Time path in innovation, imitation, and growth: the case of the motorcycle industry in postwar Japan*

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(November 2004)

Abstract. This study attempts to explore how an industry evolves over time based on a case study of the motorcycle industry in Japan from 1948 to 1964. Using individual firm data, we estimate the determinants of technology improvement and firm growth separately for different development phases, after controlling for the probability of firm survival. We find that the industry's rapid growth in the early phase can be explained by massive entry and the imitation of simple technologies, whereas sustained growth in later phases can be explained by innovations and subsequent imitations, as well as the exit of inefficient firms.

Key words: Evolution, Industrial development, Innovation, Imitation, Motorcycle industry

JEL Classification: O14, L10, L62, N65

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* We are grateful to Kotaro Horiuchi, Shunji Tanaka, Katsuaki Nishino, Michael Kevane, Uwe Cantner, and two anonymous referees for their helpful comments and suggestions.

1 Introduction

Since the seminal work of Gort and Klepper (1982), there has been increasing interest in the evolutionary process of industrial development, in which a series of innovations and subsequent imitations lead to changing market structures. Such a process typically entails the active entry of new firms in an early phase of development, the exit of many firms in later stages, and the formation of an oligopolistic market structure characterized by a smaller number of surviving firms. In order to explain such an evolutionary process, a large number of theoretical models have been developed (e.g., Jovanovic, 1982; Hopenhayn, 1992; Ericson and Pakes, 1995; Pakes and Ericson, 1998; Klepper, 1996).

In addition, there have been a large number of empirical studies, which attempt to elucidate the factors underlying the evolutionary process of industrial development, using US or UK industry data (e.g., Dunne et al., 1988; Klepper and Graddy, 1990; Jovanovic and MacDonald, 1994; Klepper and Miller, 1995; Agarwal and Gort, 1996). These studies generally agree that changing patterns of innovation and imitation lead to observed patterns of industrial evolution. More recent studies analyze the impacts of the size, location, and other characteristics of the firm on its adoption of new technology and its survival in the product life cycle, using firm-level panel data from the US and the UK (e.g., Greenstein and Wade, 1998; Klepper and Simons, 2000a; Klepper, 2002). Yet, little is known about industrial evolution in developing economies, where industrial development begins with the imitation of existing technologies developed abroad, and, hence, all producers except foreign multinationals are imitators initially.

This study presents an attempt to explore how an industry evolves over time, using firm-level data on the development of the motorcycle industry in Japan from 1948 to 1964, the period in which Japan was a technological follower with a low average income. The motorcycle industry in Japan started with the production of about 200 motorcycles in 1948, but thereafter grew rapidly and became the world's largest producer by 1960, producing nearly 1.5 million motorcycles per year. A unique feature of this study is the focus on how technological changes were involved in the industry's evolution. We find that quality improvement matters to the survival and growth of firms, and that quality improvement stems from imitation initially and from innovation later.

The organization of this article is as follows. Section 2 describes the evolutionary process of the development of the motorcycle industry in Japan in terms of the entry and exit of firms, the changing growth rate of motorcycle production, and changes in the quality of engines. Section 3 formulates hypotheses and specifies regression functions for empirical testing, which is followed by regression analyses in Section 4. Section 5 concludes the paper.

2 Evolutionary growth of the motorcycle industry

2.1 Data

We collected the firm-level data on the year and location of foundation, pre-entry experience in manufacturing, production in terms of the number of motorcycles produced, internal production or purchase of engines, and horse-power and engine displacement volume of almost every model from 1948 to 1964 from a large number of sources.[1] The coverage of our data is almost perfect, except for production data from

[1] The data sources are: Kotsu Taimusu (1960), Nihon Jidousha Kogyokai (various years), Nihon Kogata Jidousha Kougyoukai (various years), Yaesu Shuppan (1987, 1997), Honda Collection Hall (1997), and Tomitsuka (1997).

tiny workshops in the early years. The data on engine quality are taken from a comprehensive collection of catalogues of new models compiled by a publisher, Yaesu Shuppan (1997), for motorcycle enthusiasts.[2] Thus, we could trace the evolutionary process of this industry almost from its birth to the stage in which the oligopolistic big-four structure emerged.[3]

2.2 Entry and Exit

There were only five motorcycle producers in Japan immediately following World War II (Honda Collection Hall, 1997). “They were merely tiny workshops and there is no exaggeration to say that motorcycle production in Japan started from scratch from the global point of view….” (Tomitsuka, 1997, p. 1). As shown in Table 1, the number of firms increased to 27 by 1950, even though 18 of these firms produced only a handful of motorcycles. Like a number of new industries in the US and the UK (e.g., Gort and Klepper, 1982; Klepper and Graddy, 1990), the motorcycle industry in Japan experienced the entry of a substantial number of new firms in its early stage of development, followed by a shakeout -- a dramatic reduction in the number of firms.[4]

Figure 1 clearly demonstrates the rapid changes in the number of firms in the motorcycle industry. In the peak year of 1952, the number of firms reached 127. The rising phase until 1952 was associated with the rapid entry of new firms. Since then, the entry of new firms began to decline and practically ceased in the late 1950s, and the rapid exit of firms followed, particularly from 1953 to 1955. In subsequent years, the

[2] The book is as voluminous as a thick telephone book showing the catalogues of approximately 4,000 new motorcycle models of a large number of firms including very small ones since 1946.

[3] The big-four motorcycle firms, which still exist, are Honda, Yamaha, Suzuki, and Kawasaki.

[4] Braun and Panzer (2003) show that the motorcycle industries in Germany and Great Britain also experienced similar processes of entry and exist from the late 1910s to the early 1930s.

exit continued steadily, eventually resulting in only the four major firms.

