en)

Figure 1.2 shows the results of Japan's NAAA for 2019. Similar to the results obtained by Akabayashi and Nakamura (2014) and Senoh, Hojo, Shinozaki, and Sano (2014), a negative correlation is found for the Japanese language test scores in 6th grade, while no correlation is found for 6th-grade mathematics and 9th-grade Japanese language and mathematics. In addition, a positive correlation is found between class size and educational attainment for English test scores. As shown in Figs. 1.1 and 1.2 and established in previous studies, there is no consistent correlation between class size and educational attainment. This leads us to the conjecture that other factors, such as characteristics of the subject and grade level, also play a key role.

These counterintuitive empirical results with respect to the relationship between class size and educational attainment are called the "class size puzzle." Lazear (2001) conducts a theoretical investigation on this puzzle by focusing on interactions among students. The analysis was based on the assumption that positive interactions (positive peer effects) occur when well-behaved students gather in a class, while negative interactions (negative peer effects) occur when poorly behaved students gather. In the former case, increasing the class size improves educational attainment, while in the latter case, decreasing the class size improves educational attainment. Bosworth and Caliendo (2007) also explain the class size puzzle by focusing on the amount of time a teacher spends lecturing to a whole class compared with the time spent with less able students.[2]

An agreed upon fact is that the smaller the class size, the better the teacher's control over a class, thereby leading to better educational attainment in a small class. Therefore, in pedagogy and educational psychology, analyses have focused on a teacher's control of a class and the students' cognitive and non-cognitive abilities alike. However, the analysis must also consider the allocation of limited educational resources while increasing or decreasing class size. It is apparent that increasing class size will reduce the number of hours teachers engage with a class. Conversely, reducing class size will lead to an increase in a teacher's lecturing time. In a case where educational resources are not limited, and the class size is small, educational attainment will be higher; thus, setting pupil–teacher ratios to 1, or one-to-one education, would be optimal. However, since educational resources are limited, this is impossible. Moreover, as Lazear (2001) points out, a negative correlation does not always exist between class size and educational attainment. Keeping this in mind, the relationship between class size and educational attainment needs to be analyzed and clarified considering that educational resources, especially teacher working hours, are limited. In other words, the resources are used not only in class but also outside of class. The effects of the allocation of the limited teachers' working hours is the main concern of this chapter.

In this chapter, we take a different approach to solving the class size puzzle compared with those taken by Bosworth and Caliendo (2007) and Lazear (2001). We focus on teachers' limited working hours, an invaluable educational resource that is not adequately taken into account in the literature. In the model presented in this

[2] Schanzenbach (2020) well summarizes recent studies on class size effect.

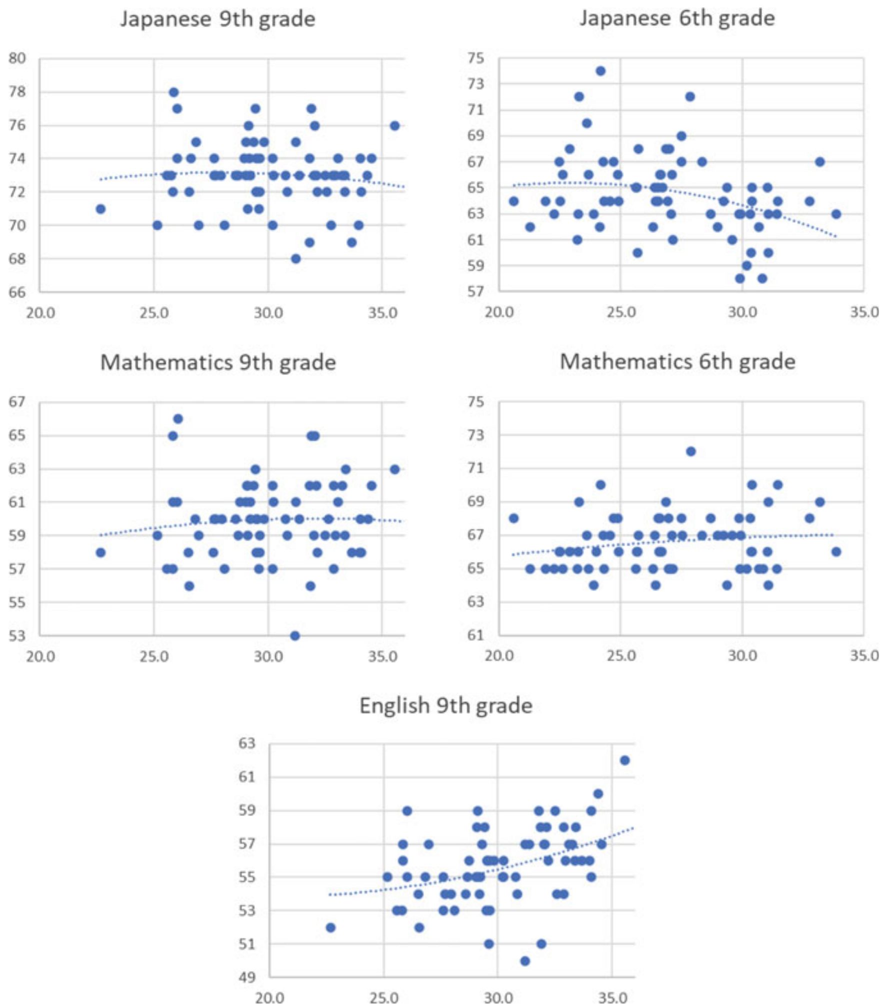

Fig. 1.2 National Assessment of Academic Ability score and class size 2019. [47 prefectures + 20 ordinance-designated cities] Created from https://www.nier.go.jp/19chousakekkahoukoku/factsheet/19prefecture-City/

chapter, teachers' time is endogenously allocated to classes and other educational activities. The model allows us to analyze the impact of class size and the pupil–teacher ratio on educational attainment. The simulation analysis demonstrates that our approach can solve the class size puzzle.

This chapter is organized as follows. Section 1.2 presents a theoretical model to analyze the relationship between class size and educational attainment. Section 1.3 specifies the model for conducting the simulation and to explain the possibility that the relationship between class size and educational attainment can be U-shaped, inverted U-shaped, downward sloping, and/or upward sloping. Section 1.4 presents the simulation analysis and the interpretations and implications of the results. Section 1.5 concludes the chapter and discusses future issues.

1.2 Model

1.2.1 The Basic Setup

Shedding light on the allocation of educational resources, which has been rather overlooked in former studies, we analyze the relationship between class size and educational attainment. Here, we assume that the number of classes each student takes is constant. Therefore, the number of classes per student does not change even if class size changes. The total number of classes offered by the school decreases as class size increases and vice versa. When class size increases, since the number of classes per teacher decreases, the time that one teacher spends for educational activities other than teaching the class increases. These non-classroom educational activities include preparing teaching materials, tutoring students, and responding to parents. Thus, the finite educational resource, namely teachers' working hours, is allocated to classes and non-class educational activities. Let us now consider how non-classroom educational activities change in response to changes in class size, and show that they play an important role in determining the relationship between class size and educational attainment.

In reality, the number of classes a student takes is fixed for each subject, so the number of classes per student does not change. Hence, we can assume that a change in class size leads to a change in the number of classes taught by a teacher. In other words, it is natural to assume that adjusting class size will change the number of hours that teachers spend in class. If class size is large, teachers will spend less time in class and more time outside of class. This will positively impact educational attainment because teachers are then able to use the saved time for other educational activities, such as preparing for class and understanding students' characteristics. In contrast, a smaller class size increases the number of class hours and decreases the hours spent on other educational activities than in class, which may have a negative impact on educational attainment.

Let us construct a formal model. All class sizes are the same, S_c, and the total number of students in the school is N_S. If all students attend only one class, the number of classes is N_S/S_c. Hence, if all students attend n classes, the total number of classes, T_s, is

$$T_s = n \times \frac{N_S}{S_c} \tag{1.1}$$

Assuming that the number of teachers in the entire school is N_T, the number of classes per teacher N_c is

$$N_c = \frac{T_s}{N_T} = \frac{nN_S}{S_c N_T} \tag{1.2}$$

If a teacher's working hours is H, it is the sum of working hours for classes N_c and working hours outside of classes, X. Thus,

$$H = N_c + X = \frac{nN_S}{S_c N_T} + X \tag{1.3}$$

Denoting the pupil–teacher ratio as PT, since the total number of teachers in the school is N_T, and the total number of students in the school is N_S, we obtain

$$PT = \frac{N_S}{N_T} \tag{1.4}$$

From Eqs. (1.3) and (1.4), we obtain

$$H = \frac{n}{S_c} \times PT + X \tag{1.5}$$

Then, the working hours outside of classes, X, becomes

$$X = H - n\frac{PT}{Sc} \tag{1.6}$$

Equation (1.6) can be expressed in the following functional form:

$$X = X(Sc; H, n, PT) \tag{1.7}$$

Assume here that the number of working hours per day for teachers H, the number of class hours per day for students n, and the pupil–teacher ratio PT are exogenous. If class size S_C, which is an endogenous policy variable, increases, the number of hours worked outside the classroom X increases because the number of teaching hours in class decreases, that is,

$$\frac{\partial \mathrm{X}}{\partial S_c} > 0 \tag{1.8}$$

As previous studies have shown, educational attainment P is mainly determined by class size S_C. However, since the working hours outside class X also have a significant impact on the quality of each class, we assume that educational attainment P is determined by the following function:

$$P = P(S_C, X) \tag{1.9}$$

In this case, the function P has the following properties:

$$\frac{\partial P}{\partial Sc} < 0, \frac{\partial P}{\partial X} > 0 \tag{1.10}$$

The above shows that, as class size decreases, educational attainment increases. Also, as out-of-class work hours increase, educational attainment increases.

From Eq. (1.9),

$$\frac{dP}{dS_c} = \frac{\partial P}{\partial S_c} + \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial S_c} \tag{1.11}$$

In the model presented in this chapter, in which peer effects do not exist, the first term on the right side of Eq. (1.11) is negative, while the second term is positive.[3] Thus, the effect of class size on educational attainment becomes indeterminate. In other words, the model could explain various relationships between class size and educational attainment, depending on the relative magnitudes of the two effects.

1.2.2 Relationship Between Pupil–Teacher Ratios and Educational Attainment

The other important variable PT, the pupil–teacher ratio, is treated as an exogenous variable in the model. As it increases, the teachers' out-of-class time X decreases. In other words, from Eq. (1.6),

$$\frac{\partial X}{\partial PT} < 0 \tag{1.12}$$

Differentiating Eq. (1.10) with respect to PT,

$$\frac{\partial P}{\partial PT} = \frac{\partial P}{\partial X} \cdot \frac{\partial X}{\partial PT} < 0 \tag{1.13}$$

Educational attainment P will be a decreasing function of the pupil–teacher ratio PT. For class size S_c, it can be either an increasing or a decreasing function, as Eq. (1.11) shows.

[3] Lazear (2001) assumes that, in the presence of peer effects, as class size increases, educational outcomes also increase.

1.3 Simulation Analysis

As mentioned above, the first term on the right-hand side of Eq. (1.11) is negative, while the second term is positive. Therefore, the relationship between class size S_C and educational attainment P can be upward sloping, uncorrelated, downward sloping, U-shaped, or inverted U-shaped. Let us confirm it by specifying the functions in the model. Since educational attainment P is determined by class size S_C and out-of-class time X (S_C), Eq. (1.9) is rewritten as follows:

$$P = P(S_C, X) = P_1(S_C) + P_2(X) \tag{1.14}$$

Since P_1 (S_C) is a decreasing function, let us specify it as follows:

$$P_1(S_C) = 90 - 16(S_C - 13)^{\alpha} \tag{1.15}$$

where α is a positive constant. $P_2(X)$ is also assumed as

$$P_2(X) = 70 + X^{\beta}$$

where β is a positive constant.

Substituting the definition of X into the above:

$$X = \left(H - n\frac{PT}{Sc}\right)^{\beta}$$

Hence, $P_2(X)$ becomes

$$P_2(X) = 70 + \left(H - n\frac{PT}{Sc}\right)^{\beta} \tag{1.16}$$

Differentiating Eq. (1.15) by S_C, we obtain

$$\frac{\partial P_1}{\partial Sc} = -16\alpha(S_C - 13)^{\alpha-1} \tag{1.17}$$

Since Eq. (1.17) becomes $P_1^{'}(Sc) < 0$ when $S_C > 13$, we know that Eq. (1.15) is a decreasing function. Since, from Eq. (1.4), the pupil–teacher ratio PT is expressed as N_S/N_T, if, for example, $N_S = 600$ and $N_T = 20, 30, 40$, respectively, $PT = 30, 20, 15$. In what follows, we assume that teachers work 8 hours, that is, $H = 8$, and each student takes 6 classes, that is, $n = 6$. In the following simulation, we will demonstrate that, when $P_1(S_C)$ is a decreasing function, educational attainment P can be upward sloping, downward sloping, U-shaped, or inverted U-shaped with respect to class size S_C.

