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Lim, Chaisung and Kim, Y and Lee, Keun

2015

Asian Journal of Technology Innovation 25 (1): 61-78, 2017

Changes in Industrial Leadership and Catch-Up by Latecomers in Shipbuilding Industry

This revision: May 2016
First draft: December 2015

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Earlier versions of this paper were presented at several occasions, including the Asialics conference held in Tokyo, 2013. The authors would like to thank the comments by the anonymous referees, and the corresponding author acknowledge the financial support from the Insitute of Economic Research (its Center for National Competitiveness) of Seoul National University.

Abstract

This study considers the shipbuilding industry to explain the successive changes in leadership from the Schumpeterian perspective. The window of opportunity for Japan to forge ahead of the UK was the arrival and employment of new technologies, a method referred to as welding block. The Japanese firms also adopted path-creation, a strategy that involves the use of innovations more promptly than the incumbent UK, which had delayed adoption due to the opposition of labor unions. The leadership shift from Japan to Korea also represents path-creation given that Korean firms responded quickly to the rise of a new window of opportunity (i.e., systematized 3D computer aided design technologies) and met the newly rising demand in large vessels that was the second window of opportunity. Both of these cases of path-creation are an adoption and follow-on innovation mode because the latecomers not only adopted new technologies, but also reinvented them further into a new system of production. This study also finds the unique, institutional nature of the source of the incumbent trap in the shipbuilding industry, which is different from that associated with the relative costs and benefits of new versus old technologies. In addition, this study identifies the peculiarity of the technological regimes of the shipbuilding sector and the associated unique nature of the technological window of opportunity, which are not merely competence-destroying innovations (Tushman and Anderson 1986) of component technologies but a consolidation of a new systematized technology that has changed the entire process of shipbuilding.

Keywords: systems of innovation, catch-cycles, shipbuilding, window of opportunity, incumbent trap, path-creation, leapfrogging

1. INTRODUCTION

The changes in industrial leadership from an incumbent to a late entrant country are often observed in various industries, involving both the advanced and latecomer countries from the South. Mowery and Nelson (1999) examined such changes among advanced countries, whereas Lee and Malerba (2015a and b) looked into the rise of latecomer countries from the South. In particular, the latter studies focused on more than two or successive changes in industry leadership. For example, in the mobile phone industry, Motorola was an early leader with its invention of the product itself but was dethroned by Nokia with the rise of digital phones. Korean firms have been the market leader of the industry since 2012 although it is seriously being challenged by Chinese firms.

Lee and Malerba (2016a) referred to these phenomena of successive changes in industrial leadership as “catch-up cycles,” in which catch-up pertains to the substantial closing of the gap in market shares between the firms in a leading country and those in a latecomer or follower country. Among the attempts to explain these phenomena, the sectoral studies collected in the special issue of *Research Policy* have handled cases of various sectors, such as mobile phones, the memory chip segment of semi-conductors, cameras, steel, mid-sized jets, and wine. These cases were analyzed in view of the common theoretical framework on successive changes in industrial leadership and the catch-up cycle proposed by Lee and Malerba (2016a); the main results are summarized in the work of Lee and Malerba (2016b).

The current study considers the shipbuilding industry because it has also experienced similar changes in industrial leadership over the last 200 years. Leadership is measured through the size of production by firms in each country. The American wooden ship dominated the shipbuilding industry in the first half of the 19th century but was later governed by the UK in the latter half of the same century. After World War II, in the late 1950s, the leadership shifted to Japan but was eventually obtained by Korean firms in the 2000s although they are challenged recently by Chinese firms.

This study follows the framework of Lee and Malerba (2016a) that suggests that successive changes in industrial leadership can be explained by considering the newly opened windows of opportunity and diverse responses to them by the incumbents and latecomers. In other words, the framework explains the successive changes of leadership because of the responses of the firms in the incumbent or latecomer country to the diverse windows of opportunity. The concept of the windows of opportunity was first used by Perez and Soete (1988) to refer to the role of the rise of new techno-economic paradigms in generating leapfrogging by the latecomers who take advantage of a new paradigm and thereby surpass the old incumbents. The framework broadens this notion by considering additional dimensions that correspond to the building blocks of a sectoral system, such as technological, demand, and institutional windows (Lee and Malerba, 2016a). With the notion of "windows of opportunity," the framework uses the concept of "response" by firms and systems, particularly path-following, stage-skipping, and path-creation (Lee and Lim 2001). A few firms from emerging countries and the sectoral system that supports them may respond to the emergence of opportunities and rise to global leadership. Nonetheless, the current leaders from a certain country may fall behind be due to their lack of effectiveness in the response, often due to an "incumbent trap" (Chandy and Tellis, 2000), by the firms and their sectoral system, leading to misalignments to the new window. To utilize this framework, this study can also be considered to follow the method of "appreciative theorizing," (Nelson and Winter, 1982: 46) which aims to provide the "causal explanations of observed patterns" of leadership changes across sectors.

We primarily hypothesize that in the shipbuilding industry, the shift of leadership from the UK to Japan can be considered path-creation because the Japanese firms created a comprehensive system (inter-related sets) of welding-block technology. This system is effective for producing standard vessels and results in high productivity. Contrary to the advancement among Japanese firms, the UK was trapped in the traditional craft skill-based non-standard vessel shipbuilding system with the labor union of skilled labor force favoring the old technology. In the case of leadership change from Japan to Korea, the windows of opportunity for path-creating catch up were opened by the demand shifts to

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large vessels and the emergence of the "extended 3D computer aided design (CAD) system" that can integrate various operations. Compared with Korean firms, the Japanese firms were stuck into the incumbent trap of remaining with the "unextended 3D CAD system" because of their slow response in accommodating 3D CAD technology from Western countries and their decision not to invest in upgraded facilities (e.g., large docks) to build large vessels. These factors were affected by the rapid appreciation of the Japanese currency and the past trauma of the deep depression in the 1970s and 1980s. This study attempts to contribute to the literature in two means. First, this study extends the literature by elaborating the details of the process of leadership changes in the shipbuilding industry with focus on the windows of opportunity and the specifically required nature of the technological window in this sector. Second, this study widens the literature by indicating that the source of the incumbent trap may include not only the economic calculations of the costs and benefits of new versus old technologies, but the previous institutional rigidities and legacies as well.

The remainder of the paper is organized into six sections. Following the Introduction, Section 2 presents the theoretical framework and hypotheses. Section 3 provides a descriptive account of the leadership changes from UK to Japan and then from Japan to Korea. Sections 4 and 5 analyze these cases of leadership change, respectively, to explain the process by referring to the theoretical framework and hypotheses. Finally, Section 6 concludes the paper.