2.3 Growth

Corresponding to the alternating trends of entry and exit of firms, there are distinct phases in the growth of the motorcycle industry in terms of the number of motorcycles produced (Figure 2).[5] The growth rate was particularly high in the very early 1950s, when new entry was active.[6] Such a high growth period was followed by more stable growth in the mid-1950s, a period characterized by the rapid exit of firms. Finally, the growth rate slowed considerably in the early 1960s, when the steady exit continued.

As shown in Figure 3, which shows changes in the number of motorcycles produced in major industrialized countries from 1946 to 1965, Japan's production was negligible in the 1940s. While England was the top producer in 1946, France, Germany, and Italy increased their production more rapidly in the 1950s. Japan's production remained much smaller than these European countries until the early 1950s, but then grew most rapidly in the late 1950s and far exceeded the production in other countries by the early 1960s.

2.4 Quality

In the high growth period from the late 1940s to the early 1950s, low-quality, simple, and relatively homogeneous motorcycles were produced by a large number of small firms. Typically, motorcycles produced in this period were nothing more than bicycles with simple engines. It was therefore possible for anybody with a certain amount of

[5] Since the quality of motorcycles improved over time, we underestimate the growth rate of production in later years.
[6] Note that Figure 2 shows growth rates during the following year.

engineering knowledge to assemble motorcycles by purchasing engines and bicycles (Tomitsuka, 1997). Moreover, the technology was so simple that imitation was easy and, hence, rampant. In this early period after the war, four-wheeled cars and imported motorcycles were not yet affordable to small businesses and the average consumer in Japan, despite the rapidly growing demand for cheap means of transportation, which reflected the brisk recovery of the domestic economy from the devastation of the war. Attention thus turned to domestically produced small motorcycles. As a result, many small-scale firms, which employed only a few workers, emerged in the early period. Thus, the motorcycle industry grew without much technological change.[7] While the exportation of motorcycles was negligible relative to production in the 1950s, it increased from 4% in 1960 to 29% in 1964, and jumped to 45% in 1965. Such rapid increases in exportation suggest that the quality of domestic motorcycles was significantly improved in the late 1950s and 1960s, to become comparable to foreign products. Throughout the study period, the importation of motorcycles was negligible.

Among the most important technological issues in motorcycle production is the improvement in engine quality. Following the formula developed by Taylor (1960),[8] we computed the engine quality index using the aforementioned exhaustive collection of catalogues of new motorcycle models (Yaesu Shuppan, 1997). Figure 4 shows the average quality of engines by surviving and exiting firms. Since the number of exiting firms was generally small in a single year, the average quality for the surviving firms was close to the overall average. It is clear that the average quality of engines did not improve until the mid-1950s; it actually declined in 1949 because the quality of the

[7] According to a recent case study of the machine tool industry in Taiwan (Sonobe, Kawakami, and Otsuka, 2003), the total factor productivity did not improve much in the early phase of rapid industrial growth in the 1960s and the early 1970s, when there was active entry of new firms.
[8] The quality index formula is (horsepower)/(displacement volume)$^{2/3}$.

engines produced by the new entrants in that year was particularly low. Thus, it seems reasonable to characterize the period from the late 1940s to the early 1950s as the "quantity expansion phase" accompanied by the rapid entry of firms but not by quality improvements.

The next phase can be characterized by the increasing incidence of firm exits, the burgeoning improvement of engine quality, and the fairly stable growth of the industry. The Japanese economy had fully recovered from the devastation of the war by 1955, and consumers began to demand higher quality products. Also, because of the abundant supply of low-quality motorcycles, the profitability of producing such products declined (Tomitsuka, 1997). Efforts to improve the quality of motorcycles, including the quality of engines, began in the late 1950s. It seems that many firms with only the capacity to imitate the outdated technology failed to improve their engines, other parts, and overall designs and were forced to exit the industry. As is shown in Figure 4, the quality of engines of the exiting firms declined with respect to that of the surviving firms in the late 1950s. It is legitimate to describe this period as an "early period of the quality improvement phase."

The efforts to improve the quality of engines and products culminated in the advent of the "Super Cub" by the Honda Motorcycle Company in 1958. This was an epoch-making model, and variants are still being produced in a number of countries (Miki Shobo, 2001). The Super Cub embodies a large number of novel ideas, such as the use of newly developed automatic centrifugal clutches, a large front-cover made of polyethylene, and large wheels, and surpasses other motorcycle models technologically and functionally. Needless to say, the engine of the Super Cub was decisively superior to those of other motorcycles: the 4.5 horse-power generated from its four-cycle engine of 50cc displacement exceeded the standard of that time by two to three times, according to a chief engineer of the Honda R&D Company. Although it was technologically so advanced that it became difficult for other firms to imitate Honda's leading technologies, the surviving firms attempted to do so. Yet, some firms directly imitated the Super Cub and were sued for violation of patent rights. For example, Yamaha, a major rival of Honda, had to pay a sizable reparation fee, which caused tremendous damage to Yamaha's management. As a consequence, direct and outright imitation became infeasible.[9] Nonetheless, tacit and indirect imitation occurred in the period after 1958. It is likely that, since the late-1950s, only those firms with the capacity to innovate or imitate tacitly could survive, while less capable firms had to leave the industry. In fact, the average engine quality of surviving firms was clearly higher than that of exiting firms. Thus, as shown in Figure 4, the average engine quality continued to improve after the advent of the Super Cub in 1958, due partly to the exit of less capable firms and partly to the innovation and subtle imitations by the surviving firms. We call this period the "later period of the quality improvement phase."

2.5 Firm size

Another major innovation brought about by Honda was the standardization of the production process of high-quality products and the initiation of mass production in large-scale and automated factories. For example, Honda purchased high precision machine tools from abroad in 1952, which cost 450 million yen, 70 times as much as

[9] Murmann and Homburg (2001) compare evolutionary dynamics of the synthetic dye industry in several countries and argue that patent laws reduce the entry of new firms by preventing them from copying the incumbents' technologies directly.