Table 1.1 $P_1(Sc)$, $P_2(X)$. , and P when $\alpha = 1/5$ and $\beta = 5/3$

(Sc)	P(Sc)	P(X)			P		
		PT = 30	PT = 20	PT = 15	PT = 30	PT = 20	PT = 15
25	63.70	70.57	88.32	110.61	134.27	152.02	174.31
26	63.28	71.20	91.08	113.88	134.48	154.35	177.16
27	62.88	72.05	93.84	117.05	134.93	156.71	179.92
28	62.50	73.10	96.59	120.10	135.60	159.09	182.60
29	62.14	74.31	99.31	123.05	136.45	161.45	185.20
30	61.80	75.66	102.00	125.90	137.46	163.80	187.70
31	61.48	77.13	104.64	128.65	138.60	166.12	190.12
32	61.17	78.69	107.24	131.29	139.86	168.41	192.46
33	60.87	80.34	109.78	133.84	141.21	170.65	194.71
34	60.59	82.04	112.26	136.30	142.63	172.84	196.88

1.4 Simulation Results

Since Eq. (1.14) is the sum of Eqs. (1.15) and (1.16), educational attainment P the sum of $P_1(Sc)$ and $P_2(X)$. The simulation will be performed by substituting specific values for α and β in Eqs. (1.15) and (1.16).

1.4.1 When Educational Attainment P Is Upward Sloping

When $\alpha = 1/5$ and $\beta = 5/2$, educational attainment P is an increasing function of class size S_C, as shown in Table 1.1 and Fig. 1.3. If the pupil–teacher ratio PT decreases, the graph of $P_2(X)$ shifts upward, and the graph of P also shifts upward. In other words, to increase educational attainment P, the pupil–teacher ratio should be lowered, class size should be increased, or both.

1.4.2 When the Educational Attainment P Is Downward Sloping

When $\alpha = 1/5$ and $\beta = 1/2$, educational attainment P becomes a downward sloping curve, as shown in Table1.2 and Fig. 1.4. In other words, while $P_2(X)$ is an increasing function and $P_1(Sc)$ is a decreasing function, the combined outcome P is a decreasing function of Sc. If the pupil–teacher ratio PT decreases, the graph of $P_2(X)$ shifts upward, and consequently the graph of P also shifts upward. Since educational attainment decreases as class size increases, it can be improved by lowering the pupil–teacher ratio, reducing class size, or both.

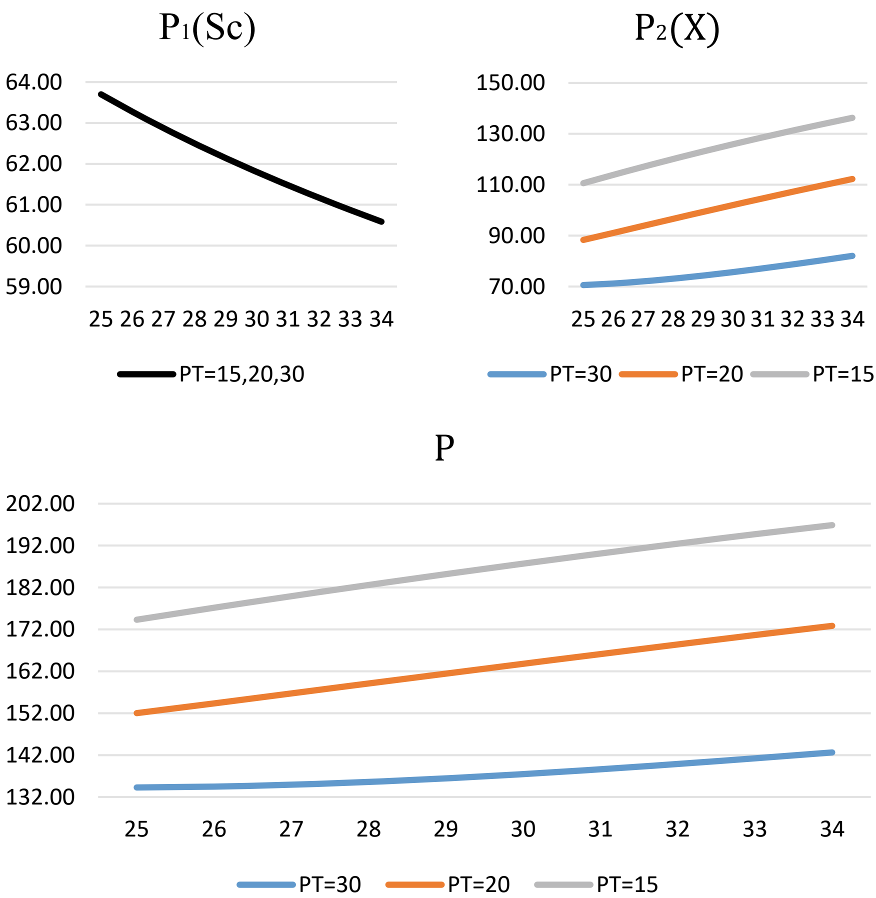

Fig. 1.3 $P_1(Sc)$, $P_2(X)$, and P when $\alpha = 1/5$ and $\beta = 5/2$

1.4.3 When the Graph for Educational Attainment P Is U-Shaped

When $\alpha = 1/5$, $\beta = 4/3$, and $P_T = 30$, a U-shaped graph is obtained for educational attainment, as shown in Table 1.3 and Fig. 1.5. In this case, the most inappropriate class size exists because the educational attainment P takes the minimum value when $S_C = 29$. We can increase the educational attainment P by making the class size either larger or smaller than the most inappropriate class size. Additionally, lowering the pupil–teacher ratio PT will increase $P_2(X)$, which will, in turn, increase the educational attainment P. In other words, if the graph for educational attainment P is U-shaped, educational attainment can be improved by controlling the class so that it is away from the most inappropriate one, and/or by lowering the pupil–teacher ratio.

Table 1.2 $P_1(Sc)$, $P_2(X)$, and P when $\alpha = 1/5$ and $\beta = 1/2$

(Sc)	P(Sc)	P(X)			P		
		PT = 30	PT = 20	PT = 15	PT = 30	PT = 20	PT = 15
25	63.70	70.89	71.79	72.10	134.59	135.49	135.80
26	63.28	71.04	71.84	72.13	134.31	135.12	135.41
27	62.88	71.15	71.89	72.16	134.03	134.76	135.04
28	62.50	71.25	71.93	72.19	133.75	134.43	134.69
29	62.14	71.34	71.97	72.21	133.48	134.11	134.36
30	61.80	71.41	72.00	72.24	133.22	133.80	134.04
31	61.48	71.48	72.03	72.26	132.96	133.51	133.74
32	61.17	71.54	72.06	72.28	132.71	133.23	133.45
33	60.87	71.60	72.09	72.30	132.47	132.96	133.17
34	60.59	71.64	72.11	72.31	132.23	132.70	132.90

It is worth noting that, in this case, it is possible to increase educational attainment by increasing the class size even when it is initially large.

1.4.4 When the Graph for Educational Attainment P Is Inverted U-Shaped

When $\alpha = 1/2$, $\beta = 7/100$, and $P_T = 30$, an inverted U-shaped graph is obtained for education attainment P, as shown in Table 1.4 and Fig. 1.6. In this case, the maximum educational attainment P is attained when $S_C = 28$. Therefore, whether class size S_C is larger or smaller than 28 students, educational attainment P will decrease. Also, lowering the pupil–teacher ratio PT will increase $P_2(X)$, which, in turn, will increase educational attainment P. In other words, controlling class size so that it comes closer to the optimal level and/or lowering the pupil–teacher ratio will improve educational attainment.

1.4.5 Implications

Previous empirical studies have obtained a variety of results on how the pupil–teacher ratio and class size affect educational attainment. As far as we know, no theoretical model exists that can explain them in a unified manner. In the previous section, we presented one such model by focusing on the fact that teachers' working hours are finite. In this section, specifying the values of the parameters, we have conducted a simulation to derive the relationships between class size and educational attainment. The results show that the class size puzzle can be explained without the peer effects,

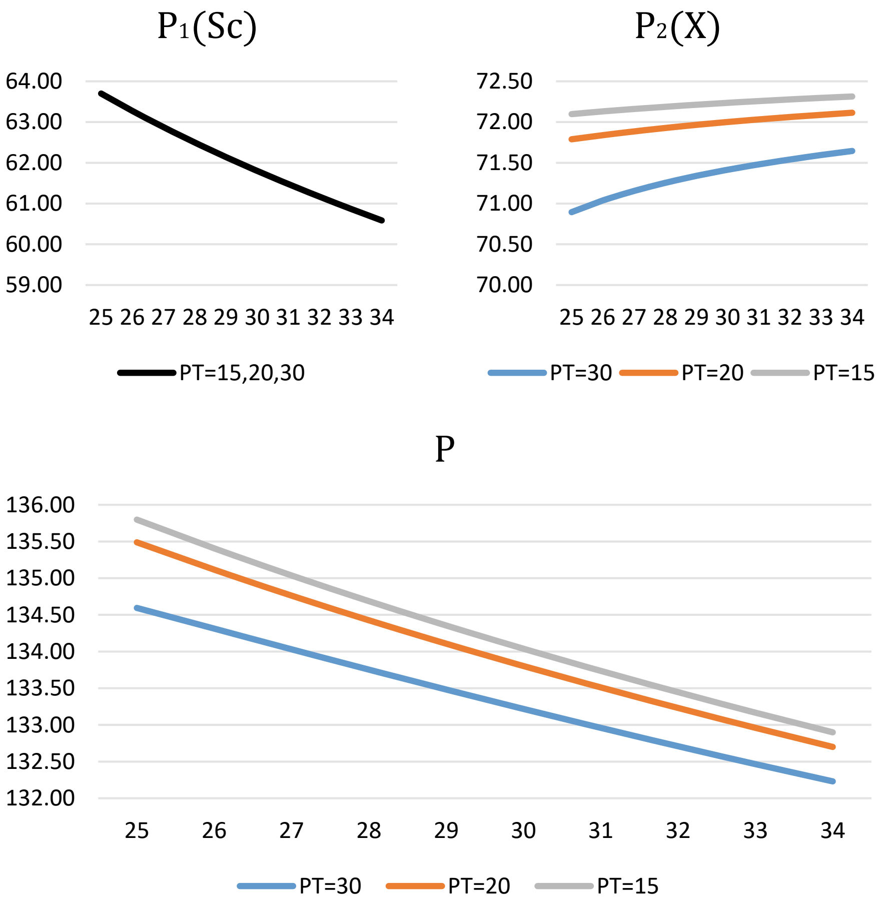

Fig. 1.4 $P_1(Sc)$, $P_2(X)$, and P when $\alpha = 1/5$ and $\beta = 1/2$

which are pointed out by Lazear (2001). In addition, various relationships between class size and educational attainment emerge when the finite nature of teachers' working hours is taken into account.

The simulation results obtained in this section can be used to explain the real-world data. As established by Akabayashi and Nakamura (2014) and the results obtained from Japan's NAAA for 2009, a negative correlation exists between scores and class size in the Japanese language test for 6th-grade students. One reason is the detailed instruction on sentence structure and grammar that is necessary in Japanese education. This is especially true for lower-grade levels, and hence educational attainment can be achieved by reducing class sizes. There may also be negative correlations between class size and educational attainment for subjects with similar characteristics.

Table 1.3 $P(Sc)$, $P(X)$, and P when $\alpha = 1/5$ and $\beta = 4/3$

(Sc)	P(Sc)	P(X)			P		
		PT = 30	PT = 20	PT = 15	PT = 30	PT = 20	PT = 15
25	63.70	70.74	74.72	77.21	134.44	138.42	140.91
26	63.28	71.10	75.08	77.51	134.38	138.36	140.79
27	62.88	71.47	75.43	77.80	134.34	138.30	140.67
28	62.50	71.83	75.75	78.06	134.33	138.25	140.56
29	62.14	72.18	76.06	78.31	134.32	138.20	140.46
30	61.80	72.52	76.35	78.55	134.32	138.15	140.35
31	61.48	72.85	76.62	78.77	134.33	138.10	140.25
32	61.17	73.17	76.88	78.98	134.34	138.05	140.15
33	60.87	73.48	77.13	79.18	134.35	138.00	140.05
34	60.59	73.77	77.36	79.36	134.36	137.95	139.95

Subsequently, for the English language test, a positive correlation was found between score and class size. This is because oral communication and working in pairs are crucial factors for acquiring a foreign language to improve conversational skills, and hence class size above a certain level is necessary. For subjects with similar characteristics, increasing class size may improve educational attainment.

A slightly inverse U-shaped relationship between class size and educational attainment exists in the case of 9th-grade mathematics. This is probably due to a mixture of the two effects. The same applies in the case of subjects such as 6th-grade mathematics, where a slight upward slope or lack of correlation exists, probably due to the mixture of the two effects.