2. Theoretical Framework and Hypotheses[1]

Vernon's product life cycle theory (1966) is not a theory at the sector level but at the product level. Thus, his theory does not serve the main purpose of our study, as it does not consider the possibility or phenomenon that latecomer firms control not only the production but also R&D, and brands of goods, whereas firms from advanced countries lose in the competition. As such, this study relies on the work of Lee and Malerba (2016a) and its application to the steel industry. Lee and Malerba proposed an alternative theoretical framework, which considers the diverse factors beyond

[1]The theoretical framework is elaborated based heavily on Lee and Ki (2016), but the hypotheses are suggested to reflect the specifics of the shipbuilding industry.

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the level of a single product or technology to include the factors at the levels of industry and even those at the levels of national institutions and the interactions among them. The framework introduced by these researchers and this study rely on the neo-Schumpeterian concepts of innovation systems, including the national systems of innovation (Lundvall 1992; Nelson 1993) and setoral systems of innovation (hereafter SSI) (Malerba 2002, 2004). Malerba (2004) applied the SSI framework to industries in advanced countries and defined sector as a set of activities unified by linked product groups for a given or emerging demand and share a common knowledge. Matching each component of the SSI to diverse windows of opportunity is useful to explain the successive changes in industrial leadership.

Several types of windows can be opened up for late entrants. One is the rise of a new techno-economic paradigm (Perez and Soete 1988) that tends to threaten the advantage of the existing first movers or incumbents rooted in pre-existing investment in the existing vantage of capital. When a new paradigm arrives, both latecomers and incumbents stand on the same starting line with the new technology, but the latter may fall behind by clinging to old technology they dominate. The propensity for incumbents to stick with the old paradigm is somewhat rational considering the replacement effect (Arrow 1962) because the incumbents who considerably invest early want to recover the investment costs fully.[2] In this study, we do not address the shift of techno-economic paradigm; instead, we look into a mini paradigm, a new generation of technologies, or a new trajectory.

Another type of window of opportunity is derived from the second components of SSI (demand conditions or market regimes), that is, a business cycle and/or abrupt changes in market demand, including the rise of new consumers. Mathews (2005) indicated that business cycles create opportunities for challengers to stir up the industry because downturns play a cleansing role. Thus, the weak incumbents are forced into bankruptcy, and resources are released at low prices to be picked up by the challenger firms that aim to enter the industry. The third window of opportunity can be opened up by the government because this opportunity can often generate an asymmetric

[2]Innovation replaces the existing profits of incumbents, but a late-entrant firm has few profits to replace. Thus, compared with incumbents, the entrants have stronger incentives to adopt or undertake an innovation.

environment for incumbents and entrants through a range of regulations and direct supportive actions for entrants. These asymmetries can be used by latecomers to offset the initial cost differences associated with the late entry (Mu and Lee 2005).

Although these types of windows of opportunity are events that are exogenous to latecomer firms, as discussed in the preceding paragraphs, firms should recognize the open windows and take advantage of them to realize their potential. In other words, the strategies of firms themselves interact with the windows of opportunity as well as the technological and market environments that affect their performance. Accordingly, our model is not deterministic but it emphasizes the role of actors, particularly those of firms and governments.

Lee and Lim (2001) explained that several choices are available for possible entry or catch-up strategies by latecomers, such as path-following, stage-skipping, and path-creating, in which the *path* refers to the trajectory of technologies and *stage* represents the stages in the trajectories.

The first choice is to adopt the first-generation or oldest technology with the lowest prices; this method is called path-following. This strategy implies that latecomers move along the old technical trajectories of incumbents. An advantage of this strategy is that the established firms care less about the transfer or leakages of proprietary technologies because latecomers target and want to purchase the oldest technologies readily available at low prices, particularly during business downturns. The late entry by Korean firms in the shipbuilding industry can be considered path-following backed up by the government to seek its survival as a late entrant.

The second choice is stage-skipping, which refers to the case in which latecomer firms follow the same path as that of incumbents, but skip older-generation technology to adopt the latest technology. Thus, fierce competition may occur between incumbents and late entrants because the latter fully utilizes the advantage of latecomers to adopt up-to-date technology. Aside from the matter of available financial resources to purchase up-to-date technology, the market availability of such an up-to-date technology or the willingness of any established firm to transfer such technologies to latecomer firms is also an issue. Once this matter of technology transfer or acquisition is solved to benefit a late entrant, this firm may emerge as a powerful rival because it does not only enjoy the same level of productivity as the incumbent, but it utilizes the likely low costs of labor or other factor conditions as well. Government assistance in the form of industrial policy is an additional advantage.

The third choice pertains to path-creation, an aggressive and risk-taking strategy. This strategy refers to the case in which a latecomer explores its own path of technological development by using a new techno-economic paradigm or a new generation of technologies (Lee and Lim 2001). This strategy is consistent with the idea of leapfrogging discussed by Perez and Soete (1988), who observed that leapfrogging may occur during the shifting in generations or paradigms of technologies. An obvious advantage of path-creation or leapfrogging is that this strategy chooses technologies with high long-term potential or productivity, whereas a potential risk is that the emerging or new technology is neither stable nor reliable; such technology also has low productivity or high costs at its early stage (Lee et al., 2005).

The preceding idea is consistent with the theory of S-curves (Chandy and Tellis 1998; Foster 1986), which states that the inferiority of a new technology at its first appearance discourages incumbents from introducing the new generation of technology. In this sense, a new technology can be a source of the "incumbent trap" and is a window of opportunity for latecomers who are free from the "replacement effect of new technology" (Arrow 1962). In other words, incumbent firms tend to ignore, by rational calculation or mistake, the emerging technologies with potential, and they remain complacent with high productivity from current technologies. Although this choice may be rational in the short run, incumbent firms may lose to other firms that take the risk of adopting emerging technologies and eventually attain higher productivity than that of incumbents, thereby winning the market from incumbents. Nonetheless, not every firm, but probably late entrants or inferior firms whose levels of productivity are lower than those of the leading firm, has many reasons to shift rapidly and lightly to new technologies. In this sense, latecomers have a greater incentive than the incumbents to take the risk of adopting new technologies.

Lee and Malerba (2016b) found that the incumbent trap tends to occur in most cases of leadership changes in various sectors. In this case, this study further modifies the theoretical framework of Lee and Malerba (2016a) to consider a new dimension of the incumbent trap. Specifically, this study proposes that the incumbent trap may also result from the institutional rigidities or legacies of firms in addition to the relative costs and benefits of new versus old technologies that are associated with theory of S-curve or replacement effects. This modification is applied because the trap in the shift of leadership from the UK to Japan resulted from the institutional rigidity in the UK (i.e., the resistance of UK labor unions against new technologies), whereas that from Japan to Korea is associated with the institutional memory of depression and the rigidity in the government's regulations on investments which discouraged Japanese firms from investing in new technologies and facilities for large vessels.