Honda's capital at that time (Honda Co., 1995). While Honda was originally established in Hamamatsu city in 1948, in 1960 it built a major new factory in Suzuka, southwest of Nagoya, for large-scale production of the Super Cub. According to the annual reports of the listed companies, the reliance of Honda on subcontracting was relatively low and decreasing. Honda's early rival, Tohatsu, relied exclusively on subcontracting, and hence its dependence on purchased parts amounted to 95% in the 1950s. By contrast, Honda's dependence on the purchase of parts was only 35%, except when the Super Cub was being developed using a variety of new parts. In order to ensure the production of the high-quality key-parts, Honda standardized the production of such parts and opted to produce them in-house. Because of the standardization, a finer division of labor within a factory by the intensive use of automated equipment became possible. In this way, Honda pursued volume manufacturing to realize scale economies (Otawara, 2000). Other surviving firms also introduced the mass production system gradually. Beginning in the early 1950s, the average size of surviving firms continued to increase over a fifteen-year period (see Figure 5). On the other hand, the average size of exiting firms was significantly smaller than the surviving firms, which suggests that smaller firms were forced to exit the industry.

It is interesting to observe from Table 2 that the average size of firms increased geometrically. In fact, the average size tripled from the first to the second period and increased 12 times from the second to the third. It is also noteworthy that the standard deviations were large because of the coexistence of large producers, notably Honda, as well as small ones. Honda produced approximately 11, 64, and 910 thousand motorcycles annually in the three respective periods, which were five to ten times as large as the averages. Therefore, it seems reasonable to hypothesize that not only the quality competition of the products but also the competition towards large-scale production became intense among motorcycle firms in later years.

2.6 Geography

Motorcycles were produced in various places in Japan after the war, including Tokyo, Nagoya, and Hamamatsu and its vicinity. It is interesting to note that, during the evolutionary growth process, there were marked changes in the geographic distribution of motorcycle production. As is shown in Table 1, Tokyo was a major center of production in 1950, whereas its production share declined thereafter. The share of Nagoya also declined from 1955 to 1960. By contrast, the production share of Hamamatsu continued to increase, and it became the major cluster of motorcycle production in Japan.[10] The recent empirical literature on industrial clusters in developing countries suggests that clusters are generally conducive to the improvement of product quality (e.g., Schmitz and Nadvi, 1999; Schmitz, 2000). It appears that the geographical concentration of motorcycle production increased with the quality improvements of motorcycles in Japan.

2.7 Pre-entry experience and financing

Another important development, which must be mentioned at this point, is the late entry of a few firms, which were supported by firms belonging to related industries. In earlier periods, about one-third of the firms had pre-entry experience in manufacturing activities (see Table 2). Gradually, those firms which had not only pre-entry

[10] Yamaha and Suzuki, the second and third largest producers, have been based in Hamamatsu, and Honda, the largest producer, started motorcycle production in this city.

experience but had also maintained relations with the original firms, entered the motorcycle industry. Good examples are Yamaha, Suzuki, and Kawasaki, the three ultimate rivals of Honda; they were diversifying branches of well-established firms producing music instruments, loom machines, and heavy machinery, respectively, and entered the industry in the early 1950s. According to our interviews, support from the related firms, particularly financial and to a lesser extent technical, was instrumental in investing massively in research and development as well as heavy equipment, by using bank loans. This is consistent with Chesbrough's (1999) observation that the diversifying entrants in the hard disk drive industry in Japan could survive novice startup firms because of their financial advantages, even though they failed to keep up with the extraordinarily rapid progress of hard disk drive technology and all of them were eventually wiped out of the market. By contrast, the three diversifying entrants in the motorcycle industry could survive all the incumbents other than Honda and grow into oligopolists, presumably because this industry was less technologically progressive than the hard disk drive industry. In addition, the proportion of firms producing engines internally increased in this period, which indicates that firms intent on improving the quality of engines, rather than relying on purchased engines, tended to survive in the later periods.

3 Testable hypotheses

Overall, the review of the development of the motorcycle industry in Japan suggests that technological advancement played a critically important role in the determination of changing market structure leading to the formation of an oligopoly, consistent with the theory of the product life cycle developed by Klepper (1996). As engine quality increased, demand grew, which in turn allowed firms to exploit economies of scale. Firms that could innovate or successfully imitate higher quality products grew rapidly, whereas firms that fell behind in the quality race exited. In order to substantiate this view, this section advances some testable hypotheses regarding the effects of product quality on firm survival and growth performance, as well as the determinants of innovativeness.

We assume that the technology level of each firm changes either through innovation or imitation.[11] We also assume that technological change depends on the level of own technology (*T*), the size of firm (*S*), pre-entry experience (*P*), operation experience (*E*), and geographic agglomeration (*A*), and formulate the following function explaining changes in technology (ΔT):

$$\Delta T_i = \alpha_0 + \alpha_T T_i + \alpha_S S_i + \alpha_P P_i + \alpha_E E_i + \alpha_A A_i + \varepsilon_i \,, \tag{1}$$

where α's are unknown parameters and ε is an error term. We use the engine quality index as a proxy for *T* and its changes for ΔT. Firm size (*S*) is measured by the number of motorcycles in a year. Pre-entry experience (*P*) is a dummy variable indicating whether the motorcycle firm had experience in manufacturing before it entered the motorcycle industry.[12] Operation experience (*E*) is measured by the number of operation years, which may capture the effect of accumulated technological knowledge through experience. Geographic agglomeration (*A*), represented by total production in

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[11] Innovation is defined here as useful new ideas, or "new combinations" in the sense of Schumpeter (1912), created by a firm's own innovation efforts. The innovation thus defined does not necessarily refer to a drastic change in technology.

[12] According to our own interviews, support from the original firms seems to have been highly beneficial for motorcycle firms in obtaining bank loans, because banks trusted the solvency of the supporting firms. The pre-entry experience may also be useful for technology development and management of motorcycle firms.

the locality minus own production, is intended to capture the external economies arising from the geographical clustering of motorcycle firms.