Thus, depending on the characteristics of the subject, grade, and pupil–teacher ratio, the relationship can be upward sloping, downward sloping, U-shaped, inverted U-shaped, or uncorrelated. By accurately identifying the two factors and controlling the pupil–teacher ratio and class size, educational attainment can be improved. If improving educational attainment proves difficult by controlling only one of them, it becomes appropriate to control both at the same time. In other words, if the relationship between class size and educational attainment differs depending on the subject and grade level, we can improve educational attainment allocation by controlling both the pupil–teacher ratio and class size because educational resources are usually limited.

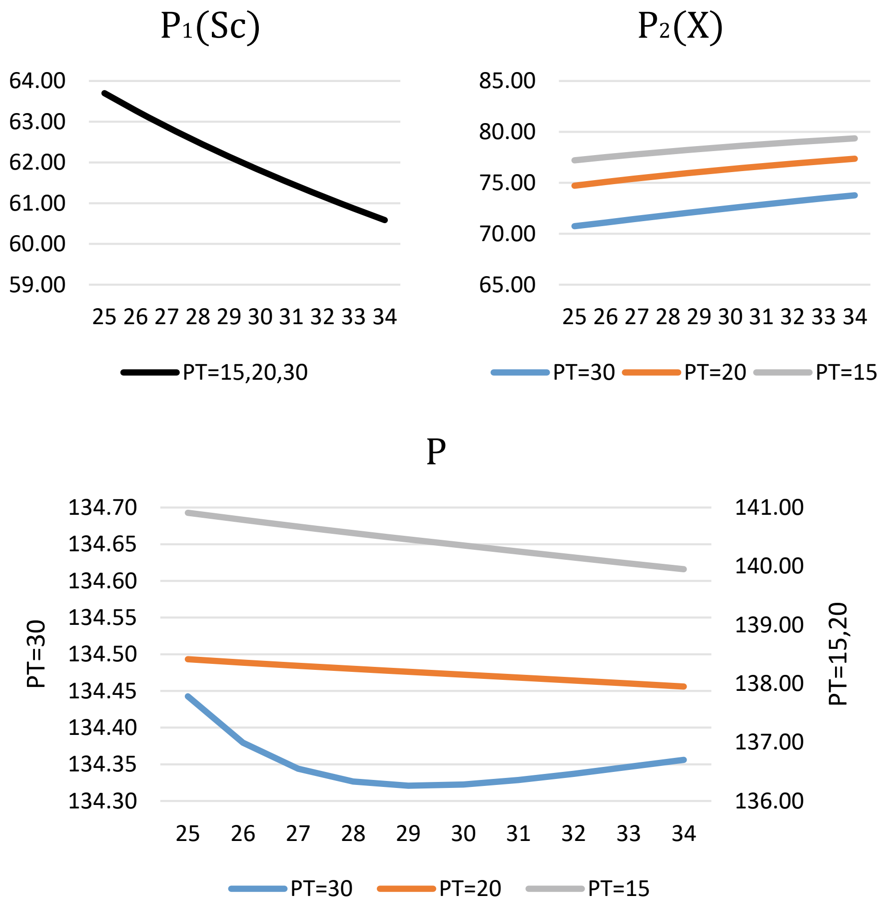

Fig. 1.5 $P_1(Sc)$, $P_2(X)$, and P when $\alpha = 1/5$ and $\beta = 4/3$

1.5 Conclusion

Consistency with theory has been missing in previous empirical studies on the relationship between class size and educational attainment. In this chapter, we have endogenized the allocation of teachers' working hours between teaching in class and out-of-class work hours to explain how class size and the pupil–teacher ratio influence educational attainment. Consequently, the model presented in this chapter can reproduce various relationships between class size and educational attainment: upward sloping, downward sloping, U-shaped, and inverted U-shaped. In the proposed model, class size and the pupil–teacher ratio affect educational attainment through the allocation of teachers' working hours. This allocation is important because further reduction is not feasible in either class size or the pupil–teacher ratio when educational resource is limited.

Table 1.4 $P_1(Sc)$, $P_2(X)$, and P when $\alpha = 1/2$ and $\beta = 7/100$

(Sc)	P(Sc)	P(X)			P		
		PT = 30	PT = 20	PT = 15	PT = 30	PT = 20	PT = 15
25	70.96	70.89	71.79	72.10	141.85	142.75	143.06
26	70.85	71.04	71.84	72.13	141.89	142.69	142.98
27	70.75	71.15	71.89	72.16	141.91	142.64	142.91
28	70.66	71.25	71.93	72.19	141.91	142.59	142.85
29	70.57	71.34	71.97	72.21	141.91	142.54	142.79
30	70.49	71.41	72.00	72.24	141.90	142.49	142.73
31	70.41	71.48	72.03	72.26	141.89	142.44	142.67
32	70.34	71.54	72.06	72.28	141.88	142.40	142.62
33	70.27	71.60	72.09	72.30	141.86	142.36	142.56
34	70.20	71.64	72.11	72.31	141.84	142.31	142.51

Teachers' working hours can be roughly divided into class time and non-class time. Teachers use their out-of-class time to prepare for classes. As the number of in-class teaching hours increases, the amount of out-of-class time decreases. On one hand, as the number of in-class hours increases, the educational quality in class may improve because classes are well prepared. On the other hand, the quality may decrease through the increase in class size. When educational resource is limited, increasing the number of class hours will decrease teachers' out-of-class time—How do teachers cope with this decrease from an increase in the number of in-class hours so that they may avoid lowering the quality they deliver? It could be in the form of overtime work used to prepare for classes. In Japan, overtime hours for teachers have not yet decreased despite the efforts to reform the ways of working.

The model in this chapter explicitly addresses teachers' working hours, which have been overlooked despite their importance in explaining the class size puzzle. However, it is quite conceivable that teachers' class time and other working hours can be categorized as on-the-job or off-the-job training, which may impact their skill development. However, changes in the quality that the teachers deliver owing to their investments in themselves outside the classroom and teaching hours have not been considered in this chapter. Those are crucial and should be researched further to analyze the long-term quality of education and the accumulation of human capital owing to education quality.

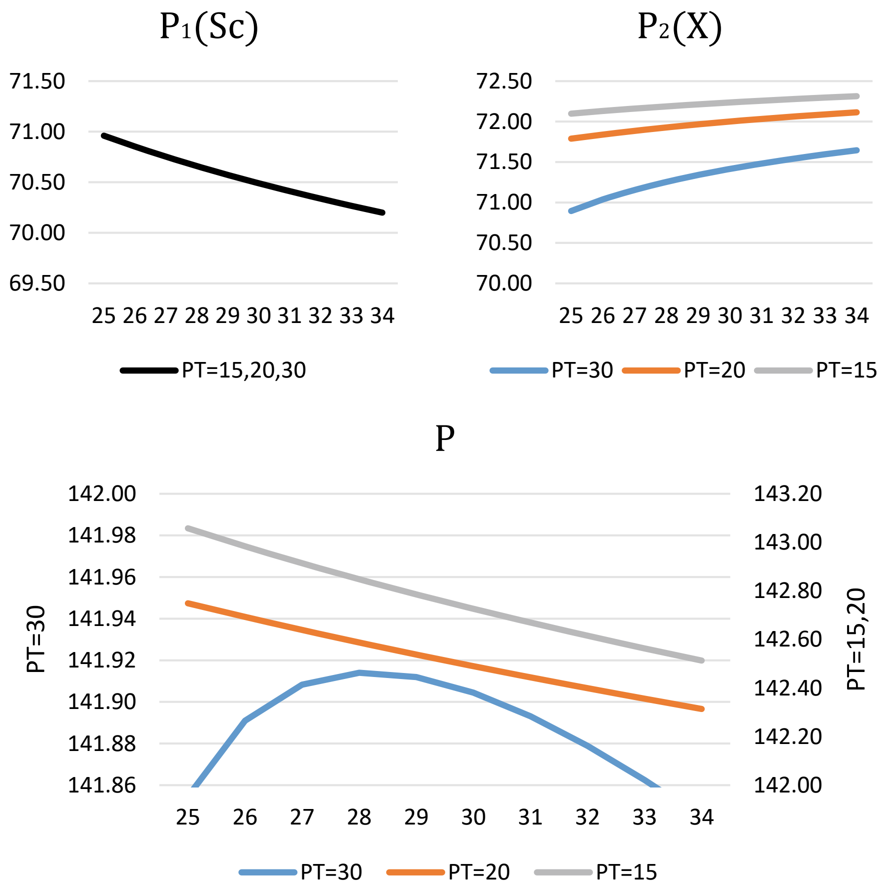

Fig. 1.6 $P_1(Sc)$. , $P_2(X)$, and P when $\alpha = 1/2$ and $\beta = 7/100$

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Chapter 2
Investment in General and Specific Human Capital: Social Optimality via Labor Turnover

Shinji Oi

Abstract Extending the model proposed by (Acemoglu D and Pischke J-S (1999) J Political Econ 107(3):539–572), this chapter analyzes the relationship between labor turnover and human capital investment by firms. While (Acemoglu D and Pischke J-S (1999) J Political Econ 107(3):539–572) assume an imperfect labor market with wage contract friction, we assume a competitive labor market. Workers acquire firm-specific and general skills through firms' human capital investment. After acquiring skills, some workers leave their firms as the result of wage bargaining, while others remain. Workers' decisions depend crucially on the degree to which their skills are "adaptable" to other firms. A firm's estimate of its degree of adaptability is a key factor in determining its human capital investment. Since each firm invests in human capital to increase its own profits, it decreases investment in human capital in the presence of high labor mobility. However, the productivity of the entire economy increases through reallocation of labor. In general, firms consider the possibility that their workers will change jobs; thus, their human capital investments are lower than the socially optimal levels. This chapter examines which contribute more to social welfare: workers' specific skills or general skills. The results reveal the presence of the ratio of specific skills to general skills that maximizes social welfare when labor market is in a seller's market.

Keywords Human capital investment · Specific skills · General skills · Labor turnover · Nash bargaining

2.1 Introduction

An increasing number of Japanese university graduates change jobs and switch to different industries. As Panel (A) in Fig. 2.1 shows, while the percentage of workers who never change their jobs from 2006 to 2014 has remained stable or increased slightly for "overall," "regular employees," and "contract and temporary employees," it has declined moderately for "university graduates."[1] The fact suggests

[1] Figure 2.1 was compiled by the author based on the Working Person Survey 2006, 2008, 2010, 2012, and 2014, which is the Recruit Works Institute survey for people aged 18 to 59. (https://www.works-i.com/surveys/personal/working-person-survey.html).

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that the job change market has been gradually shifting from non-university graduates (high school, technical college, and junior college graduates) to university graduates because most university graduates have been regular employees in Japan.

Panel (B) shows that inter-industry migration has exceeded intra-industry migration for university graduate job changes, except in 2012. As Panel (C) indicates, the average number of job changes did not change much between 2006 and 2014 for workers overall but has increased from 1.8 (2006) to 2.4 (2014) for university graduates.

Workers try to change jobs to increase their income. Wages are determined by an estimate of the productivity of workers who have accumulated human capital through education and training. Workers want firms to highly value their productivity, which has resulted in frequent job changes. When jobs turn over, wages are commonly determined by direct negotiations between an individual firm and an individual worker. According to the bargaining model,[2] a firm and a worker agree upon a wage as a unique solution to the maximization problem where their negotiation is based on contractual gains and outside options. For the worker, the outside option is their opportunity cost, and the gain is what they receive when bargaining is settled.

The alternating offer game[3] considers the possibility of a breakdown in bargaining. In this case, either the worker rejects the wage the firm offers or the firm does not accept the wage the worker offers. Thus, there may be a gap between the wages offered by the firm and those proposed by the worker. If the two parties come close to an agreement, the outcome largely depends on the outside option and the probability that the negotiation will break down. The outside option can be interpreted as the "worker's value" as a factor of production in the labor market. Knowledge capital is more crucial to the digital technology than physical capital as per the current industry trend; great emphasis is placed on workers with human capital such as individual skills and knowledge.

