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Introduction

The purpose of this paper is to explore a mechanism by which a particular innovation came about at a particular point in time. The case to be analyzed is the technological innovation of automotive emission control in the 1970s. Why did Japanese automakers, who still lagged in technological capabilities at the time behind their U.S. and European competitors, develop the three-way catalytic converter system in 1977 - at a time earlier than widely expected within the industry? This is the question we will address empirically.

The timing of technological innovation is one of the critical issues to better understand innovation, both theoretically and practically. As Rosenberg (1969) and Mowery and Rosenberg (1979) pointed out, without determining the forces that pushed exploratory activities of a particular technology at a specific time, i.e., not earlier or later, our understanding of the mechanisms behind technological changes would not be satisfactory. The advent of a dominant design has a profound effect on innovation activities and industrial competition (Abernathy and Utterback, 1978). Where network externalities exist, late-comers with superior technologies would hardly replace the first-comers with their entrenched customer base (David, 1985; Arthur, 1992). The timing at which a new technology takes place thus has decisive consequences for managers.

With the aim to explain the timing of a particular innovation, this paper builds on the "social construction of technology (SCOT)" perspective proposed by Bijker (1995) and Pinch & Bijker (1987). We particularly draw on two basic viewpoints from the SCOT perspective: the "interpretative flexibility" approach and "symmetrical analysis" approach. The latter takes both successful and unsuccessful technologies into account symmetrically, while the former pays attention to different interpretations of an artifact by different relevant social groups. Our case analysis will show that the dominant emission control technology (three-way catalytic converter system) was realized earlier than expected because the development of the technology was prompted through the social and political processes among different social groups, mobilized by an unsuccessful technology (CVCC engine). We demonstrate that the SCOT perspective could be applied to explain the timing of technological innovation.

The remainder of this paper is organized as follows. Section 2 describes our research agenda, arguing why the timing of a particular innovation is an important issue to understand technological change. In Section 3, our analytical viewpoints to understand the issue of timing in the context of the "social construction of technology" perspective are presented. Section 4 introduces the case material and defines our empirical question. Section 5 traces historically, based on the analytical viewpoints, how the three-way catalytic converter system was developed. Section 6 describes the mechanism we have found behind the historical developments. Finally, in Section 7, conclusions are drawn.

2. Research Agenda

Why did a particular innovation come about at a particular point in time? This is a critical question for innovation research, as Rosenberg (1969) and Mowery and Rosenberg (1979) repeatedly emphasized in their critical reviews of innovation studies.

Some scholars explain that technological innovations are realized by economic incentives to save money, such as labor and capital costs, or by responding to the market demands. Yet, such explanations are problematic since all of these economic incentives and needs are so pervasive and general. Economic incentive, per se, cannot explain particular directions and timing of technological changes.[1] Other students proposed that the innovation process consists of several stages such as: (1) the recognition of the potential and its technical feasibility, (2) the idea formulation stage to create a design concept, and (3) the problem solving stage leading to a testable item. However, nowhere does this argument provide a satisfactory answer to the question of what determines the time lag between these stages. Why does a particular innovation take a long time from the recognition stage to the conceptualization, whereas another moves within a short period of time? Unless we can determine the time lag, the explanation has limited value to understand the mechanism of a technological change. Rosenberg and Mowery argued, if we cannot explain the timing, how dare we claim to understand technological

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[1] For example, in order to explain why the development of the telephone was realized in the mid 19th century, it is not sufficient to say that it was because people wanted to communicate. The need to communicate with others had existed for centuries.

innovations?

Timing is also an important issue for practitioners, if we recognize that the emergence of a particular technology can have irreversible effects on the industry and competition. For example, a dominant design divides the industry evolution (Abernathy and Utterback, 1978). With the advent of a dominant design, the focus of innovation shifts from product to process. Since the emergence of a dominant design significantly alters the competitive landscape, those who bet on other technologies and cannot catch up with the change may lose competitive advantage and even go out of business. Therefore, managers desperately need to know which technology is emerging as the dominant design at a particular time.