We estimate equation (1) separately for the three periods: (i) the quantity expansion phase from 1948 to 1953, (ii) the early period of the quality improvement phase from 1954 to 1958, and (iii) the later period of the quality improvement phase from 1959 to 1964. Much of the literature on economic development argues that imitation is the major source of technology growth in the early stage of industrial development in developing economies (e.g., Hobday, 1995; Sonobe, Kawakami, and Otsuka, 2003). When innovation is impractical even for the most technologically advanced firms, the less-advanced firms would be able to catch up through imitation, so that current technological prowess is negatively related to the rate of technology growth. Once innovation becomes practical,[13] however, the leading firms would have an advantage at innovation (Schumpeter, 1950; Kamien and Schwartz, 1982; Klepper, 1996) and hence innovate more. These arguments can be summarized by the following hypothesis:

Hypothesis 1: The negative effect of the current technology level on the rate of technological change decreases as innovation assumes greater significance in technology improvement.

According to recent case studies of the development of industrial clusters in East Asia, industrial clusters tend to develop when the quality of products improves, as the clusters facilitate the dissemination of new ideas and reduce the transaction costs of

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[13] Innovation would become practical because the quantity expansion reduced the profitability of producing low-quality products, on the one hand, and because the supporting industries had developed, on the other hand.

high-quality parts and intermediate products between part-suppliers and assemblers.[14] This suggests the following hypothesis:

Hypothesis 2: Firms located in industrial clusters experience relatively rapid technological change.

The data on engine quality are available only for the surviving firms that published product catalogues. Since such firms would be relatively efficient, the ordinary least square estimation of equation (1) would entail sample selection bias. To avoid such bias, we estimate the Heckman selection model consisting of equation (1) and a selection equation that determines the availability of the engine quality data. For the selection equation, we use the same set of explanatory variables as for equation (1).

We hypothesize that firm size increases with the improvement of product quality as well as the reduction in production costs due, for example, to enhanced volume manufacturing (e.g., Filson, 2002). The reduction in production costs would also be affected by the same factors that affect technological change, which are specified in equation (1). Thus, we assume that change in the size of surviving firm i is a function of the same set of explanatory variables as in equation (1):

$$\Delta S_i = \beta_0 + \beta_T T_i + \beta_S S_i + \beta_P P_i + \beta_E E_i + \beta_A A_i + \mu_i \,, \qquad (2)$$

where β's are unknown parameters and μ stands for an error term.[15] The ordinary least square estimation of equation (2) would entail a selection bias problem due to the fact

[14] See, e.g., Sonobe, Hu, and Otsuka (2002), Sonobe, Kawakami, and Otsuka (2003), Yamamura, Sonobe, and Otsuka (2003).
[15] Unlike Dunne et al. (1989), Dunne and Hughes (1994), Hall (1987), and Evans (1987a, 1987b), we estimate the firm size change function separately for the three periods.

that the sample comprises the surviving firms only. Thus, we apply the Heckman selection model and estimate equation (2) together with a selection equation that determines the survival or exit of firm *i*. The selection equation is assumed to have the same set of explanatory variables as equations (1) and (2) and the selection equation ancillary to equation (1).

In the literature on firm survival and the product life cycle (e.g., Agarwal and Audretsch, 2001; Disney, Haskel, and Heden, 2003; Klepper and Simons, 2000a, 2000b; Klepper 2002), the size and pre- and post-entry experience of firms are considered to be critical determinants of their survival. In addition, Klepper and Simons (1997) point out that those firms which fail to improve product quality are likely to be forced to exit from the industry. Thus, it seems reasonable to postulate the following hypothesis:

Hypothesis 3: Not only firm size and production experience but also the quality of products is a critical determinant of the survival of firms.

The effect of quality improvement on firm size, i.e., β_T in equation (2), would strongly depend on whether their products were salable in international markets. In fact, as the best Japanese producers became competitive with the leading motorcycle producers in other nations, they could produce for international markets and their sales grew immensely, as shown in Figure3. Moreover, as the income levels of Japanese consumers increased over time, they would become more fastidious in the quality of motorcycles. Thus, we postulate the following hypothesis:

Hypothesis 4: The effect of quality improvement on firm size increases over time.

The firm size expansion seems to have been affected not only by the improvement of engine quality, but also by other types of technical change, such as the introduction of the mass production system. Although direct measures of technology traits other than engine quality are not available, firm size may serve as a proxy because the recent literature suggests that larger firms are more innovative (Cohen and Klepper, 1996; Klepper and Simons, 1997). Once innovation become practical, therefore, the large firms would improve these aspects of technology more than would the small firms and, hence, the former would expand more than the latter. Thus, it seems reasonable to hypothesize as follows:

Hypothesis 5: While the effect of the current firm size on the rate of firm size expansion is negative during the imitation phase, it is positive during the innovation phase.

4 Estimation results

The estimation results of the engine improvement function (1) and the firm expansion function (2) are shown in the lower panels of Tables 3 and 4, respectively.[16] The upper panels of these tables report the estimates of the auxiliary selection equations. It must be pointed out that, while the selection equation in the upper panels of Table 4 picks up survivors,[17] the selection equation in the upper panel of Table 3 picks up a subset of the survivors which advertised their products. Thus, the determinants of firm survival can be analyzed only by the selection function in Table 4: the one in Table 3 is useful only in avoiding selection bias. On the most right-hand side columns in these tables, we added the dummy for firms conducting formal research and development activities for the

[16] We did not show the coefficients of year dummies in the regression tables, because most of them are insignificant.

[17] We did not estimate the selection equation for the first period (1948-53) because only one sample firm went bankrupt.

estimation of the engine quality function and firm size expansion function for the third period. This dummy was not included in the selection function because all those firms operating research departments survived. Nor was it included in the first- and second-period regressions because of the sheer lack of data on R&D in these earlier periods.