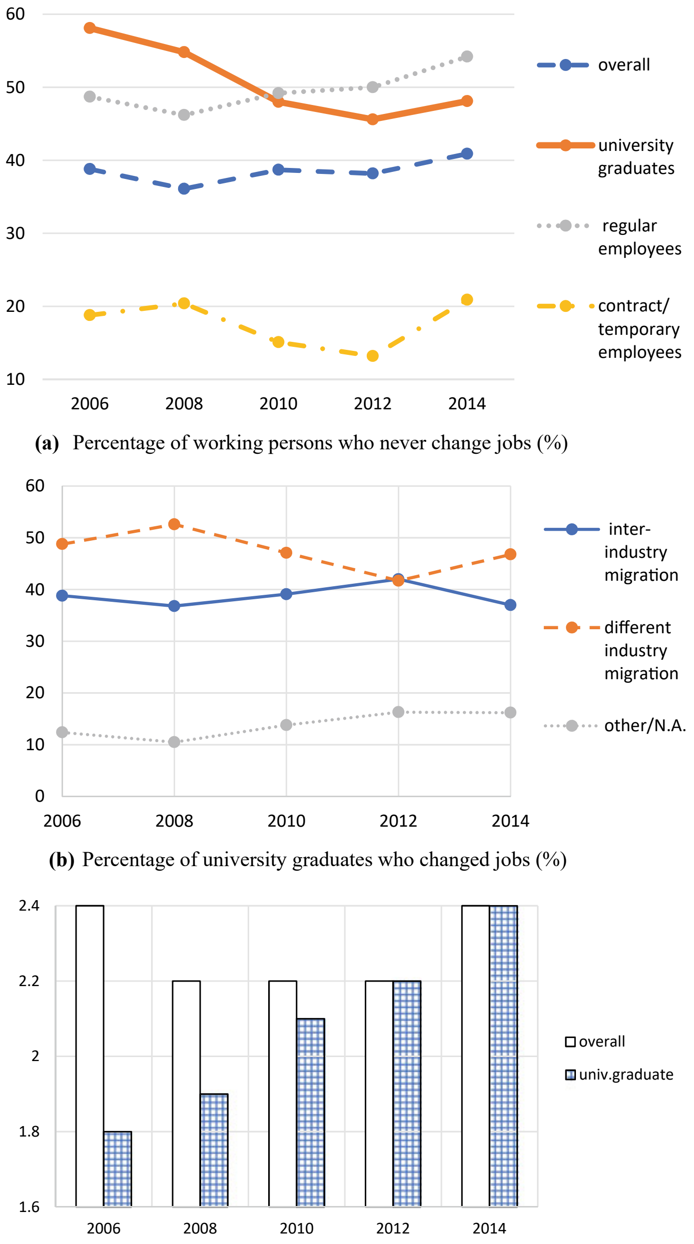
Looking at the reality, postwar Japanese firms invested in human capital under the lifetime employment system, which is no longer as strong as before due to the increase in job changes. However, they still invest in human capital. As workers accumulate human capital, which gives them an advantage in wage bargaining, they can earn higher wages. For workers, the decision to change jobs depends on their outside options. Firms may either raise wages to retain workers or not. They must carefully consider their investment because the investment becomes only a waste if the workers leave.

This chapter helps answer a series of questions through a careful examination of the effects of job changes on human capital investment, such as "Do firms stop investing in human capital when job changes become more frequent?" In other words, firms may stop investing because they recruit "trained workers" from the labor market, rather than because they lose workers due to bargaining.

Other questions include "Are workers with general skills popular in the job change market?" or "Are workers with specific skills popular?" In Japan, under the lifetime

[2] See Nash's (1950) seminal work.

[3] See Rubinstein's (1982) pioneer research.



(a) Percentage of working persons who never change jobs (%)

(b) Percentage of university graduates who changed jobs (%)

(c) Average number of job change (unit=times)

Fig. 2.1 Current job changes in the Japanese labor market employment system, workers are trained as generalists by job rotation, but they also acquire specific skills in the process. In contrast, workers in the workplace are also trained in specific skills. The fact that many workers change ~~to~~ jobs in different industries means that even if a worker has received specific training by a firm, they can change jobs if their skills are highly valued by firms in different industries.

Turning to the United States, workers invest in themselves to acquire general skills. Acemoglu and Pischke (1999) show that in imperfect labor markets with friction, firms have incentives to provide workers with general training. Workers have no incentive to change jobs when their marginal productivity growth exceeds the growth in external wages. Consequently, firms can become profitable by hiring workers at lower wages and increasing their investment in training. Even if they possess general skills, workers can switch jobs only if they are highly valued in the external market. Acemoglu and Pischke (1999) insist that the distortion in the wage structure turns "technically" general skills into specific skills.

According to the traditional view, firms accumulate a specific kind of human capital to suit their own production needs. They need professional expertise for operating machines, selling products, and so on, and hence require training to master these skills. However, according to Acemoglu and Pischke (1999), general skills that can be used in other firms are considered "specific" for a certain firm because they are ultimately used only for that firm under an incomplete labor contract. Becker (1964) also points out that this is a case of "extreme types of monopsony," and whatever the content of the training, the skill must be specific.

In contrast, if workers with an acquired skills can change jobs, then the training they received may be general. They take it for granted that negotiating wages or changing jobs makes them better. Firms will hire workers in the labor market if the workers have the relevant skills for the firm. Even if a firm invests in human capital for its own sake, the action of workers changing jobs changes the allocation of human capital. Social productivity increases as a result of the reallocation. A worker's adaptability to a firm affects the firm's investment behavior. This is this chapter's main research question.

The rest of the chapter is organized as follows. Section 2.2 sets up the model used to investigate the relationship between human capital investment and job changes. Section 2.3 conducts the comparative statics. Section 2.4 extends the model by adding new assumptions about the adaptability between firms and workers to analyze whether human capital investment by firms can achieve the social optimum. Section 2.5 concludes the chapter.

2.2 The Model

2.2.1 *Basic Setup*

Consider an economy that consists of many heterogeneous firms and workers. The workers have firm-specific skills h^S and general-purpose skills h^G. Firms use those skills to produce a product or service. h^G is the ability of workers to yield the same productivity in any other firm, while h^S is the ability of workers to yield different productivity depending on the combination of worker and firm. Assuming that the degree of adaptability of a worker i is β_i (>0), productivity, which is the same as output, is

$$y_i = h^G + \beta_i h^S. \tag{2.1}$$

The firm invests in human capital. Human capital h is a function of investment I, as follows:

$$h(I) = h^G + h^S \ with\ \ h^{'}(I) > 0,\ h^{''}(I) < 0. \tag{2.2}$$

As a result of the investment, h^G and h^S are accumulated. Denoting the ratio of general skill to overall skill by λ ($0 \leq \lambda \leq 1$), we have

$$h^G = \lambda h(I), \tag{2.3}$$

$$h^S = (1 - \lambda)h(I). \tag{2.4}$$

Here, λ is assumed to be constant. If $\lambda = 0$, the worker has acquired only specific skills, which is good for the firm that has invested. However, no matter how much firms invest in specific training, workers will also acquire general skills h^G. In other words, as λ increases, workers become more versatile. For workers, this is a crucial factor when considering a career change. For firms, it is a key factor when assuming labor turnover.

2.2.2 *The Two-Period Setting*

A worker who has been trained at Firm A increases their human capital from h_0 to h_1. They consider whether to switch jobs. If they remain at Firm A, the degree of adaptability is β_A, and if they move to another firm, it is β_{-A}.

At period 0, Firm A invests I_A in a worker to increase its human capital. At the beginning of the next period, period 1, wage bargaining is held (Fig. 2.2).

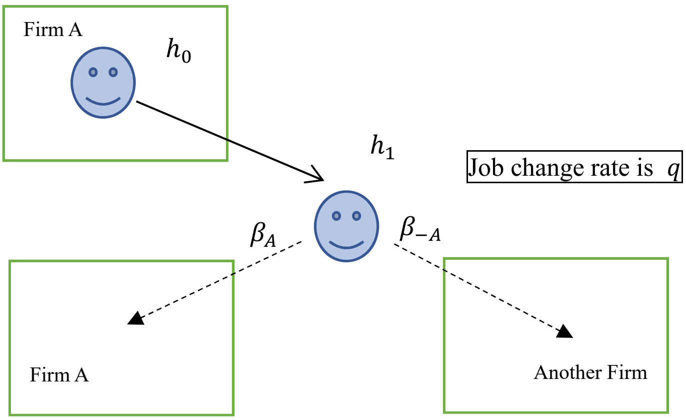


Fig. 2.2 Trained worker's choice

After bargaining, the worker changes jobs at a rate of q. If the worker quits, the investment I_A is wasted for Firm A. Firm A can secure its output by continuing to hire incumbent workers at the rate of $1 - q$ and by hiring new workers from other firms at a rate of q. The expected output of Firm A is as follows:

$$y_A^E = (1-q)[\lambda h(I_A) + \beta_A(1-\lambda)h(I_A)] + q\left[\lambda h(I_{-A}) + \beta_{-A}(1-\lambda)h(I_{-A})\right], \tag{2.5}$$

where I_A is Firm A's investment and I_{-A} is the investment by other firms.

2.2.2.1 Nash Bargaining

As a result of investment, a worker acquires new human capital, and then negotiates their wage. Firms continue to hire the worker for wages w^* or hire another worker from the job market at wages w^{**}. A firm and worker jointly maximize the following Nash product,

$$\max\left[\left(y_A - w^*\right) - \left(y_{-A} - w^{**} - I_A\right)\right]^{1-\gamma}\left[w^* - y_T\right]^{\gamma}, \tag{2.6}$$

where γ $(0 < \gamma < 1)$ is the relative bargaining power of workers.

On one hand, the first set of parentheses in the square brackets shows Firm A's profit if wage bargaining is successful and the worker stays with Firm A. The worker earns wage w^* while the firm produces y_A. The second set of parentheses in the square brackets represents Firm A's profit if the bargaining breaks down, and the worker quits. Firm A instead employs another worker trained at another firm and has productivity y_{-A} at wage w^{**}. If bargaining results in the worker quitting, the investment I_A that Firm A committed to in the previous period would be completely wasted. Therefore, the firm expects the newly hired worker to be productive enough to make up for it. This affects the amount of wages w^{**} and the amount of initial investment. As discussed above, the first pair of square brackets indicates the firm's profits.

On the other hand, the term $[w^* - y_T]$ represents the worker's net gain. If bargaining is successful, the worker gets paid wage w^* from Firm A. However, if it breaks down, the worker changes jobs and produces y_T at another firm.

Under complete information and no transaction costs, $w^* = w^{**}$ is attained in equilibrium, and w^* is:

$$w^* = y_T + \frac{\gamma}{1-\gamma}(y_A - y_{-A}) + \frac{\gamma}{1-\gamma} I_A. \tag{2.7}$$

From (2.1), (2.3), and (2.4), we have

$$y_A = \lambda h(I_A) + \beta_A(1-\lambda)h(I_A), \tag{2.8a}$$

$$y_{-A} = \lambda h(I_{-A}) + \beta_{-A}(1-\lambda)h(I_{-A}), \tag{2.8b}$$

$$y_T = \lambda h(I_A) + \beta_{-A}(1-\lambda)h(I_A) \tag{2.8c}$$

2.2.3 Investment Decision

The profit maximization by a private firm is given by

$$\begin{aligned} \frac{d\left(y_A^E - w^*\right)}{dI_A} &= (1-q)[\lambda + \beta_A(1-\lambda)]h'(I_A) - \left[\lambda + \beta_{-A}(1-\lambda)\right] \\ h'(I_A) - \frac{\gamma}{1-\gamma}&[\lambda + \beta_A(1-\lambda)]h'(I_A) - \frac{\gamma}{1-\gamma} = 0. \end{aligned} \tag{2.9}$$

The solution I_A^* is as follows:

$$h'\left(I_A^*\right) = \frac{\frac{\gamma}{1-\gamma}}{\left[1 - q - \frac{\gamma}{1-\gamma}\right][\lambda + \beta_A(1-\lambda)] - \left[\lambda + \beta_{-A}(1-\lambda)\right]} = \frac{\frac{\gamma}{1-\gamma}}{A}. \tag{2.10}$$

If a social firm determines the optimal investment, we can replace I_A and I_{-A} with I. We can calculate the expected value of the economy-wide output by rewriting Eq. (2.5) as follows:

$$y^E = \lambda h(I) + \left[(1-q)\beta_A + q\beta_{-A}\right](1-\lambda)h(I). \tag{2.11}$$

Profit maximization of a social firm is given by

$$\frac{d\left(y^E - w^*\right)}{dI} = \left[(1-q) - \frac{\gamma}{1-\gamma}\right]\left[\lambda h^{'}(I) + \beta_A(1-\lambda)h^{'}(I)\right]$$

$$+\left[q - \left(1 - \frac{\gamma}{1-\gamma}\right)\right]\left[\lambda h^{'}(I) + \beta_{-A}(1-\lambda)h^{'}(I)\right] - \frac{\gamma}{1-\gamma} = 0. \quad (2.12)$$

The solution I^* is as follows:

$$h^{'}\left(I^*\right) = \frac{\frac{\gamma}{1-\gamma}}{\left[1 - q - \frac{\gamma}{1-\gamma}\right]\left[(1-\lambda)(\beta_A - \beta_{-A})\right]} = \frac{\frac{\gamma}{1-\gamma}}{B}. \quad (2.13)$$

2.3 Comparative Statics

2.3.1 Comparison of Investment Between Social Firms and Private Firms

Since (2.13) and (2.10) have the same numerators on the right side, comparing the denominators of (2.13) and (2.10) yields the following equation:

$$B - A = \left(q + \frac{\gamma}{1-\gamma}\right)\left[\lambda + \beta_{-A}(1-\lambda)\right], \quad (2.14)$$

where $0 \leq \lambda \leq 1$, $q > 0$, $\beta_{-A} > 0$, and $\gamma/(1-\gamma) > 0$. Therefore, (2.14) takes a positive value; that is, $h'\left(I_A^*\right) > h'(I^*)$, leads to

$$I_A^* < I^*. \quad (2.15)$$

Figure 2.3 shows the solution where the right-hand-sides of Eqs. (2.10) and (2.13) are represented by a dashed line, while the left-hand-sides of Eqs. (2.10) and (2.13) are represented by a solid downward-sloping curve. Given λ, β_A, β_{-A}, γ, and q, the level of the dashed line is determined, and the intersection with the solid curve is determined, so that the optimal human capital investments I^* and I_A^* are determined.