In the discussion of the catch-up strategies of latecomers, technologies are treated as exogenous, and firms, especially latecomer firms, are treated as if they face the binary choice to adopt such strategies or not. However, latecomers often not only assimilate the adopted technologies but also improve them substantially, an approach that is often called *follow-on innovation*, *incremental innovations*, or *reinvention*. Rogers (2003) observed that reinvention occurs at the implementation stage for many innovations and adopters, and it leads to an increased rate of adoption of an innovation. Along this line of thought, we can conceive two types of path-creation; one depends on whether a new path is created by in-house, endogenous innovation activities by the latecomers, and the second adopts the exogenous or supplier-driven innovation earlier than the incumbents do and then further improving the adopted technologies. The former may be common in product innovation or IT sectors, such as semiconductors, whereas the latter may be relevant in process innovation-prone sectors, such as steel (Lee and Ki 2016), and can be pertained to as the *adoption and follow-on innovation mode*.

Our hypothesis shown in Section 4 is based on our understanding of the technological and market regimes or the demand condition of the shipbuilding industry discussed in Section 3. We hypothesize and show in Section 4 that the combination of a path-creating strategy and the incumbent trap is most applicable to the leadership change in the shipbuilding industry from UK to Japanese firms in the 1950s when different attitudes and speed of adopting new technologies between the firms in two countries served as the critical factor for the market shake-up. This study hypothesizes that the window of opportunity for Japan to forge ahead of the UK was the arrival of new technologies, a method called welding block, and that the Japanese strategy was a path-creating strategy of adopting such innovations more rapidly than the incumbent UK did that delayed the adoption because of the opposition of labor unions. The path-creation by the Japanese firms was along the mode of adoption and follow-on innovation as explained in the latter part of the paper.

In Section 5, the leadership shift from Japan to Korea is hypothesized as path-creation because the Korean firms developed the "extended 3D CAD system" more quickly than the Japanese firms did, which enabled the former to meet the newly rising demand in large vessels. Thus, the first window of opportunity for the Korean firms was the shift in CAD technology: (i) a shift from the traditional 2D CAD to a breakthrough in 3D CAD, which was developed by specialized software suppliers in Europe and the US (Rando 2002) and can provide the graphical 3D representation of numerical data; (ii) systematization of 3D CAD, allowing it to be linked to other software and databases. The Korean path-creation can also be considered an *adoption and follow-on innovation mode because* Korean companies not only adopted the 3D CAD design technology, but also created an integrated 3D CAD system by collaborating with leading foreign companies in their in-house R&D, integrating the design systems (e.g., outfit (interior designs) and hull design (structure of the ship)), and consolidating the design software with ERP and other databases. The second window of opportunity was the shift in demand conditions or the rise of demand for sophisticated vessels of large sizes, the production of which can also be improved with 3D CAD.

Compared with Korean firms, the Japanese firms were stuck into the incumbent trap of remaining with the "unextended 3D CAD system" because of their slow response to accommodate the 3D CAD technology and their decision not to invest in upgraded facilities (e.g., large docks) to build large vessels. Nobeoka and Baba (1999) observed that the Japanese engineers were unwilling to purchase new technologies, particularly from Western suppliers who remained the major suppliers of these systems, because of their "overconfidence in their abilities and a lack of confidence in their ability to work with foreign companies," which has "a negative influence on implementing more extensive changes" in the shipbuilding process. An additional factor for the passive attitude of Japanese toward new investment was the macroeconomic environment of the rapid appreciation of the Japanese currency and the past trauma of deep depression in the 1970s and 1980s.

3. Record of the Leadership Changes

In terms of the technological regime, the shipbuilding sector is a complex product system (CoPS) industry (Hobday, Rush and Tidd 2000) with a slow pace of technical change, compared with that of the information, communication, and technology sector. This difference implies that if any window of opportunity emerges from the technology side, it should be not only component technologies but eventually in the form of the changes in systematized technology that may change the entire process of building ships. In addition, the shipbuilding industry calls for large capital investment for manufacturing and employment of numerous employees. This condition implies that even with the emergence of new technologies, incumbent firms would be less likely to invest in new technologies because of the high sunk cost of the capital goods.

In terms of the market regime or demand condition, the ship building sector corresponds to longer cycle time with the longer life expectancy of ships than typical consumer goods, as well as market demand influenced by the general business cycles of economies. In addition, the ship industry's market is characterized by i) a highly competitive global market because of the bidding system developed by many buyers and sellers as well as the relatively low transportation costs (Porter, 1986), and ii) customers are active purchasers, giving out specifications on the products to be made. Intense interaction is required during ship development to meet the customer request.

Industrial leadership has undergone continuous change over the last 200 years. The American wooden ship dominated the shipbuilding industry in the first half of the 19th century, but the UK became the leader in the latter half of the same century. After World War II, in the late 1950s, the leadership was shifted to Japan, but was eventually obtained by the Korean firms in the 2000s although they are seriously challenged recently by Chinese firms.

Between the early 1900s and the end of World War II, the demand slowly grew until it fluctuated corresponding to war. After the war, the demand grew rapidly until the middle of the 1970s (the period when Japan was able to capture leadership) and suddenly declined. The growth in demand gradually recovered from the early 1990s, reaching the level of the later 1970s during the latter part of the 1990s, along with continued growth in the 2000s (see Figure 1). Since the early 1900s, the demand for military vessels declined, whereas that for commercial vessels increased and the size of vessels have been enlarged, calling for large shipbuilding facilities. After World War II, in the realm of commercial vessels, new types of vessels, such as crude oil carriers, containers, LNG gas carriers, and offshore plant, emerged.

Changes have also been implemented in the building method from rivet, welding (methods of building ship surfaces), to block building (method of building separate blocks and completing ships by linking blocks). From the 1970s, the production process has been digitized, controlled by computers, software, and microelectronics components for automatic mechanical operation via computer-controlled welding robots and production control methods. From the 1980s, the design process has also been digitized through the emergence of design software (i.e., CAD) and complementary software (e.g., computer aided engineering (CAE) and simulation software).