In the lower panel of Table 3, it is interesting to find that the coefficient of engine quality in the engine improvement function is negative and significant in every period, and that it is smaller in absolute value in the second period than in the first and third periods. These findings support Hypothesis 1. It is also interesting to observe that firm size had a significantly negative coefficient in the engine improvement function in the first period but not in the second and third periods. These results are consistent with Hypothesis 1 in that the catch-up in engine quality by imitation became relatively difficult in the quality improvement phase. The effect of agglomeration on engine improvement was neither positive nor significant in the quantity expansion phase. However, it became positive in the quality improvement phase, and it was highly significant in the early period of this phase. These results are consistent with Hypothesis 2.

Concerning Table 3, three other results are worth mentioning. First, the dummy variable for the internal production of engines and bodies had a positive and significant effect on engine improvement in the first and second periods, even though the effect lost significance in the third period, when the majority of the sample firms produced engines and bodies in-house. Second, the dummy variable for formal R&D is significant on the most right-hand side column of Table 3, which indicates that formal research activities became important in the later phase of the quality improvement.

Finally, and somewhat unexpectedly, the effects of both post- and pre-entry experiences on quality improvements were generally insignificant, given the initial level of engine quality.

The estimation results shown in the upper panel of Table 4 are informative as to the determinants of firm survival. First, both engine quality and firm size showed positive and significant effects on firm survival, indicating that larger firms using higher-quality engines tend to survive more readily. Interestingly, the statistical significance of the coefficient for engine quality increased over time whereas that for firm size declined. These results suggest that technology became increasingly important as a major determinant of firm survival, which is consistent with the theory of the product life cycle advanced by Klepper (1996). Second, the years of operation and pre-entry experience dummy are highly significant in the last period, which indicates that both pre- and post-entry experiences are important for firm survival in the latter part of the quality improvement phase. The positive effects of pre- and post-entry experiences on firm survival were also found by Evans (1987a, 1987b) and Klepper (2002). Overall, these two sets of results support the validity of Hypothesis 3. Finally, the effect of the in-house production of engines and bodies on firm survival proved to be significantly negative in the last two periods, which suggests that, given the quality of engines a firm uses, the outsourcing of engines and bodies reduces financial risks.

Several important observations can be made from the estimates of the firm expansion function reported in the lower panel of Table 4. First, the coefficients of engine quality are positive and significant in the second and third periods but not in the first period, which suggests that the improvement of engine quality became one of the key factors promoting firm expansion only in the quality improvement phase. Furthermore, its coefficient is much larger in the third period than in the second, which indicates the increasing importance of engine quality in firm growth. These findings support Hypothesis 4. Note that the coefficient for engine quality lost significance, however, when we also included the dummy for formal R&D activities, which is taken to imply that these two variables are highly correlated.

Secondly, it is interesting to find that the effect of the initial firm size on the subsequent growth is negative but insignificant in the first period, positive and highly significant in the second period, and negative and significant in the last period. These results indicate that, compared with the periods when imitation is important, larger firms tend to have greater momentum to grow in the period when new innovations are introduced. These findings clearly support Hypothesis 5.

Thirdly, the number of years of operation is insignificant in all periods, which suggests that management knowledge acquired by experience is not useful for firm growth. Lastly and unexpectedly, the coefficient of the pre-entry experience dummy becomes negative and significant in the last period. Although this result is difficult to interpret, it is consistent with the earlier finding that the effect of pre-entry experience on the improvement of engines was insignificant in the last period, with the initial level of engine quality and firm size being controlled.

5 Concluding remarks

Proper understanding of the evolutionary process of industrial development is critically important not only for developed economies but also for developing economies. Nonetheless, empirical studies of the evolutionary process of industrial development have exclusively focused on the U.S. and U.K. experience. This study represents a rare attempt to analyze the evolutionary process in the low-income stage of a currently developed country, namely Japan.

There are interesting similarities and dissimilarities between the findings of our study and existing empirical studies. A notable similarity is that the number of firms rises initially and then falls in the evolutionary process. The Japanese case seems different, however, in that the quality improvement did not take place in the beginning but occurred in later stages of development. A recent study of the development of the machine tool industry in Taiwan by Sonobe, Kawakami, and Otsuka (2003) also indicates that quality improvement did not take place in the early period of its development. Similarly, a historical study of the motorcycle industry in Germany and UK by Braun and Panzer (2003) suggests that the quantity expansion of the industry through imitation preceded technological, financial, and organizational innovations. In contrast, the available evidence in the U.S. case studies indicates that quality improvement takes place in an early stage of development (e.g., Klepper and Graddy, 1990; Klepper and Miller, 1995; Filson, 2002).

Such differences seem to reflect the fact that industrial development begins with the imitation of existing technologies developed abroad in the case of technologically follower countries, whereas it begins with truly innovative activities involving trial and error in the improvement of products in the leader countries. If this is the case, what matters for the inception of industrial development in developing countries is the capacity to imitate, but not necessarily to innovate. The capacity to innovate becomes a key to the further development of the industry in later stages, when the quantity expansion based on direct imitation of foreign technology no longer ensures sustainable development. However, we ought to point out that the evidence presented in this paper focuses on the improvement of engine quality and the introduction of mass production, and that other types of technological change might have been rapid during the industry's early years. Clearly, further studies of the evolutionary process of industrial development in developing countries are called for in order to obtain a better understanding of the process.

According to our study, the capacity to imitate continues to play a significant role also in the period succeeding major innovations. While innovation is an engine of growth, imitation plays the role of transmission. Without imitation, the benefit of new innovation cannot be shared widely in the economy. Thus, we praise the recent attempts in the literature of endogenous economic growth to shed theoretical light on the process of imitation as well as innovation (e.g., Grossman and Helpman, 1991; Aghion and Howitt, 1998). However, we would also like to emphasize that the importance of imitation is likely to change at different stages of industrial development. Yet, such insights have not been incorporated into the theoretical studies on endogenous growth processes. Given the potential importance of imitation in realizing the fruits of industrial development, further empirical studies on the changing roles of imitations are warranted.