This leads to the following proposition.

Proposition 2.1 In the case of a completely competitive labor market, human capital investment made by private firms that assume workers change jobs is less than that made by social firms.

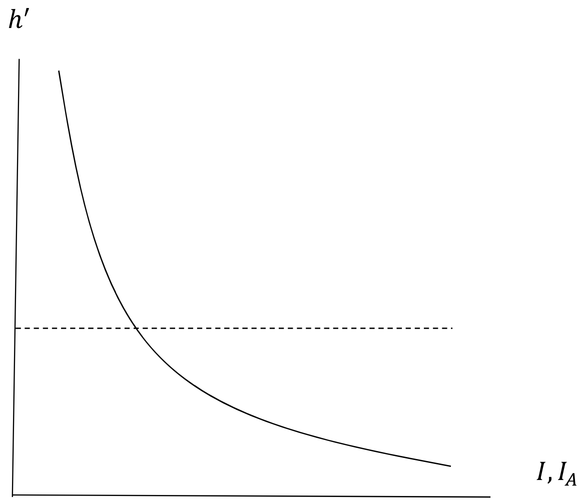


Fig. 2.3 Determining the optimal investment

Since q is the workers' turnover rate and $\gamma/(1-\gamma)$ is the relative bargaining power of workers, the first bracket on the right side of Eq. (2.14) represents workers' decisions and actions. The stronger the workers' bargaining power and the larger the turnover rate, the smaller the investment chosen by private firms relative to that of social firms.

2.3.2 Comparison of Profits Between Social Firms and Private Firms

Substituting I^* identified in Eq. (2.13) into Eqs. (2.7) and (2.8), the profit of social firms is calculated as follows:

$$y^E - w^* = \left(1 - q - \frac{\gamma}{1-\gamma}\right)(1-\lambda)(\beta_A - \beta_{-A})h\left(I^*\right) - \frac{\gamma}{1-\gamma}I^*. \tag{2.16}$$

A social firm determines its optimal investment, $I_A = I_{-A} = I^*$.

Substituting I_A^* identified in Eq. (2.10) into Eqs. (2.7) and (2.8), private firms' profit is calculated as follows,

$$\begin{aligned} y_A^E - w^* = &\left\{\left(1 - q - \frac{\gamma}{1-\gamma}\right)[\lambda + \beta_A(1-\lambda)] - \left[\lambda + \beta_{-A}(1-\lambda)\right]\right\} \\ &h\left(I_A^*\right) + \left(q + \frac{\gamma}{1-\gamma}\right)\left[\lambda + \beta_{-A}(1-\lambda)\right]h(I_{-A}) - \frac{\gamma}{1-\gamma}I_A^*. \end{aligned} \tag{2.17}$$

We should note that private firms determine only their own investment I_A, not the other firm's investment I_{-A}.

Since all private firms behave in the same way in equilibrium, $I_{-A} = I_A^*$, and thus Eq. (2.17) becomes the following:

$$y_A^E - w^* = \left(1 - q - \frac{\gamma}{1-\gamma}\right)(1-\lambda)(\beta_A - \beta_{-A})h\left(I_A^*\right) - \frac{\gamma}{1-\gamma} I_A^*. \tag{2.18}$$

This is the same form as Eq. (2.16). However, the result that $I^* > I_A^*$ in (2.15) suggests that private firms' profits may differ from those of social firms. I_A^* is a "small investment" that private firms are forced to choose when they try to maximize their profits.

Taking (2.13) into account, (2.16) can be rewritten as follows:

$$y^E - w^* = \frac{\gamma}{1-\gamma}\left[\frac{h(I^*)}{h'(I^*)} - I^*\right]. \tag{2.19}$$

Similarly, taking Eq. (2.10) into account, Eq. (2.17) can be rewritten as follows:

$$y_A^E - w^* = \frac{\gamma}{1-\gamma}\left[\frac{h\left(I_A^*\right)}{h'\left(I_A^*\right)} - I_A^*\right] + \left(q + \frac{\gamma}{1-\gamma}\right)\left[\lambda + \beta_{-A}(1-\lambda)\right]h(I_{-A}). \tag{2.20}$$

Let us specify the human capital function as $h(I) = I^\alpha$ $(0 < \alpha < 1)$. Since $h(I)/h^{'}(I) = I/\alpha$, (19) can be rewritten as follows:

$$y^E - w^* = \frac{\gamma}{1-\gamma}\left(\frac{1-\alpha}{\alpha}\right)I^*. \tag{2.21}$$

Dividing both sides of (21) by I^* gives:

$$\frac{y^E - w^*}{I^*} = \frac{\gamma}{1-\gamma}\left(\frac{1-\alpha}{\alpha}\right). \tag{2.22}$$

As this shows, the net return on investment of the social firm is uniquely determined.

2.3.3 The Effects of Turnover and Workers' Bargaining Power

Let us delve into the details of how β_A and β_{-A} affect investment. We rewrite Eq. (2.13), the optimality condition for human capital investment by social firms, as follows:

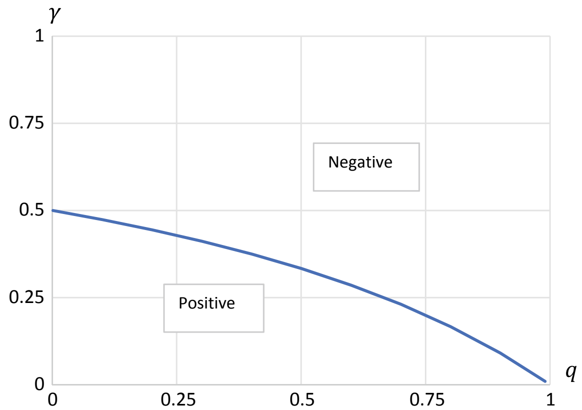


Fig. 2.4 Regions of sign of $\frac{1-\gamma}{\gamma}(1-q)-1$

Table 2.1 Investment decision

	$\beta_A > \beta_{-A}$	$\beta_A < \beta_{-A}$
$1-q > \frac{\gamma}{1-\gamma}$	(i) Invest	(ii) Do not invest
$1-q < \frac{\gamma}{1-\gamma}$	(iii) Do not invest	(iv) Invest

$$h'\left(I^*\right) = \frac{1}{\left[\frac{1-\gamma}{\gamma}(1-q)-1\right]\left[(1-\lambda)(\beta_A-\beta_{-A})\right]}. \tag{2.23}$$

The sign regions of $(1-\gamma)(1-q)/\gamma - 1$ are shown by Fig. 2.4. As q increases, the range of γ that satisfies $(1-\gamma)(1-q)/\gamma - 1 > 0$ decreases.

Table 2.1 shows that the investment decision depends on the sign of $(1-\gamma)(1-q)/\gamma - 1$ and $(\beta_A - \beta_{-A})$. The negative or positive of $(1-\gamma)(1-q)/\gamma - 1$ is rewritten as $1-q \lesseqgtr \gamma/(1-\gamma)$, where $\gamma/(1-\gamma)$ is the ratio of workers' bargaining power relative to that of firms, and $1-q$ is the worker's residual rate.

Consider case (i), which is in the positive range shown in Fig. 2.4. Suppose that q is close to zero; the investment condition is $\gamma \leq 0.5$. However as q increases, γ must decrease more. This case is considered to correspond to the "layoff in a recession." This is because if turnover rate is high, the bargaining power of workers is very low. Equation (2.23) shows that the larger β_A is relative to β_{-A}, the more social firms will increase their human capital investment. Thus, they think that workers who are not laid off will be more adaptable than those who are laid off.

Consider case (iv), which is in the negative range shown in Fig. 2.4. This case suggests that the labor market is a "seller's market." This is because even if the turnover rate is high, workers' bargaining power is not very low. Equation (2.23) shows that the larger β_{-A} is relative to β_A, the more social firms will increase their human capital investment. Thus, they think that workers will be adaptable after changing jobs.

In cases (ii) and (iii), investment decisions are opposite to those in cases (i) and (iv), respectively. In case (ii), social firms refrain from investing in hopes that they will hire highly adapted workers from the market. In case (iii), social firms refrain from investing, assuming that workers with high adaptability will leave their jobs.

We rewrite (2.10), the optimality condition for human capital investment by private firms, as follows:

$$h'\left(I_A^*\right) = \frac{\frac{\gamma}{1-\gamma} \cdot \frac{1}{\lambda+\beta_{-A}(1-\lambda)}}{\left(1 - q - \frac{\gamma}{1-\gamma}\right)\frac{\lambda+\beta_A(1-\lambda)}{\lambda+\beta_{-A}(1-\lambda)} - 1}. \tag{2.24}$$

It is possible for private firms to invest in human capital if $1 - q > \gamma \big/ (1 - \gamma)$ and $\beta_A > \beta_{-A}$. This is the same as case (i) in Table 2.1 for social firms and implies that the layoffs are taking place in a recession. Under this condition, private firms invest more as the turnover rate q decreases and workers' bargaining power γ decreases, as the adaptability β_A of the workers who do not leave increases relative to β_{-A}.

2.4 Relationship Between the Ratio of General Skill and Matching of Worker and Firm

2.4.1 Case of Social Firms

In Eq. (2.13), the optimal investment level of a social firm if β_A, β_{-A}, γ, and q are given will reduce investment as the worker's ratio of general skill λ increases. However, workers with high general skills are more adaptive to any type of firm. Now, let us introduce the following new assumption regarding λ and β.

Assumption 2.1 The higher the worker's ratio of general skill λ, the higher the adaptability β of firm-specific skills, namely,

$$\frac{d\beta}{d\lambda} > 0.$$

Assumption 2.2 When the worker's ratio is zero, the adaptability to the initial firm is larger than to other firms. However, the adaptabilities for other firms increase more rapidly than that for initial firm as the ratio increases, namely,

$$\beta_A^{\lambda=0} > \beta_{-A}^{\lambda=0}, \frac{d\beta_{-A}}{d\lambda} > \frac{d\beta_A}{d\lambda}.$$

Based on these assumptions, we specify the relationship between λ and β as follows:

$$\begin{cases} \beta_{-A} = (1+a)\lambda + b, \\ \beta_A = \lambda + c, \end{cases} \tag{2.25}$$

(*s.t.* $a, b, c > 0, b < c$).

Then, the second term of the denominator of Eq. (2.13) is rewritten as follows:

$$(1-\lambda)(\beta_A - \beta_{-A}) = a(\lambda - 1)\left(\lambda - \frac{c-b}{a}\right). \tag{2.26}$$

See Fig. 2.5. If $(c-b) > a$, the curve drawn by (2.26) is (a), and if $(c-b) < a$, it is (b).

First, in Fig. 2.5a, $\beta_A > \beta_{-A}$ for $0 \leq \lambda < 1$, and $(1-\lambda)(\beta_A - \beta_{-A})$ decreases as λ increases. If $1 - q > \gamma/(1-\gamma)$, this is the same as case (i) in Table 2.1. This leads to the following proposition.

Proposition 2.2 In a recession and when workers are laid off, social firms make human capital investments if the adaptability of workers not laid off exceeds the adaptability of those who have been laid off. The higher the worker's ratio of general skills, the lower the investment.

Second, Fig. 2.5b, the investment decisions of a social firm, as depicted in Fig. 2.5b, are as shown in Table 2.2.

Cases (ix) and (x) are consistent with case (iv) in Table 2.1. Social firms invest in human capital in both cases. However, in case (ix), investment increases as λ increases, whereas in case (x), investment decreases as λ increases. This leads to the following proposition.