This study focuses on the leadership shift in the industry from UK to Japan and from Japan to Korea in terms of production volume. The Japanese surpassed the UK in the mid-1950s, in which the former occupied 26.2% of the market share in 1956, whereas the UK shipbuilders only comprised 20.7%. Roughly 40 years earlier, in 1913, the Japanese shipbuilders remained at 2.0%, whereas the UK shipbuilders occupied the dominant market share (58%) (Table 1, Figure 1). In the 2000s, Korea surpassed Japan. The Korean shipbuilders occupied 33.0% of the market share in 2012, whereas the

Japanese shipbuilders comprised only 18.3%. Roughly 40 years earlier, the Korean shipbuilders occupied only 2.4%, whereas the Japanese shipbuilders occupied the dominant market share (40.9%) in 1976 (Table 2, See Figure 1).

TABLE 1. Ships manufactured in the UK and Japan (1913–1968)

(in percentage of gross tons)

	World	**UK**	**Japan**
1913	100.0	58.0	2.0
1921	100.0	35.4	5.2
1924	100.0	64.1	3.2
1927	100.0	54.6	1.9
1930	100.0	51.9	5.3
1933	100.0	27.3	15.4
1936	100.0	40.9	14.1
1939	100.0	25.3	13.1
1950	100.0	29.5	7.8
1953	100.0	25.8	10.9
1956	100.0	20.7	26.2
1959	100.0	15.7	19.7
1962	100.0	12.8	26.1
1965	100.0	8.8	43.9
1968	100.0	5.3	50.8

Source: Blumenthal (1976)

TABLE 2. Ships manufactured in Japan and Korea (1976–2012)

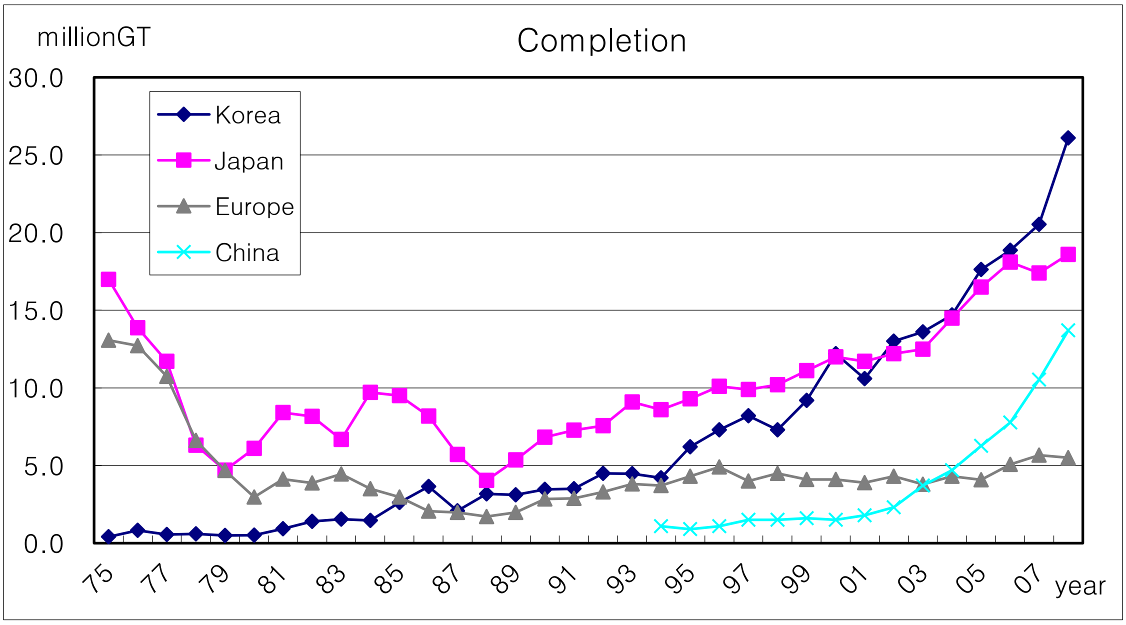
(in percentage of gross tons)

	World	Japan	Korea

1976	100.0	40.9	2.4
1979	100.0	32.9	3.5
1982	100.0	48.5	8.3
1985	100.0	52.3	14.4
1988	100.0	37.0	29.1
1991	100.0	45.3	21.7
1994	100.0	43.9	21.4
1997	100.0	39.1	32.4
2000	100.0	38.5	39.1
2003	100.0	35.2	38.3
2006	100.0	34.9	36.4
2009	100.0	24.7	37.8
2012	100.0	18.3	33.0

Source: Lloyd's

‛FIGURE 1. Ships Completed Worldwide (in 1,000 gross tons)



Source: Lloyd's

4. Explaining the Leadership Shift from the UK to Japan

The shipbuilders' production volume in Japan was recorded as the highest in the world in the latter part of the 1950s. This volume was realized through the adoption of the windows of opportunity in market and technology. Japan had retained its leading position until 1999.

4.1 Exploiting the new window of opportunity of forging ahead: utilization of welding block

Japan first constructed a modern shipyard in 1853 and built its first steel ship in 1890 (610 gross tons). Japan ranked as the third nation in terms of shipbuilding construction in 1917 (350,000 gross ton construction) (KOSHIPA 2010). Japanese shipyards were equipped with the facility to meet domestic demand, comprising 50 shipyards with 126 berths and 75 docks (Chida and Davies, 1990). The excess capacity of Japanese shipbuilders along with their accumulated capabilities enabled firms to meet this demand. After World War II, the demand expanded for Japanese ships, initially domestic, the majority of which were destroyed during the war. The domestic demand accounted for 85.2% of orders of all ships constructed from 1950 to 1954. Japan needed ships to support its import and export of capital goods, components, and raw materials for industrialization.

The demand increased further in the latter half of the 1950s, particularly after the Suez Crisis built in 1956. The 1960s and 1970s were periods when low-priced and abundant amounts of oil supported the industrialization of the world economy and when trade volume expanded with the free trade trend. The physical volume of international trade rose from 2% per year from 1920 to 1938 to 8.2% in the post-war period because of the expansion of trade and the industrialization of the recovering advanced countries and other developing countries (Blumenthal 1976). This expansion of trade increased the demand for ships, especially for oil tankers and bulk carriers. The increase of oil tankers also reflected the change of energy source from coal to oil. The rapid growth in world demand for bulk carriers reflected the demand for international trade. Large standard vessels were increasingly accepted in international markets, which allowed competitive advantage for non-UK shipbuilders that used the ‘bureaucratic method’ suitable for the large-scale production of standard vessels (Lorenz 1991; Kirby 1992; Motora, 1997).