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Table 1. Changes in the number of sample firms, motorcycle production, and their regional distributions in selected years

	1950	1955	1960
No. of firms	27	71	29
No. of motorcycles produced (1,000)	9	261	1,447
Proportion by location (%)[1]			
Hamamatsu	18.5	28.7	66.1
Tokyo	62.5	38.8	25.8
Nagoya	19.0	22.3	3.9
Others	0	10.2	4.2

[1] Locational classification is based on the place of foundation.

Table 2. Basic characteristics of the motorcycle industry by major period

	Quantity expansion phase	Quality improvement phase	
		Early period	Late period
	1948-53	1954-58	1959-64
Engine quality	0.15 (0.04)	0.24 (0.06)	0.32 (0.08)
Firm size[1]	3,756 (6,130)	11,601 (18,370)	144,429 (281,097)
Years of operation	2.76 (2.04)	5.43 (3.26)	10.2 (4.38)
Firms with pre-entry experience (%)	40	50	78
Firms producing engines in-house (%)	47	45	58

Arithmetic means and standard deviations are reported for engine quality, firm size, and the years of operation. Numbers in parentheses are standard deviations.
[1] Firm size is measured in terms of the number of motorcycles produced per year.

Table 3. Determinants of changes in engine quality by period: Maximum likelihood estimation with selection by publicity

Period	Quantity expansion phase	Quality improvement phase		
		Early period	Late period	Late period
	1948-1953	1954-1958	1959-1964	1959-1964
Number of observations	53	130	64	64
Censored observations	15	31	19	19
Selection equation				
Engine quality	-3.98 (-0.67)	-8.23** (-2.74)	2.02 (0.92)	5.15 (1.39)
ln (Firm size)	1.25 (1.09)	0.29* (1.91)	0.02* (2.29)	0.02* (2.09)
Years of operation	-0.02 (-0.18)	-0.02 (-0.52)	0.01 (0.35)	0.03 (0.50)
Pre-entry experience dummy	0.01 (0.04)	-0.05 (-0.17)	2.91** (3.15)	2.82** (2.46)
Agglomeration	-5.45 (-0.36)	7.53** (2.52)	-0.27 (-0.56)	-0.67 (-1.03)
Engine and body production dummy	0.41 (0.72)	0.76* (2.15)	0.64* (1.71)	0.60 (1.04)
Constant	16.8* (2.03)	-1.81 (-0.94)	1.19 (0.83)	-1.47 (-0.73)
Engine improvement function				
Engine quality	-0.86** (-4.44)	-0.34** (-2.81)	-0.55** (-4.74)	-0.64** (-5.67)
ln (Firm size)	- 0.27** (-2.36)	0.04 (1.42)	-0.00 (-0.38)	-0.00 (-0.49)
Years of operation	0.14 (0.41)	-0.01 (-0.80)	-0.03 (-1.47)	-0.01 (-0.67)
Pre-entry experience Dummy	-0.01 (-0.79)	-0.02* (-1.89)	-0.07 (-1.24)	-0.01 (-0.22)
Agglomeration	-0.43 (-1.18)	0.30** (2.76)	0.03 (1.54)	-0.04 (-1.57)
Engine and body production dummy	0.06** (3.36)	0.02** (2.54)	-0.01 (-0.60)	0.02 (1.19)
R & D firm dummy				0.08** (3.91)
Constant	-0.25 (-0.61)	0.08 (1.05)	0.21** (2.73)	0.12* (1.72)

z-statistics are reported in parentheses. Macroeconomic variables, which are not shown in this table, are included in the regressions. * and ** denote significance at 5 percent and 1 percent levels, respectively. In this estimation, we excluded those firms which failed to survive or failed to publicize their products in consecutive years.

Table 4. Determinants of changes in firm size by period: Maximum likelihood estimation with selection by survival

Period	Quantity expansion phase	Quality improvement phase		
		Early period	Late period	Late period
	1948-1953	1954-1958	1959-1964	1959-1964
Number of observations	53	130	64	64
Censored observations	1	9	12	12
Selection equation				
Engine quality		4.04* (2.26)	7.85** (3.56)	8.07** (3.75)
ln (Firm size)		1.19** (12.0)	0.25* (1.88)	0.02** (3.25)
Years of operation		-0.05 (-1.58)	0.10** (2.41)	0.10* (2.25)
Pre-entry experience dummy		-0.05 (-0.30)	2.90** (4.62)	3.08** (4.55)
Agglomeration		2.66 (1.35)	-0.15 (-0.34)	0.02 (0.06)
Engine and body production dummy		0.19 (0.92)	-0.79* (-1.92)	-1.02** (-2.63)
Constant		1.53 (1.09)	-3.89** (-3.48)	-3.36** (-2.90)
Firm expansion function				
Engine quality	-1.36 (-0.79)	5.04* (2.21)	44.6* (2.26)	22.7 (1.08)
ln (Firm size)	- 0.10 (-0.77)	0.67** (9.93)	-0.15** (-1.93)	-0.21** (-2.83)
Years of operation	-0.02 (-0.69)	-0.06 (-1.56)	-0.02 (-0.05)	0.17 (0.48)
Pre-entry experience Dummy	0.02 (0.13)	-0.10 (-0.42)	-22.4** (-3.66)	-24.3** (-4.58)
Agglomeration	-0.15 (-0.34)	0.34 (1.37)	0.40 (0.95)	-0.04 (-0.10)
Engine and body production dummy	1.09 (0.59)	0.23 (0.89)	-0.94 (-0.28)	-0.11 (-0.04)
R & D firm dummy				7.41 (1.63)
Constant	3.42 (1.28)	1.72 (0.96)	11.0 (1.13)	18.8* (2.10)

z-statistics are reported in parentheses. * and ** denote significance at 5 percent and 1 percent levels, respectively. In this estimation, we excluded those firms which failed to survive in consecutive years.