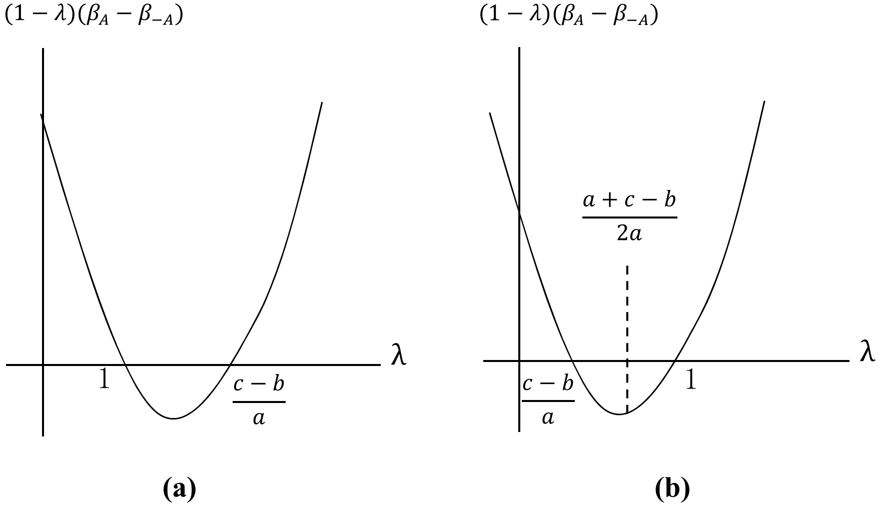
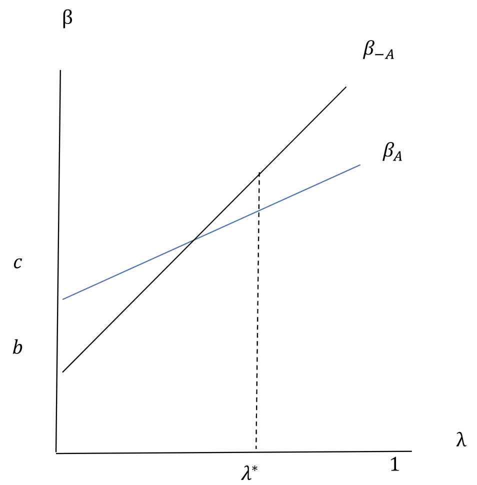


Fig. 2.5 $(1-\lambda)(\beta_A - \beta_{-A})$ curve

Table 2.2 Investment decision: Fig. 2.5(B)

	$0 \leq \lambda < \frac{c-b}{a}$	$\frac{c-b}{a} < \lambda < \frac{a+c-b}{2a}$	$\frac{a+c-b}{2a} < \lambda \leq 1$
	$\beta_A > \beta_{-A}$	$\beta_A < \beta_{-A}$	
$1 - q > \frac{\gamma}{1-\gamma}$	(v) Invest	(vi) Don't invest	(vii) Don't invest
$1 - q < \frac{\gamma}{1-\gamma}$	(viii) Don't invest	(ix) Invest	(x) Invest

Fig. 2.6 λ* maximizes the investment



Proposition 2.3 If the labor market is a seller's market and the adaptability of workers entering from the job change market is relatively high, the higher the ratio of workers' general skills, the higher the investment by a social firm. However, if the ratio of general skills increases above a certain level, investment tends to decrease.

Therefore, the value of λ^* that maximizes the investment of social firms is uniquely determined. It exists between $(c - b)/a < \lambda < 1$, where β_{-A} exceeds β_A. (see Fig. 2.6).

For example, let $a = 0.5$, $b = 1.0$, and $c = 1.25$, then the value of λ at which β_A equals β_{-A} is 0.5, and the value of λ^* that maximizes investment is 0.75.

2.4.2 *Case of Private Firms*

Using Eq. (2.26), the denominator of Eq. (2.10) is rewritten as a function of λ, that is:

$$F(\lambda) = (1 - Q + a)\lambda^2 + (2Q - 2 - a + b - Qc)\lambda + Qc - b, \qquad (2.27)$$

where $Q = 1 - q - \gamma/(1 - \gamma)$.

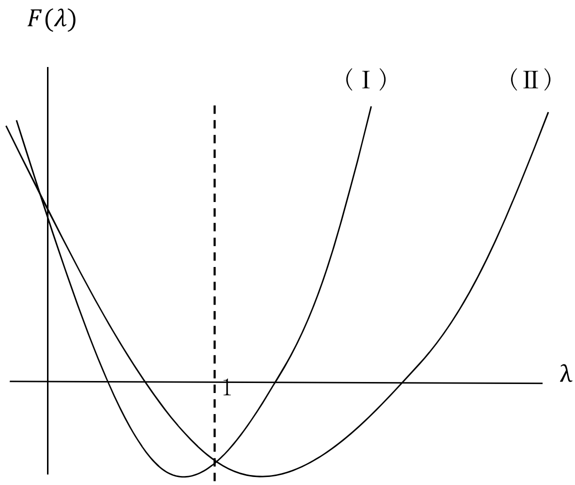


Fig. 2.7 F(λ) curve

For private firms to invest in human capital, Eq. (2.27) must have a positive solution in the range $0 \leq \lambda < 1$. $F(1) = Q - 1 < 0$; hence, investment conditions are as follows:

$$F(0) = Qc - b > 0, \text{ hence } (1-q) - \frac{\gamma}{1-\gamma} > \frac{b}{c} \tag{2.28}$$

$(1-q)$ is the worker's residual rate, and $\gamma/(1-\gamma)$ is the workers' relative bargaining power. From the assumption in Eq. (2.25), b/c takes a value between 0 and 1. Therefore, to satisfy the investment condition $F(0) > 0$, the larger the turnover rate q, the smaller the bargaining power of workers must be.

Under the above conditions, $F(\lambda)$ draws a curve as shown in Fig. 2.7.

Regardless of the shape of curve (I) or (II), for $F(\lambda) > 0$, $F(\lambda)$ decreases as λ increases, thereby decreasing; thus I_A^* decreases in (2.10). If $F(\lambda) < 0$, firms will not invest. This leads to proposition 2.4.

Proposition 2.4 Private firms tend to invest human capital in workers during times of recession and layoffs. However, if the ratio of general skill increases, the optimal investment I_A^* decreases.

2.5 Conclusion

This chapter has modeled two aspects of workers' skills. The extent to which workers' specific skills are demonstrated is determined by their adaptability to the firm. Workers' general skills will surely enable diverse ways of working. Since the investment by a social firm is social optimal, under the circumstance that only private firms exist, the result obtained that a social firms' investment is larger than that of a private firm has the following two important implications.

First for the labor market, the second labor market must be competitive and the workers' information must be transparent, so that the specific and general skills that workers acquire are determined as accurately as possible.

Second for the firms, firms must maintain transparency about the type of human capital investment, that is, the type of human resources, they need and want to develop. This provides workers with the choice to change jobs, not just wages, which helps job seekers explicitly know whether they qualify for interviews. If they do not want to fail in making a job change, they must carefully examine the information provided by a firm and decide where to step in. Enhancing such a system will increase socio-economic welfare.

The interview survey with firms that support career changes in Japan reports the characteristics of workers who have an advantage in changing jobs.[4] Among them, the following are of particular importance: "Young workers who are flexible and adaptable enough to any environment find it easy (to change jobs)," "It is important to be aware of portable skills," "It is highly appreciated that they have expertise through practice and have accumulated an MBA and qualifications," and "Non-spec skills such as the job seeker's mindset and potential are important for intangible service companies." Here, "spec" represents firm-specific skills, and "potential" represents general-purpose skills. General skills have never been neglected in recruiting, and it is not enough to only match specific skills. If workers have general skills that can be used in any firm, they are able to better demonstrate their own specific skills in a new firm. In Japan, an increasing number of firms have introduced "job-focused employment" systems. However, generalists who can lead teams while maintaining an elevated level of expertise are needed.

Our model assumes a linear relationship between adaptability that increases specific skills and the ratio of general skills. The question remains whether workers' general and specific skills complement each other. Research on this aspect deserves to be pursued further.

We also assume that the turnover rate is exogenous. Empirical analysis reveals a significant relationship between wages and job changes for male workers. [5] Intuitively, wages are one of the crucial factors in job change decisions. It is necessary to analyze how changes in wages affect job changes. This issue must be also be researched further.

[4] The Japan Institute for Labour Policy and Training (2016).

[5] See Tanaka (2013).

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Chapter 3
Necessity of Openness to Stimulate Innovation: An Investigation into Causes of Slow Innovation

Tokuji Saita

Abstract This chapter discusses the role of innovation in economic growth, focusing on the type and content of innovation and the creation process. Innovations are essential for economic development, and can be classified as "sustainable" and "disruptive" based on the important features of the type and content or as "open" and "closed" based on its creation process. In the research of innovation, many microeconomic studies have focused on this classification, which has led to significant progress in the analysis of firms' innovation activities. In contrast, analyzing innovation from the perspective of macroeconomics has been rather overlooked. Thus, it is very important to analyze the relationship between the openness (or closedness) of the creation process and the sustainability (or disruptiveness) of innovation from a macroeconomic perspective. Therefore, this chapter analyzes the desirable nature of innovation from the perspective of overall economic growth, and establishes the low "openness" of innovation brought about by low labor mobility as one of the primary reasons for the Japanese economy's long-term stagnation after the burst of the bubble economy.

Keywords Sustainable innovation · Disruptive innovation · Closed innovation · Open innovation · Employment liquidity · Labor mobility

3.1 Introduction

The Japanese economy has experienced stagnant economic growth with an almost flat nominal GDP per capita since 1990. This is partly due to the large amount of non-performing loans that followed the bursting of the bubble economy. Unfortunately, the problem of "Japan's lost three decades" remains unsolved. Two main types of research have tried to figure out the causes of this problem: one focuses on financial problems, while the other concentrates on the demand and supply side of the real economy. Of these studies, those that seek the cause of the long-term stagnation in financial problems are insufficient in considering that the Japanese economy returned to a growth trajectory in 2002, and the bad loan problem has been resolved until 2003. This helps narrowing down the cause of long-term stagnation to two factors: real demand and supply. We consider that innovation, which Schumpeter described as "creative destruction" in his "Theory of Economic Development" (1912), has a

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significant impact on both. Innovation contributes to economic growth on the demand side by bringing new products and services to the market, and it also contributes to economic growth on the supply side by improving productivity through reforms in the production process. Therefore, the stagnation in innovation can be one of the most crucial factors for the stagnation of the Japanese economy.

Although some studies suggest that the slump in innovation is due to the slump in information communication technology (ICT) investment, the cause and effect are reversed and innovation has had a significant impact on the slump in ICT investment. In other words, knowledge creation and the mechanism that links it to the realization of economic value, which is essential for ICT innovation, did not function, thereby leading to the slump in ICT investment.

To understand the sluggish innovation activities and performance in Japan, this chapter investigates the nature and process of innovation in depth. For this purpose, we classify innovation by focusing on two dimensions: disruption (or sustainability) and openness (or closedness) and present two models. The first model analyzes the investment ratio between disruption and sustainability that maximize the economic performance of innovation. The second model deals with the creation process of "closed innovation" and "open innovation" and shows that an open creation process is essential for generating innovation that leads to economic growth. The usefulness of each model will be evaluated by the previous empirical research.

Let us turn to the importance of the two classifications of innovation. First we explain "disruptive innovation" as proposed by Christensen (2000). When new products and services emerge due to disruptive innovation, existing firms focus on developing their products and services to make them more than functional to disruptive innovation. As a result, firms are caught in an innovation dilemma in which they are unable to respond to the low performance and low price of products and services brought about by disruptive innovation and lose out in competition with the potential entrants. Christensen then defined "sustainable innovation," which involves the improving products and services, as a concept that contrasts with disruptive innovation. Unfortunately, the previous research on disruptive innovation is about the environment and trends surrounding firm innovation and their impact on its creation and diffusion. A little literature exists that justifies the relationship between disruptive innovation and economic growth.

Second, we introduce previous research on open innovation and closed innovation that analyzes innovation and the creation from the institutional and organizational perspectives. The concept of open innovation was proposed by Chesbrough (2003) who defines it as combining ideas from inside and outside a firm to create value. This concept is based on the idea that cross-organizational networks generate innovation that produces economic outcomes and accelerates the firm growth. The opposite concept to open innovation is closed innovation, which is an innovation creation method used before the spread of open innovation methods.

The open innovation proposed by Chesbrough(2003) has been studied by various researchers from many perspectives. For example, a typology of open innovation activities is outlined by Manabe and Yasumoto (2010). The conditions under which firms' open innovation outcomes are produced are then analyzed. According to

Nobeoka (2010), the adoption of open innovation methods by firms can be expected to lead to successful manufacturing in many cases. However, for firms to differentiate themselves from competitors and realize economic value, in addition to adopting open innovation methods, they need to take organizational measures to ensure the uniqueness of their products.

Some of previous research study the conditions for open innovation at the firm level, focusing on organizational development that leads to economic outcomes. In the macroeconomic perspective the role open innovation to play in economic growth and development remains has not been explored.

Thus, most studies of disruptive and open innovations are microeconomic analyses of how efficiently firms innovate in line with technological progress, but not macroeconomic analysis on the effect of increased economic value due to innovation on economic growth. In addition, analyses of how the lifetime employment system and systems that inhibit labor mobility lead to sluggish innovation creation remains neglected in research.

To theoretically analyze the relationship between labor mobility and innovation from the viewpoint of economic growth, the concept of innovation can be divided into disruptive innovation and sustainable innovation. The process of creating disruptive innovation and sustainable innovation can in turn be classified into two categories, open innovation and closed innovation. The ratio of the two is useful analyze how disruptive innovation is linked to economic outcomes. We confirm the importance of open innovation in economic growth by acknowledging the relationship between labor mobility and innovation.

Using a formal model, we confirm that economic outcomes from innovation can be maximized by investing in R&D at the optimal ratio between disruptive to sustainable innovation. In addition, we show that economic outcomes differ according to the ratio of investment between open and closed innovation, which is the breakdown of investment into sustainable innovation and disruptive innovation. The model allows us to confirm that even under the optimal ratio investment level of disruptive innovation, an investment ratio of open innovation and closed innovation exists that maximizes the economic outcome. It is noted that the ratio of investment in open innovation is closely related to labor mobility, and it has been also proved by the previous studies that the economic performance of innovation cannot be maximized in an economy with low labor mobility.