Over this expansion period, the Japanese government helped local shipyards by giving them a protected market and providing them with supportive policy measures. The government had a policy for nurturing the shipbuilding industry, establishing the shipbuilding law in 1950. This law protected the domestic market, and sought various means to nurture the industry. The Japanese government decided how many ships were to be constructed using loans from the Development Bank of Japan, which provided long-term low interest loans to shipbuilding companies (Blumenthal, 1976). Other policies were also implemented to reduce the cost burden of shipyards, such as temporary measures pertaining to the reduction of steel cost in shipbuilding (August 1953 to March 1954) and providing 2.5% reduced loans (originally 5%) to steel makers to reduce the cost of steel (RIMSE 2002). A policy was also in place to link ship exports with imports of crude sugar (January 1953 to November 1954) to compensate for the export revenues by supporting profits from the import of sugar by up to 20% of the ship’s price along with long-term low interest loans for exports (from 1950) and export credit insurance (from 1950) (RIMSE, 2002). Given the rising domestic demand and supportive governmental policies, the Japanese shipyards initially seized market opportunities from their capacity and accumulated capability to keep pace with the leading country.

Japan also utilized new technological opportunities to seize the rising demand. When the welding block method was introduced first in the US as new way of building commercial vessels, Japanese shipyards soon began to adopt this method in 1950. However, at that time, the method was yet to be widely used in manufacturing commercial vessels. The US had fully developed the block building and structural welding methods (Chida, 1990), which have been applied mostly in military vessels, having not fulfilled their full potential. Japanese shipbuilders had led the application of the block building method in commercial vessels. The application was led by firms and was facilitated by the government who supported the projects to solve problems in the application of welding block methods.

The productivity of the welding method was substantially improved with the automatic welding method invested in by the Japanese shipbuilders. The automatic welding technology called for complementary goods: steel that can be welded together with the automatic welding machine. The steel and shipbuilding industries in Japan worked collaboratively from 1951 to 1952, which resulted in creating such steel (Blumenthal, 1976). The developed steel was fine quality “killed” steel rather than “rimmed” steel (Chida and Davies, 1990). The welding method called for other complementary goods, precise cutting machines for plates, and development of improved welding rods. Automatic gas cutting was introduced in 1951 (Motora, 1997). Factory layouts and facilities had also to be accordingly changed, following the introduction of the building block methods. Given that the welding block method facilitated the prefabrication of blocks indoors, the shipyard needed rail cranes to move blocks to the berth (Lorentz 1991). The shipyard did not have to have infrastructure for the riveting method, in which the sections of the hull were constructed on a job shop basis and then fitted piece by piece at the berth (Lorenz 1991). This flexibility led to a straight-line organization of production, which was bureaucratic (Lorentz 1991).

With the adoption of welding block methods, all these interdependent changes amounted to a total revolution in shipbuilding. For example, the welding of thick iron and steel plates cannot be introduced without automatic cutting. The welding block method cannot be efficient without changes in the shipyard layout (Blumenthal 1976, p.157). Japanese shipbuilders achieved all these changes, which became the basis of the long-term competitiveness of the Japanese shipbuilding industry. From 1950 to 1955, with this new method, the Japanese shipyards successfully delivered ships with shorter lead times without interruptions from trade unions. With such a disciplined labor force, the Japanese firms adopted bureaucratic shipbuilding methods with capital-intensive modern facilities, as in the case of other successful non-UK European shipyards (Lorentz 1991), to overcome its weakness of skilled labor in comparison with the UK. Japanese ships managed to deliver 10,000 deadweight tons tanker in 164 days as opposed to the UK's 281 days in 1950–1955 (Kaneko, 1964). Productivity was considerably improved through the welding block method. For example, the period spent on shipbuilding berth/dock was reduced from 10 months in 1949 to 5 months in 1960. The maximum utilization of the berth/dock (including large capital investment) was crucial to the improvement of productivity.

One caveat on the price competitiveness of Japanese ships is that the wage advantage was not automatically guaranteed. The cost of the locally built ships, despite cheap wages, was higher than that of the UK because of expensive imported steel. In 1956, because of a 62% higher cost of material costs (imported materials), the cost of a ship built by Japanese shipbuilders were 27% higher than that of the UK (Blementhal, 1976). The cost could become cheaper than that of the UK's only after the local production of the necessary steel in Japan. Finally,from 1959 onward, Japanese shipbuilders managed to achieve a cost advantage (3% cheaper) over UK shipbuilders (Kaneko,1964).

After being successfully positioned as the leader monopolizing the largest demand of the world's shipbuilding, Japan continuously invested in creating original technologies. After more than 15 years of investment to reduce the gap between Japan and Western countries as well as in-house R&D for original technology, Japanese yards began to develop original technologies by themselves in 1960s (Chida and Davies, 1990), such as developing the world's largest tanker Nissho Maru in 1962, Tokyo Maru in 1965, and Idemitsu Maru in 1966 (Cho and Porter, 1986). With its mastery of block building methods and its capability to create original ships and design concepts with low wages, Japanese shipbuilders successfully established the basis of strong competiveness in the shipbuilding industry that lasted for 30 years.

UK companies failed to cope with the competition from Japanese shipbuilders because the UK firms' traditional craft system of building nonstandard vessels as well as the established labor unions served as a barrier against adoptin the new bureaucratic system (Lorentz 1991; Kirby 1992) and to adopt welding block (Cho and Porter 1996). There was also fear toward the application of the new method because the work done by four workers in the old rivet method can be accomplished by one worker in the new method (Cho and Porter, 1996). While the UK was delayed in adopting the new method, competitive advantage had shifted toward the new methods during the postwar boom in demand (Lorenz 1991).

5. Explaining Leadership Shift from Japan to Korea

5.1 Entry by government activism

The Korean government drove the country's entry into the large shipbuilding industry by industrial policy. In 1973, the policy for the shipbuilding industry, including the plan to build three shipyards that can produce million-ton ships by 1976, was declared. Large Korean firms, which did not have any experience in building ships, entered the market. However, this was not considered rational by foreign experts. The Japanese government inspecting group, which provided government loans, concluded that large shipyards cannot be constructed in Korea (Hyundai Heavy Industry, 1992). The CEO (Mr. Chung) of a Chaebol firm (Hyundai) under the support of the government repeatedly failed in securing loans from foreign financial institutions although he managed to get the loan by securing a first customer in spite of the fact that the company's dock for shipbuilding was yet to be built (Lee and Park, 2013).

The government's drive toward the shipbuilding industry was a part of the heavy and chemical industry promotion policy, which aimed to make the shipbuilding industry an export industry. The policy provided shipbuilding and other preferred sectors with (i) financial incentives, (ii) complementary investments, (iii) trade incentives, and (iv) tax holidays. Financial incentives included preferential rates from state-owned banks with low nominal rates. The government's complementary investments were one form of incentives that covered large infrastructure programs for new facilities. The government invested in industrial complexes for shipbuilding in Ulsan, Okpo, and Chukdo (KSA, 2005).The government also protected the domestic market, and the shipbuilding for domestic customers was implemented with government support in 1974 (KOSHIPA, 2012).