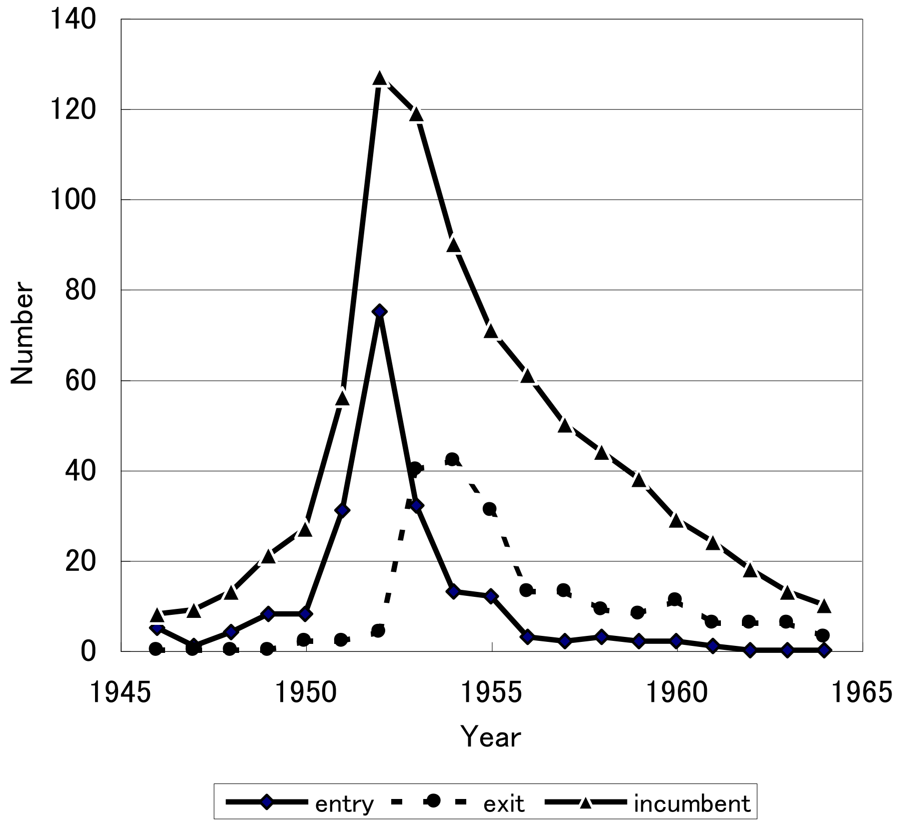

Fig. 1. Number of operating firms, entries, and exits

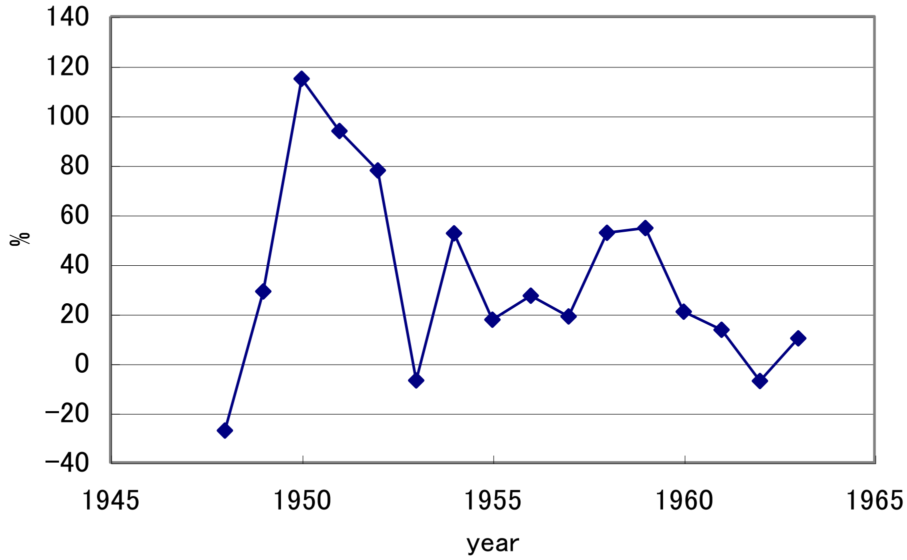

Fig. 2. Annual growth rate of total motorcycle production

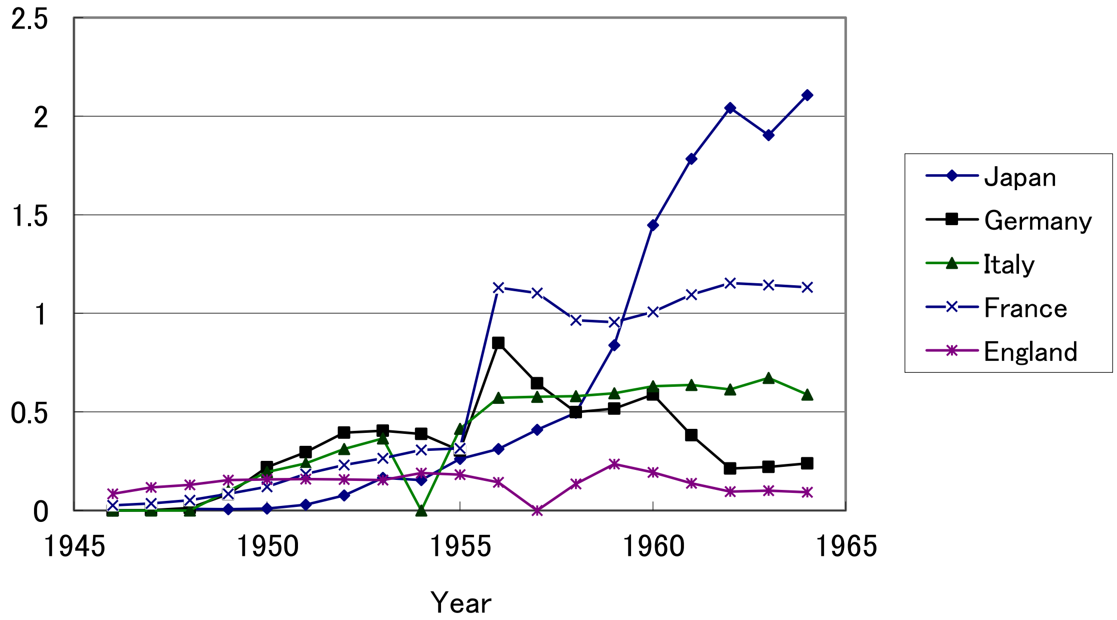

Fig. 3. Production of motorcycles by major countries (Million motorcycles)