The structure of this chapter is as follows. Section 3.2 explains the innovation concepts that are the key to solving our problem. We introduce disruptive innovation and sustainable innovation as the types of innovation, and closed innovation and open innovation as the creation processes, based on the various concepts used in previous innovation research. In Sect. 3.3, the model of the relationship between disruptive innovation and sustainable innovation in Sect. 3.2, without considering the innovation creation process, to show that there is an optimal ratio of investment between the two. The empirical data obtained from previous research shows that the Japanese economy has failed to achieve such optimality. In Sect. 3.4, the relationship between R&D investment in closed innovation and open innovation is examined using the concept of the open innovation investment ratio, and the existence of an appropriate value for the ratio is shown by a formal model. Section 3.5 summarizes our conclusions and their implications, and we suggest the scope for future research.

3.2 Arrangement of Innovation Concept

Innovation can be defined in a variety of ways. Previous research defines several concepts of innovation according to their own analytical point of view. Since our attempts are directed toward analyzing the impact of innovation on macroeconomic growth, we refer to previous research and define the classification from two aspects.

The first aspect is a categorical definition of disruptive and sustainable innovation, while the second is a categorical definition of the innovation creation process. Table 3.1 shows the comparison between sustainable innovation and disruptive innovation.

Previous research on the types of innovation includes the classifications of "process innovation" and "product innovation". The former has the effect of lowering average manufacturing costs by improving production processes, while the latter is to improve the quality of existing products and/or developing new products. These

Table 3.1 Comparison of sustainable innovation and disruptive innovation concepts

Classification	Sustainable innovation	Disruptive innovation
Factor		
Researchers	Research and development personnel with a deep understanding of the technology and content, of disruptive innovation are needed	Research and development personnel with a variety of ideas that are not limited by current ideas are needed
Risk and uncertainty	There is a risk that the innovations must be improved at a certain rate	There is uncertainty about when and where innovations will be created
Relationship with the market	Gradual improvement in products and services in response to requests from existing customers	It is essential that the existing rules in the market be fundamentally overturned
The victory party	Firms and developers working on closed innovation	Firms and developers working on open innovation
Economic value realization	Improve roughness at the point of creation and gradually increase its economic value	It is possible to create new products and services, but due to the roughness of these at the time of creation, it is impossible to immediately realize economic value

concepts are great importance at the microeconomic level but not at the macroeconomic level of economic growth. Therefore, in this chapter, although we do not distinguish between process innovation and product innovation, we do classify the types of innovation into disruptive innovation and sustainable innovation, because the classification is useful in terms of overall economic growth.

The second aspect dictates that there are two categories of innovation creation process: closed innovation and open innovation. The classification focuses on how firms use their internal resources to create innovations. In the case of closed innovation, the development of ideas and the creation of value through the entire process of marketing, financing, and bringing new products and services to the market take place inside a single firm. In open innovation, in contrast, a firm combines internal resources and external ideas to develop new products. Also, the firm collaborates with external parties on marketing and finance to create the market value of those products. Table 3.2 shows a comparison between closed innovation and open innovation.

Let us now consider the relationship between the outcomes of innovation and its creation processes. Disruptive innovation requires the creation of a new major technological advance that fundamentally overturns the existing rules of the market. In a

Table 3.2 Comparison of closed innovation and open innovation concepts

Classification	Closed innovation	Open innovation
Factor		
Researcher	The most talented R&D people need to be in the firm	It is necessary to hire people and build an environment that can collaborate with excellent R&D developers outside firms
Development process required	Profiting from R&D requires a firm to handle discovery, development, and commercialization on its own	The required development process requires an internal management system that protects the confidentiality of R&D and development activities conducted with external parties
Relationship with the market	A relationship with a gainful market is possible by first improving and differentiating the product or service and then selling it in the market	A relationship with a gainful market is uncertain as to whether differentiated products and services can be sold in the market
Innovation Winners	Firms and developers who create products with the best ideas in the industry	Firms and developers who make effective use of ideas from within and outside the firm
Economic Value Realization	Raise the level of existing products and services by improving them	Create new products and services, such as licensing (other firm's market), technology spin-out, etc

Table 3.3 Preference of creation methods when firms aim to create open innovation and closed innovation

Disruptive innovation	Open innovation $\succ\succ$ Closed innovation
Sustainable innovation	Open innovation $\succsim$ Closed innovation (depend on situation)

nowadays economy where the sophistication of technologies and products requires mobilizing diverse resources and capabilities, innovation is more likely to occur when the scope of value creation is broadened by adding external R&D. For this reason, firms are likely to be inclined toward open innovation; this is because the higher the ratio of investment in open innovation, the greater the likelihood of creating disruptive innovation. The fact that the number of research consortiums consisting of several firms, which play a central role in creating disruptive innovation, have been decreasing since the 1980s shows that the possibility of creating disruptive innovation through closed innovation is decreasing. This implies that firms' preference has shifted to open innovation.

The developed product as the outcome of disruptive innovation is usually not accepted by the market at first by nature. To increase economic value so as to be accepted by the market, it is essential for sustainable innovation to follow the disruptive innovation. Whether a firm prefers an open innovation or closed innovation that effectively generates sustainable innovation depends on the firm's strategy. In other words, a firm that wants to ensure confidentiality within the firm probably chooses closed innovation, while a firm that wants to work on product improvement together with other firms probably chooses open innovation. Thus, the firms' preference is crucial in choosing the method for sustainable innovation, open or closed.

Table 3.3 summarizes our implications and shows firms' preferences in terms of whether they choose open or closed innovation methods in their investment decisions for disruptive and sustainable innovation.

The above discussion points out that a desirable balance in the economy between R&D investment in open innovation and closed innovation exists for product development to lead to economic outcomes after the creation of disruptive innovation.

3.3 Optimal Allocation Between Disruptive Innovation and Sustainable Innovation

Sustainable economic growth requires both disruptive innovation and sustainable innovation. Naturally, a series of related sustainable innovations follow a disruptive innovation. So in this section, we explore investment levels that maximize economic performance and lead to sustained economic growth.

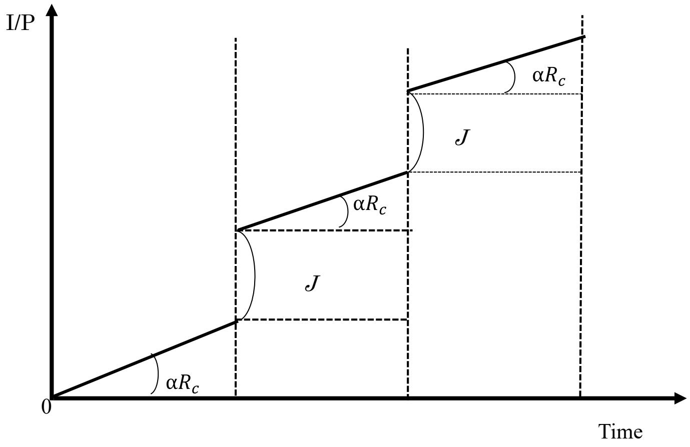

Fig. 3.1 Time path of innovation performance (I/P). Where J is performance of disruptive innovation and αR_c is performance of sustainable innovation

3.3.1 Economic Performance of Innovation

The economic performance of innovation is assumed to come from disruptive and sustainable innovation. Disruptive innovation occurs intermittently due to breakthroughs in thinking and generates economic performance that leads to a large jump in the level of technology. After that jump, sustainable innovation, which leads to a steady and continuous increase in the level of technology, yields to a continuous increase in economic performance. Figure 3.1 presents this relationship graphically.

3.3.2 The Model

Let us present a formal model to analyze the relationship between disruptive innovation and sustainable innovation. Denote J as a jump in technology by disruptive innovation and α as an increase rate in technology by sustainable innovation. The process of technological progress as a whole can be demonstrated in Fig. 3.2. To clarify the roles of disruptive innovation and sustainable innovation, let us assume as follows:

i. Disruptive innovation occurs at the interval of I_n,
ii. $I'_n(R_D) < 0 \;\; I''_n(R_D) > 0$,
iii. $\alpha R_C > 0$,

where R_D is the R&D investment for disruptive innovation and R_C is the R&D investment for sustainable innovation. As for the interval (I_n)is assumed to become shorter as R_D increases. However, the shorter the width, the more R_D increases,

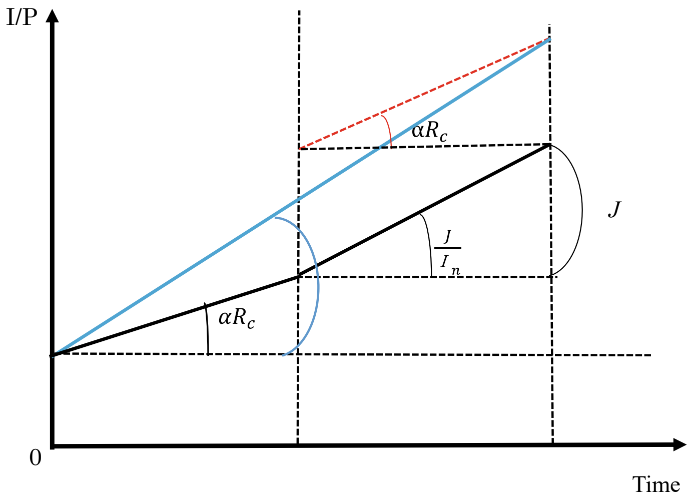

Fig. 3.2 Combined Effect of R_c and I_n on Innovation performance (I/P)

the less effective the investment is, and the longer the interval for it to be realized, as assumed in (ii). The economic performance realized by R&D investment for sustainable innovation increases with αR_C, as described above. R&D investment (constant) $R = R_C + R_D$, and is standardized to $1 = R_C + R_D$. When $R_D = 0$, it is assumed that the economic value J is not created.

3.3.3 The Optimal Allocation of Innovation

To verify the existence of a level of investment in disruptive innovation that maximizes innovation outcomes, we define S as the rate of change in innovation outcomes. From the aforementioned assumptions, S can be expressed as follows:

$$\mathrm{S} = \alpha R_C - \frac{J}{I_n(R_D)} = \alpha(1 - R_D) + \frac{J}{I_n(R_D)}. \tag{3.1}$$

The above relationship is shown in Fig. 3.2.

To find the level of R&D investment in disruptive innovation that maximizes S, the first-order condition for maximum with respect to R_D is.

$$G = \frac{\partial S}{\partial R_D} = -\alpha + \frac{-J I_n^{'}(R_D)}{(I_n(R_D))^2} = 0, \tag{3.2}$$

and the above can be rewritten as,

$$\frac{-JI_n^{'}(R_D)}{(I_n(R_D))^2} = \alpha.$$

By assumption, $I_n^{'}(R_D) < 0$, α on the left side has a positive value. To check the second-order condition differentiating Eq. (3.2) with respect to R_D

$$\frac{\partial^2 S}{\partial R_D^2} = \frac{-JI_n^{''}(R_D)(I_n(R_D))^2 - \left(-JI_n^{'}(R_D)\right)2I_n(R_D)I_n^{'}(R_D)}{(I_n(R_D))^4}.$$

For the second-order condition to be satisfied, the above must be negative. The denominator on the right side of this equation is positive, and the first term of the numerator is negative because $I_n^{''}(R_D) > 0$ by assumption. The second term of the numerator is also positive because $\left(-JI_n^{'}(R_D)\right) > 0, \quad I_n^{'}(R_D) < 0$ and $I_n(R_D) > 0$ from the same assumption. S arranges the right side to determine whether the maximum exist:

$$\frac{2\alpha}{J} I_n(R_D) > -\frac{I_n^{''}(R_D)}{I_n^{'}(R_D)}. \tag{3.3}$$

Looking at Eq. (3.3) in detail, if R_D increases, the left-hand side decreases, and the denominator of the right-hand side is negative and decreases, while the numerator of the right-hand side increases. As a result, $\frac{\partial^2 S}{\partial R_D^2} < 0$, and there is a disruptive innovation investment level R_D that maximizes S. The above relationship is shown in Fig. 3.3.