However, the protection policy was not considerably significant because the local market volume was very small such that the provision of the local market did not provide a solid cradle market for Korean shipbuilders, who considered the export market a major market. Export loans were also enacted in 1976 (KOSHIPA, 2012) that provided loans for shipbuilding for export.

The Korean government emphasized the importance of local delivery of materials and components for shipbuilding. The state-owned Pohang Iron and Steel Corporation has been nurtured as part of the government's heavy and chemical industry policy (Lee and Ki 2015). The government also implemented policy measures for raising the ratio of locally manufactured components (KOSHIPA, 2005). In the case of engines, if the quality of the locally developed components was beyond a designated level, then the import of the engine component was banned (KOSHIPA, 2005). The localized component that had high implications regarding technology and economic effects was given financial and administrative support (KOSHIPA, 2005).

Several chaebols initially entered the shipbuilding business, with the first in 1974, or immediately before the global downturn after the oil shock. Nonetheless, these firms continued to invest during the 1980s. The investment made by Hyundai Heavy Industries and Samsung Heavy Industries was driven by the visions of their respective CEOs to become one of the largest shipbuilders in the global market (Hong, 2004). The downturn market was a challenge for the Korean firms, who had newly entered the industry. The companies attempted to survive the downturn market by bidding the lowest price on the basis of its cost advantage based on low wages and low currency value. The firms' investment was allotted to build a shipyard for building large vessels to capture the current and forecasted market demand. In a sense, the Korean large shipbuilders skipped the stage of building ships using berths but jumped to the stage using docks. In other words, the Korean firms invested primarily in a modern building dock, which is a type of graving dock or basin usually built of concrete, in which ships are constructed and then floated out after the dock is flooded. In comparison, a berth is a structure located on the shore of a sea, a river, or a lake. Thus, Hyundai Heavy Industries built three docks that produced very large crude carriers

(VLCCs) in 1972–1975 and four other docks in 1977–1979 (KOSHIPA, 2005). Daewoo shipbuilding completed one dock with one million tons, and Samsung constructed one dock with 150,000 tons in 1979 and one with 250,000 tons in 1983. Thus, Korea managed to come up with the most modern docks and layouts in the world. With the continued investment on modern docks, Korean companies could have more number of large docks than Japan in 2005(Table 3).

TABLE 3. Comparison of the number of shipbuilding facility in Korea and Japan

	1985		1995		2005	
Country	Total	Large facility docks (more than 300 m)	Total	Large facility docks (more than 300 m)	Total	Large facility docks (more than 300 m)
Korea	46	7	47	8	47	19
Japan	269	11	223	9	195	11

Note: Shipbuilding facility means the number of building berths and docks. Berths are on-land space for building ships. In modern shipbuilding, building berths have been replaced by docks.

Source: Kim (2010)

Korean firms adopted a path-following strategy of importing foreign technology and using low-price strategies, thereby undercutting the competition in the 1980s. These firms expanded the country's market share through aggressive marketing. Korean companies invested in learning production technology such as front-loaded outfitting, pallet management, and management of supply information (Lee and Park 2013). Korean firms also invested in improving their productivity to reduce the cost (KOSHIPA, 2005), challenged themselves to develop high-value added vessels and offshore plants, and diversified into new businesses. Korean firms began to develop high-value added vessels and offshore plants by importing technology on offshore platforms, LNG LPG carriers

(Lee and Park 2013). Korean companies expanded their market share by investing in learning foreign technology, resulting in imitative shipbuilding between the 1970s and 1980s. The downturn provided good conditions to obtain access to foreign sources of knowledge. In the 1980s, European firms suffered from the downturn market and declining competitiveness, and they were therefore forced to sell their technology in better condition than that from Japan (Lee and Park 2013, p. 150).

5.2 Forging ahead by path-creation in the 2000s

In the 1990s, Korea had windows of opportunity in market and technology: expansion of demand for large vessels and systematization of 3D CAD. From the 1990s, the demand trend became an upturn in the market. This shift involved the rise of the replacement demand for outdated ships and also for the substitution of the existing demand due to the regulation on sea pollution, resulting in the requirements of the International Maritime Organization to produce double hull ships in 1993. The increase in demand was led by large oil tankers and bulk carriers. Further demands stemmed from large gas containers, other large specialized ships, and offshore plants to develop energy in the sea that called for large locks and large spaces. These changes in demand were an important window of opportunity for Korean firms. In turn, these firms invested aggressively in new facilities for large vessels by investing in large docks in the 1990s. This upturn lasted until the end of the 2000s, which lasted longer than the expected date of the international forecast experts (interview senior executive of KOSHIPA, 24 January 2014).

The increase of Korean firms' global market share was facilitated by their capacity to seize the rapidly expanding demands in large oil tankers as well as gas and chemical carriers and containers. From 1995 to 2005, the global production volume of oil tankers more than doubled (from 5.5 to 13.6 billion gross tons), the volume of gas and chemical carriers almost quintupled (from 1.1 to 5.5 billion gross tons), and that for containers tripled (from 3.3 to 10.0 billion gross tons). Contrarily, the production for other vessels was less than doubled. Korean firms took the bigger shares in the rapidly increasing types of the ships (see Table 4). All these volume increases were driven by the production and existence of large vessels, which call for modern docks with more than 300 m length (Lee and Park, 2013, p. 111).

TABLE 4 Market shares of ships completed during 2005 by category(1,000 gross tons)

	EU		Japan		Korea		Total	Total
		(%)		(%)		(%)	(%)	
Oil tankers	28,380	0	3,780,744	28	7,428,484	55	100	13,625,165
Bulk carries	8,685,104	1	8,685,104	72	444,780	4	100	12,105,366
Gas and chemical	118,219	0	1,090,682	20	3,494,158	64	100	5,452,449
General cargo	180,406	0	323,737	29	69,124	6	100	1,109,682
Container	1,716,835	0	987,225	10	5,711,334	57	100	9,999,953
Total	3,140,573	0	16,191,935	35	17,686,860	38	100	46,507,208

Source: Lloyd's

Regarding this increased market share, KOSHIPA (2005) stated that the competitiveness of Korean shipyards was estimated to be inferior to that of Japan in basic design and production technology, but is superior in detailed design and production design (KOSHIPA 2005, p. 267). Such superiority is derived from the design flexibility. Korea's main products, such as large oil tankers and gas and chemical carriers and containers, are ships that call for design customization by close interaction with customers. The emerging trend of the systematization of 3D CAD allowed Korean firms to enhance their design flexibility. In particular, the "extended 3D CAD system" enabled Korean shipbuilding companies to be flexible in the design of ships to be built. Such flexibility was achieved by design customization strategy, which aimed to thoroughly accomdate the requests of customers before and after the contract without planned standardized vessels (Chinnery, 1993). This system was developed by combining the imported software and databases as well as the software and databases made in-house or by local suppliers.