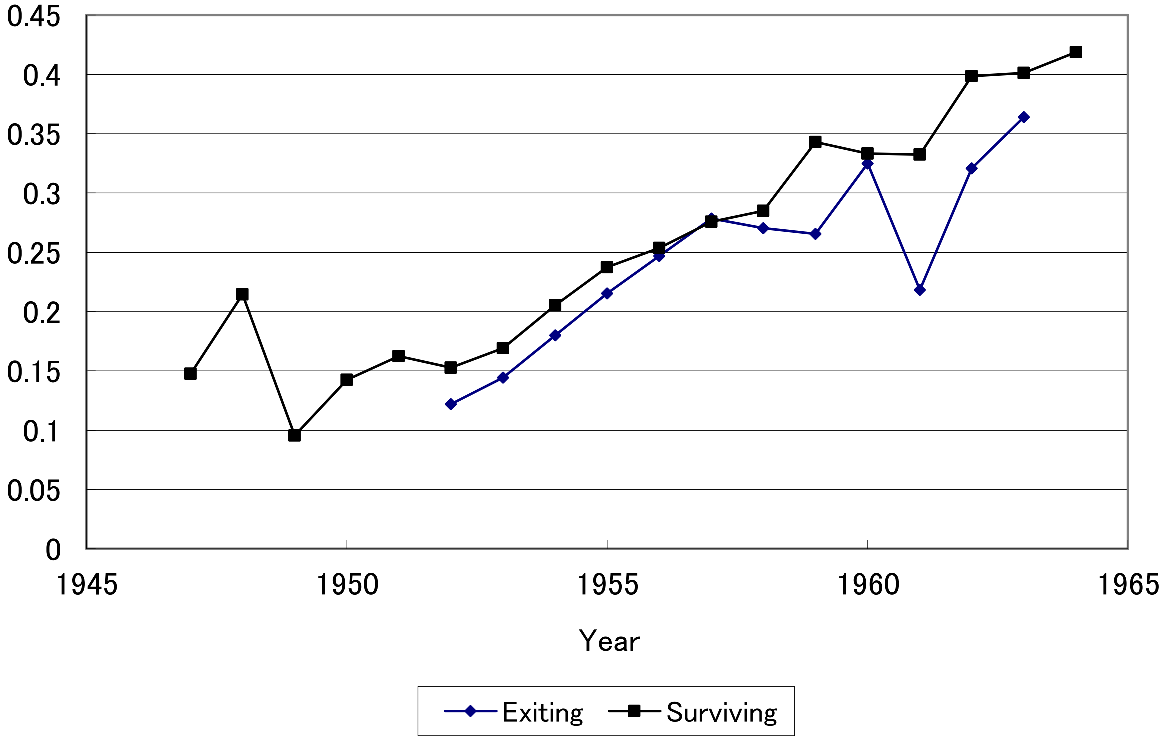

Fig. 4. Average quality of engines by surviving and exiting firms

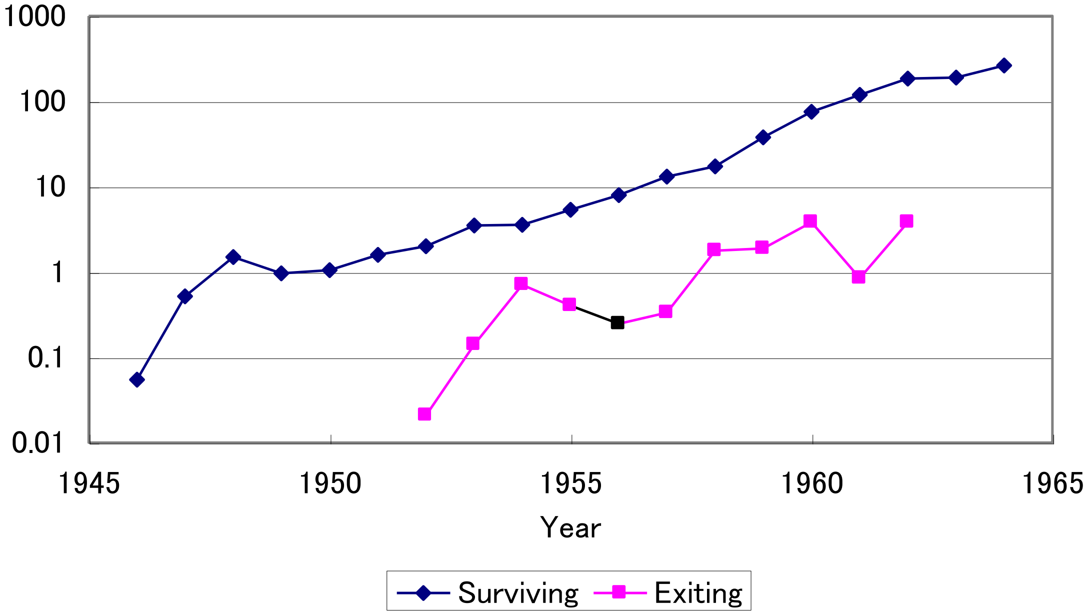

Fig. 5. Average size of firms by surviving and exiting firms (Thousand motorcycles)