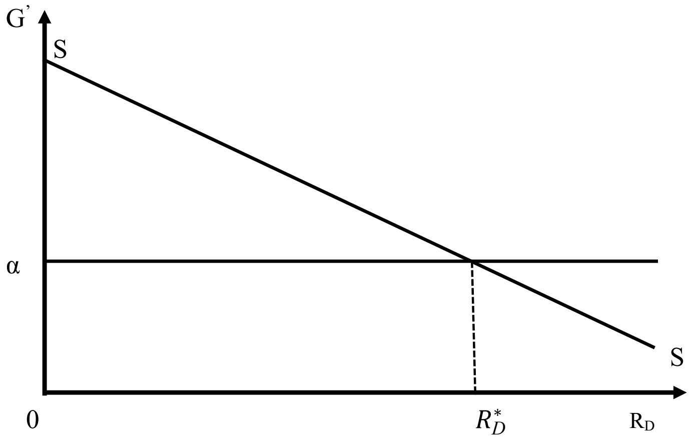

Fig. 3.3 Relationship between S-curve and investment for disruptive innovation

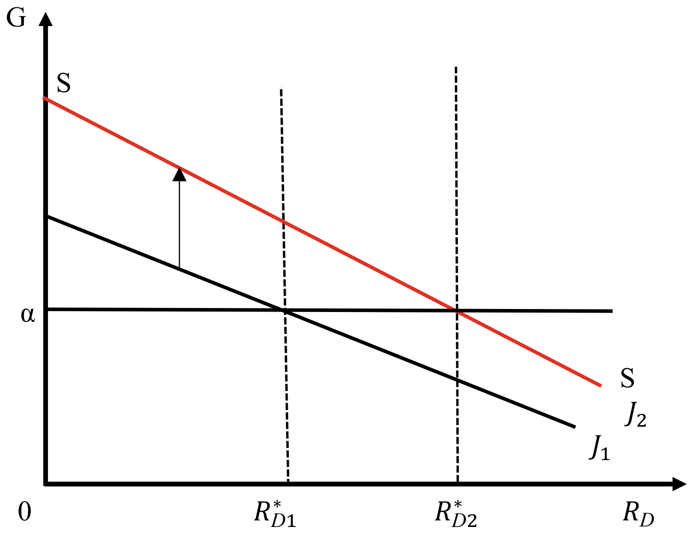

Fig. 3.4 Comparison of disruptive innovation performance

3.3.4 Comparative Statics

Let us investigate the case where both of a change in the rate of increase in the economic value J realized by disruptive innovation and the rate of increase in economic value α generated by sustainable innovation assumed to be exogenously.

When J increases from J_1 to J_2, such as government subsidies for R&D investment, the second term on the right-hand side of Eq. (3.1) increases, and hence the slope of S $\left(S^{'}(R_D)\right)$ for the innovation outcome rises. As a result, the level of investment in disruptive innovation that maximizes S will increase from R^*_{D1} to R^*_{D2}. This means that basic R&D investment in disruptive innovation by the government stimulates disruptive innovation investment by firms, as illustrated in Fig. 3.4.

In contrast, when the coefficient α of sustainable innovation increases from α_1 to α_2 due to a change in the economic system, the first term on the right side of Eq. (3.1) increases. As a result, the level of investment in disruptive innovation that maximizes S decreases from R^*_{D1} to R^*_{D2}. This means that an increase in α leads to a decline in disruptive innovation as in Fig. 3.5.

3.3.5 Discussions or Implication

As described above, under a given α and J, the optimal investment ratio between disruptive and sustainable innovation exists that maximizes economic outcomes, and hence, below that ratio, economic outcomes cannot be maximized. Although

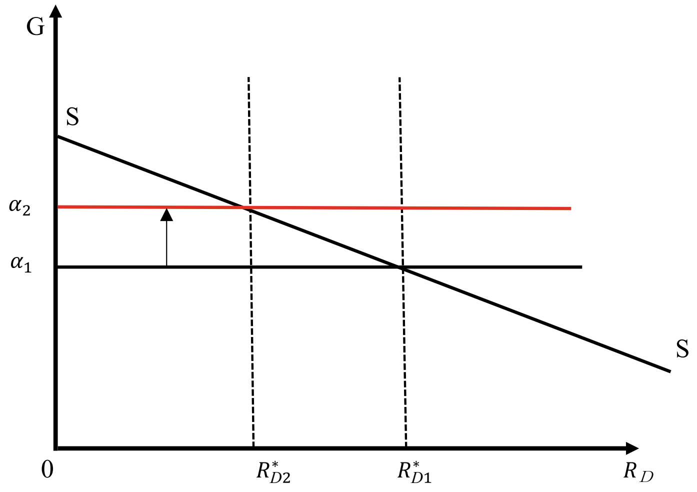

Fig .3.5 Comparison of sustainable innovation performance

it is difficult to identify this ratio, some suggestions can be made based on actual data from previous studies. For example, the results of a large-scale survey of inventors conducted by Nagaoka (2011) at the Research Institute of Economy, Trade and Industry (RIETI) in Japan and the U.S. in 2007 suggest that Japanese firms are under-investing in disruptive innovation compared to their the U.S. counterparts. The survey covers all areas of technology from inventor to invention and commercialization processes, and categorizes the R&D portfolios of Japanese and the U.S. firms into four categories. The four categories are "strengthening existing businesses," "launching new businesses," "strengthening the technology base," and "others." Their respective ratios are calculated to show that the ratio of R&D for "strengthening existing businesses," which corresponds to sustainable innovation, was 68% for Japanese firms and 48% for the U.S. firms. Moreover, for "launching new businesses," and "strengthening the technological base," which can be considered to be related to disruptive innovation, the ratio for Japanese firms was 32%, while the ratio for the U.S. firms was 48%, 1.5 times higher. The fact that Japanese firms' R&D investment in "launching new businesses" and " strengthening the technology base" is substantially lower that of the U.S. suggests that investment in disruptive innovation is not sufficient and is below the optimal ratio.

3.4 The Importance of Open Innovation

In the previous section, we assumed that the coefficients α of the economic outcome for sustainable innovation and *J* for disruptive innovation are exogenously given. However α and J depend on the ratio of investment in open innovation and closed innovation. In this section we analyze that ratio that maximizes the economic performance.

3.4.1 The Model

Let us present a formal model to analyze the relationship between open innovation and closed innovation. The share of open innovation investments is defined by p as follows:

$$p = I^O \big/ (I^O + I^C)(0 \le p \le 1),$$

where I^O is the amount of open innovation investment and I^C is the amount of closed innovation investment. We assume that J and α depend on the ratio p.

J, the economic performance of disruptive innovation, is expected to increase as open innovation raises the level of knowledge in R&D, resulting in creating economic performance of new products and services such as licensing and technology spinouts. However, the marginal performance is assumed to diminish as the ratio of open innovation increases.

The coefficient of the economic performance of "sustained innovation," α, is assumed to decrease as the open innovation investment ratio, *p*, increases, because the effect of crude improvements after the creation of disruptive innovation diminishes due to the decrease in sustained innovation R&D investment. Furthermore, we assume that the range of decrease in α becomes larger as *p* increases, with a further delay in the improvement of roughness. That is,

$$J = F(p), \frac{\partial J}{\partial p} > 0, \frac{\partial^2 J}{\partial p^2} < 0, \quad \text{(A)}$$

$$\alpha = f(p), \frac{\partial \alpha}{\partial p} < 0, \frac{\partial^2 \alpha}{\partial p^2} < 0. \quad \text{(B)}$$

3.4.2 The Impact of Innovation Openness on Economic Performance

TO confirm the existence of an open innovation investment ratio that maximizes innovation outcomes, let us define *W*, which is the sum of disruptive innovation *J* and sustainable innovation αRc. We obtain the following equation with *p*

$$W = F(p) + f(p)\left(1 - R_D^*\right).$$

The first-order condition for the open innovation investment ratio that maximizes W is as follows:

$$\frac{\partial W}{\partial p} = \frac{\partial F}{\partial p} + \frac{\partial f}{\partial P}\left(1 - R_D^*\right) = 0. \quad (3.4)$$

Since $\partial F/\partial P > 0$ $\partial f/\partial p < 0$, p that satisfies Eq. (3.5) exists. Further, the second-order condition as follows;

$$\frac{\partial^2 W}{\partial p^2} = \frac{\partial^2 F}{\partial p^2} + \frac{\partial^2 f}{\partial p^2}\left(1 - R_D^*\right). \quad (3.5)$$

Since by assumption $\partial^2 W/\partial p^2 < 0$, p that maximizes W exists.

3.4.3 Discussion

The optimal investment ratio p for open innovation that maximizes economic outcomes exists, as described above. Applying this to Japan's innovation activities allows us to argue that the optimal ratio has not been reached. That is, the total R&D expenditures, a measure of innovation investment, have increased from 13.1 trillion yen in 1990 to 19.1 trillion yen in 2017. On the other hand, the number of patent applications, which is considered one of the indicators of innovation performance, decreased from 367.6 thousand in 1990 to 318.4 thousand in 2016. The reason for the decrease in the number of patent applications despite the increase in investment can be attributed to the low ratio of investment in open innovation and the failure to achieve optimal investment, as discussed later. Putting it differently, problems may have occurred in the efficiency of innovation investment.

Yoneyama et al. (2017) show that Japanese firms' efforts in open innovation lag behind those of Western firms. Their study surveys 121 European and U.S. firms with sales of $250 million or more that are based in Europe, the U.S., and Canada as of 2014/2015. For Japanese firms, the survey covered 101 firms of roughly the same size with sales of 25 billion yen or more as of 2015. The results of the survey show that 78% of European and the U.S. firms had implemented open innovation activities, compared to 47% of Japanese firms, indicating that Japanese firms' level of open innovation activities is lower than that of European and the U.S. firms.

According to the results of the survey of Japanese firms conducted by Techno-Research (2011), 67.7% of Japanese firms conducted R&D independently, while 32.3% conducted R&D in collaboration with other firms or organizations. In addition, 61% of European and U.S. firms increase investment in open innovation compared to their investment two years before. However, only 30% of Japanese firms increase investment in open innovation, about half of European and the U.S. firms, and 68% of Japanese firms report that their investment in open innovation has remained unchanged. The results of the survey indicate that Japanese firms have been more reluctant to engage in open innovation than their European and the U.S. firms, and as a result, they have not been able to achieve the optimal ratio of open innovation *p*, and have not achieved sufficient innovation outcomes.

The question then shifts to why Japanese firms do not attains optimal investments in open innovation. Open innovation does not necessarily require a firm to hire talented in-house R&D personnel. It is sufficient to hire excellent R&D personnel or conduct R&D in collaboration with excellent R&D personnel outside the firm when necessary. However, due to the low liquidity in the Japanese labor market, necessary human resources are not available and R&D investment is not sufficient. This is supported by Nagaoka (2011), who compares the status of inter-organizational labor mobility of R&D personnel between Japan and the U.S. as an indicator of R&D personnel mobility. The study finds that inter-organizational labor mobility of R&D personnel for scientific and technological inventions that lead to innovation is important for reducing the mismatch between existing human resources and those needed to realize open innovation and transfer knowledge held by organizations. Furthermore, based on a survey of inventors in Japan and the U.S. conducted by the Research Institute of Economy, Trade and Industry (RIETI) in 2007, the report clarified the difference between Japan and the U.S. in the frequency with which researchers moved within five years prior to the invention of an innovation. The results reveal that the frequency of inventor mobility is 26% in the U.S., while it is 11% in Japan, including dispatches. With regard to the institutions they belonged to before relocating, as shown in Table 3.4, the rate of relocation from other companies in the same industry in the U.S. is very high at 46%, suggesting that the movement of R&D personnel is leading to the efficiency of open innovation activities.

As for the effect of the mobility of R&D personnel between organizations, 62% of the R&D personnel who changed jobs from other organizations answered that there was a mobility effect: 56% of the R&D personnel who were dispatched or seconded to other organizations answered that there was a mobility effect, thus acknowledging the importance of mobility. Thus, the labor mobility influences technological development through open innovation, which is the basis of innovation.

Table 3.4 Japan-U.S. comparison of inter-organizational mobility of R&D personnel

	Non-industrial research organizations (%)	Other firms in the same industry (%)	Suppliers and users (%)	Other industries (%)
The.U.S	29	46	6	19
JAPAN	35	24	15	26

Source Fujita and Nagaoka. (2011) p 184

3.5 Conclusions

In this chapter, to analyze the impact of innovation on economic growth and as well as the relationship between labor mobility and innovation, we have first discussed the investment ratio between disruptive innovation and sustainable innovation. Using a formal model, we have shown that the existence investment ratio of disruptive innovation to sustainable innovation that maximizes the economic outcomes of innovation. We have also presented empirical evidence from previous studies outlining the difference in the investment ratios in Japan and the U.S., which brought about a difference in economic growth.

The model has also been used to shows that even under that appropriate level of the investment ratio, the investment ratio between open innovation and closed innovation makes a difference in economic outcomes. We presented the empirical data from previous studies showing that firms in Japan with insufficient efforts in open innovation have low productivity. Further, the empirical data from previous studies show that Japanese firms' efforts in open innovation are lower than those of U.S. and European firms. It is considered to at least partly due to low labor mobility. In other words, labor mobility due to institutional factors may have led to inefficient R&D investment and the inability to maximize the economic outcomes of innovation.

Employment practices such as a seniority-based wage system, a lifetime employment system, and firm-based union, that create low labor mobility supported Japan's rapid postwar growth. However, in an economy where open innovation plays a key role in creating "disruptive innovations", such employment practices hinder the achievement of an optimal open innovation investment ratio. The relationship between the level of investment in innovation and labor mobility has become crucial, and a major challenge is to deepen the analysis of this relationship. In addition, this chapter does not include a theoretical analysis of the impact on innovation of general-purpose technologies. These are major technologies used in many industries that mainly determine productivity, and proprietary technologies, which have a limited range of technological applications, are used only within a firm. In future, as Harada (2007) points out it would be meaningful to analyze the impact of general-purpose technology on innovation.

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