The technological trajectory of CAD that emerged in the latter part of 1990s was the change of CAD technology, from 2D to 3D, and the systematization of the unit technology (3D CAD) through the extension of functions and others approaches. Since then, CAD evolved from being a simple 2D/3D drafting tool "for drafting and data transfer" into an "extended 3D CAD system" that radically changed the design process (Nobeoka and Baba 1999). This new technology offered a 3D model that can become a platform to integrate all related operations from the system level perspective for real concurrent engineering: (i) extension of functions to check the validity of designs (i.e., CAE simulations and digital prototypes) and interface with other systems (e.g., ERP and PDM) of a company for shared databases that facilitate communication between design, production planning, and production control; (ii) integration of designs created with different kinds of software; and (iii) integration of the design with computer-aided manufacturing (Nobeoka and Baba 1999).

From the late 1990s to 2000s, in response to the technological trend, Korean companies not only imported 3D CAD design technology in an agile manner, but they also created their own "extended 3D CAD system" by collaborating with leading foreign companies and in-house R&D to integrate the design systems (e.g., outfit (interior designs) and hull design (structure of the ship) as well as the design software with ERP and other databases). The "extended 3D CAD system" of the Korean companies was the most advanced because they cooperated with leading CAD suppliers worldwide and forged ahead to integrate the CAD software and link the CAD system with other databases. This approach may be considered a "follow-on innovation" as a variant of path-creating innovation (Lee and Ki 2015).

One example of a company's "extended 3D CAD system" is Daewoo shipbuilding (DSME)'s DACOS. This system was developed in 2002, incorporating Tribon and CADDS, both imported software, for hull (started using 1989) and outfit designs (1983), respectively. DACOS includes 99 application modules for the modeling and automatic generation of blueprints and is connected to the ERP system. The integrated system incorporating the offshore plant design was completed in 2004 and was the most advanced integrated CAD system in Korea (Kim, 2008). With the extended 3D CAD system, shipbuilders no longer have to go through trials and errors because of the enabled checks of the validity of designs, and they can facilitate communication between different

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departments such as design and production. Shipbuilders can also quickly change the designs and reflect these changes in the detailed design for manufacturing. This undertaking reduces the time for customizing vessel designs, for instance, reducing designing effort-hours to less than half (Kim, 2008). This "extended system" granted Korean shipbuilders with a competitive advantage.

In addition, the design flexibility that utilizes the 3D CAD system was secured from investment in human resources, including design engineers. Such flexibility was achieved by a rich pool of engineers equipped with advanced 3D CAD systems and who can make customized design (Lee and Park, 2013). In 2006, Korea's pool of design human resources was summed up to 8,000, which were greater, or four times bigger, than that of Japan.[3] The lower wages in Korea were also one source of advantage, as the Japanese wages were 1.5 times higher than that of the Korean wages in 2002 (POSRI data as cited in KOSHIPA 2005, p. 262). The Korean workforce thus contributed to the country's gain of price competitiveness in the 1990s and early 2000s.

The "extended CAD system" supported the improvement or innovation in shipbuilding methods. In the 2000s, Korean shipmakers developed the frontier process of building and launching a ship. The size of blocks was enlarged so that a ship can be made by erecting seven to eight blocks. The block building method has been advanced to mega blocks, reducing the number of blocks to five, and terablocks, with only two blocks (KOSHIPA, 2010). The tandem block method allows two ships to be constructed in tandem in the same dock. The block building method calls for the investment in large cranes (Lee and Park, 2013; KOSHIPA, 2005). These block methods are supported by the 3D CAD system, allowing companies to check the design errors of separate blocks before the erection of separate blocks by examining the 3D designs and simulated data.[4] According to an interviewee, "previously, when the blocks were erected and fitted together, some of the subtle difference of the design of components had to be cut away. But, nowadays there is almost no such occasion due to the advancement of CAD, CAE and simulation technology, besides the advancement of pricintness of the CNC machine works." The large building block technology, one of the innovations made by Korean shipbuilders, has been been able to be implemented owing to the consolidation of the CAD

[3] Interview with Jeonghan Lee at DSME in Ministry of Trade, Industry and Energy (2006).

[4]. From an interview of an executive and a senior manager of DSME and Hyundai Heavy Industries on February 17, 2014.

system (see Table 5 for various innovations by the Korean shipbuilding industy) .

Table 5. Innovations by Korean Shipbuilders

Innovations	Year
World's Largest Block Manufacturing Technology	2002
World's First On-land Shipbuilding Technology	2005
Ship-Bow's Underwater Assembly and Mounting Technology	2005
Skid Launching System Utilizing Building Technology	2007
Korea's First Medium-Sized Marine Diesel Engine	2000
LNG Re-Liquefaction System Technology	2007
LNG Re-Gasification Vessel	2003
Arctic Ice-Breaking Oil Tanker	2006

Source: The Korea Shipbuilders Association (2009)

5.3 The Incumbent Trap in Japan

In the face of upturn demand with new types of vessel (large sophisticated vessels), the already invested production facilities in Japan served as a lock-in condition that deterred investment in building large docks greater than 300 m. For example, the investment in Japanese shipyards equipped with building berths cannot be as aggressive as that of Korean companies who invested in building large docks from 1980s to 2000s. In addition, given the historical memory of the very weak demand during the downturn in the 1970s and 1980s, the Japanese industry faced a kind of 'institutional' barrier against aggressive investment. The government regulations set up for the survival of the Japanese firms during the recession in the 1980s included the regulations on the total tonnage, scrap and build, parallel building method, and VLCC dock. These regulations lasted until late 1996 (KOSHIPA 2010, p. 15) and prevented firms from investing in new production facilities. Suffering from the downturn in the past, the Japanese firms were conservative to forecast the upturn market demand and were reluctant to invest in facilities to capture such demand. An example of the conservative forecasting in 1995 was the forecast by the Japanese Shipowners' Association about the average annual global demand which was only "about 20 million' gross tons (GT) between 1996 and 2005 (Japanese Shipbuilders' Association 1996), which was 2 to 5 million GT less than the forecasted by the equivalent Korean organization (Korea Shipbuilder's Association, 1996). The forecast over the next three years indicated a similar difference (Korea Shipbuilder's Association 1998). All these conditions prevented the Japanese shipyards from making timely investment for the upturn market with new types of demand, especially sophisticated vessels larger than the previously constructed ones.

Japanese firms were also lock-in in the old technology system, not offering design flexibility necessary for large sophisticated vessels. The firms were reluctant to set up the "extended" 3D CAD system essential to secure design flexibility (Nobeoka and Baba 1999). Until the 1990s, Japanese shipyards, who used to develop in-house 2D CAD software that was as good or even better than that made by other software developers in the 1970s to 1980s, had the most advanced processes in designing ships, adopting in-house developed CAD, or purchased CAD (Nobeoka and Baba 2009 ; Interview). At this time, 2D CAD did affect the process change of traditional drafting processes. However, the 3D CAD that reflects the breakthroughs in technology (graphical 3D representation of numerical data) achieved by specialized software suppliers in Europe and the US (Rando 2002) became a complex networked technology that uses 3D CAD models (Nobeoka and Baba 1999). In the 1980s, the 3D CAD technology, including solid modeling, mathematical representation of freeform surfaces, and parametric modeling, was developed and advanced by Western companies such as MAGI, Silicon Graphics, and Pro/Engineer. Such technology was substantially different from 2D CAD technology. 3D CAD has been extensively utilized in the automobile industry and was relatively diffused slowly to the shipbuilding industry in the 1990s.

The leading Japanese shipyards faced a problem in responding to the changes. Engineers in the leading shipyards were also unwilling to purchase technologies, particularly from Western suppliers who remained the major suppliers of these systems, because of “overconfidence in their abilities and a lack of confidence in their ability to work with foreign companies,” which has “a negative influence on implementing more extensive changes in the shipbuilding process” (Nobeoka and Baba 1999). The Japanese also tried to develop their own 3D CAD technology. However, given that such technology was substantially different from the existing 2D CAD but failed to create the 3D technology equivalent to that supplied by the Western suppliers, (Nobeoka and Baba 1999). The Japanese shipyards had also not been investing in human resources for the new information systems. Mitsubishi’s Nagasaki shipyard and machinery employed 300 designers, 100 production engineers, 20 software systems support, and 30 to 40 factory automation personnel, and these 50 to 60 software and automation personnel were scheduled for downsizing by the time of evaluation of the 1996 report (Moore 1996).

6. Conclusions

This study considers the shipbuilding industry to explain the successive changes in leadership. The key concepts in the explanations are the windows of opportunity, as well as the incumbent trap and path-creation which are used to express different responses by the incumbent and latecomers. The window of opportunity for Japan to forge ahead of the UK was the arrival of new technologies, including welding block. In particular, the Japanese adopted path-creation by using innovations more promptly than the incumbent UK, which delayed their adoption due to the opposition of labor unions. The leadership shift from Japan to Korea is also a form of path-creation because the Korean firms responded quickly to the rise of a new window of opportunity (systematized 3D CAD technologies) and were able to meet the newly rising demand in large vessels that was the second window of opportunity. The Korean path-creation can also be considered an adoption and follow-on innovation mode because Korean companies not only adopted the 3D CAD design technology, but also created an integrated 3D CAD system by collaborating with leading foreign companies in their in-house R&D

and by integrating the design systems (e.g., outfit (interior designs) and hull design (structure of the ship) with other software in the ERP, databases, procurement, and manufacturing. Compared with Korean firms, the Japanese firms were stuck into the incumbent trap of remaining with the "unextended 3D CAD system" and opted not to invest in upgraded facilities (e.g., large docks) to build large vessels because of the appreciation of the Japanese currency and the past trauma of the deep depression in the 1970s and 1980s.

While we consider this sector as another case of the technology window playing key roles, one of the interesting and new findings of this study is the unique, institutional nature of the source of the incumbent trap in the shipbuilding industry. This study determines that the incumbent trap occurred in this sector because of institutional rigidities or legacies of the firms, which is in contrast to the sectors covered in Lee and Malerba (2016b) where the source of the trap was in relative costs and benefits of new versus old technologies, associated with the theory of S-curve or replacement effects. In the shift leadership from the UK to Japan, the rigidity was the resistance of the UK labor unions against new technologies, whereas the legacy in the shift from Japan to Korea was the institutional memory of the depression that discouraged Japanese firms from investing in new technologies and facilities for large vessels as well as a rigidity in government regulation on the investment by the firms in the sector. Given that incumbent countries tend to age and accumulate additional institutional rigidities over time, the shipbuilding cases underscore the need to consider the source of the incumbent trap broader factors, including not only the economic or rational calculations but the institutional and non-rational dimensions as well.

In the meantime, the peculiarity of the technological regimes of the shipbuilding sector and the associated unique nature of the technological window of opportunity are also noted. Lee and Malerba (2016b) indicated that instead of every innovation, only a certain type of it may serve as the window of opportunity that may lead to leadership change, distinguishing destructive or competence-destroying innovations from competence-enhancing innovations (Christensen 1997; Tushman and Anderson 1986). The shipbuilding sector is a CoPS industry (Hobday, Rush and Tidd

2000), and the window of opportunity from the technology side came from a systematized technology that may change the entire process of building ships. In the case of Japan, the welding block method was not about the technical change of the specific design of ships, but was about the entire process of shipbuilding. In the case of Korea, the introduction of 3D CAD was not the final solution but was used to consolidate a new system of designing and "real concurrent engineering" by integrating the drafting software with other software for digital assembly, ERP, procurement, simulation, data transfer to manufacturing, and shared databases (Nobeoka and Baba 1999).

The above findings may offer some implications for Korean shipbuilding firms that are currently assuming leadership positions yet are also suffering from one of the most serious crises associated with the global downturn and the rise of Chinese shipbuilders. First, given the cyclical nature of the business, the past experiences of Japan reveal that any restructuring measures implemented during the current downturn must be carefully designed to prevent permanent damage to the core competence of firms. Moreover, the government must avoid introducing any regulations that may increase the level of institutional rigidities to private sectors that will respond to the changing market conditions in the future. Second, as the current leaders, Korean firms must keep initiating new innovations which would futher strengthen their existing technologies, while avoiding a situation where the rival companies take initiatives embracing new innovations potentially disruptive to the current technological systems led by Korean firms. Based on their studies on Canon and Samsung, Lee and Malerba (2016b) suggested the same strategy (called endogenizing the future innovations) to protect leading firms from falling into the incumbent trap. The entire industrial world is going through another round of changes in the techno-economic paradigm along with the rise of 3D printing and the Internet of things, which usher in the "Fourth Industrial Revolution" that can significantly affect product, process, and business model innovations (Bechtold et al. 2014). When combined with institutional rigidities and firm legacies, these new innovations may place the current leaders in the incumbent trap, thereby preventing these firms from responding.

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