Similarly, in a world where network externalities and increasing returns are important, once a particular technology becomes a dominant standard, it becomes increasingly difficult for later technologies to replace the standard one, no matter how superior it might be (David,1985; Arthur, 1992). Where path-dependency matters, the timing in which a particular technology is realized can have lasting effects on the future of society.

If we stand on the assumption of technological determinism, in which the superior technology prevails and shapes our society, or if we treat technological changes as a series of random events or as an outcome driven by the unpredictable imagination of individual genius, then the timing of technological change wouldn't deserve attention in our research efforts. At a given place and a given time, a superior technology is developed and prevails in the society as a superior option. Firms are advised to concentrate on the perceived superior technologies and governments are supposed to support these technologies (Liebowits and Margolis, 1990).

However, if the advent of a dominant technological innovation is socially-embedded in both its causes and consequences, then an attempt to explore the mechanisms by which a particular technology comes about at a particular point in time deserves special priority in our research efforts. This is the premise on which this paper is based.[2]

3. Analytical Viewpoints

A clue to our inquiry as to the timing of innovation can be found in Tushman and Rosenkopf (1992). Among a variety of factors affecting technological changes, they

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[2] Although we assume that technology is embedded within the society, we don't mean that society shapes technology unilaterally, as we will make clear later in the paper. Our assumption is that technology doesn't progress autonomously. Technology cannot escape the influence of society.

suggested that not only technological and economic factors, but also social and political factors play important roles, especially in the process of the emergence of a dominant design. Once the dominant design emerges, product functions and configurations are mostly determined and critical technical problems are defined. Subsequent changes in the technology are likely to take a rational path, both technically and economically (Dosi, 1982). In the era of ferment, however, uncertainty prevails. Multiple choices of different technologies remain and there is no well-established standard to evaluate these choices. Therefore, although technological possibilities may be contingent on the technological logic, the choice among the possibilities would be largely influenced by social and political factors.

Given the substantial importance of socio-political factors, how should we analyze the process more in-depth? A promising hint for further investigation comes from two viewpoints designed for the social construction of technology (SCOT) perspective, suggested by Pinch and Bijker (1987) and Bijker (1995): "interpretive flexibility," and "symmetrical analysis" approaches. The former focuses on different interpretations taken by different "relevant social groups," each of which sees and interprets a particular artifact differently with its own set of problems. The latter takes both successful and unsuccessful technologies into account in the same framework symmetrically. These two viewpoints, which underpin the SCOT perspective, consider technological change and its acceptance not as an intrinsic property of the artifact, but subject to interactions among relevant social groups, each of which have different interpretations of the artifact. They attempt to overcome the limitation of functional explanations and technological determinism, which assume that an artifact succeeded because it worked well technologically, while others failed because they simply didn't work well.

So far, however, the SCOT approach has been applied to such research issues as the success or failure of a technology, evaluation criteria for a technology, and directions of technological changes. To the best of our knowedge, it has not been applied to the issue of timing. In this paper, we attempt to demonstrate that the SCOT perspective is valuable in understanding the timing of technological innovation. By comparison, Rosenberg (1969), who emphasized the importance of understanding the timing of a particular technological change, indicated one mechanism to define the timing of technological changes - an imbalance within a technological system as a means of focusing innovation. When one part of a system improves its performance substantially, it requires other parts in the system to improve so that the integrated system realizes the potential benefits. This is a mechanism where an intrinsic property (e.g., interdependency) of the technological system defines the timing (Kato, 1999). By contrast, our goal in this paper is to present a set of empirical evidence to demonstrate that the "timing" issue can be addressed effectively by the two SCOT viewpoints.

4. The Empirical Field and Previous Studies

4.1. The Empirical Field

The field for our empirical investigation is the historical development of the automotive emission control system in the 1970s. This is a case where a dominant technology appeared unexpectedly early, thus providing a useful subject to examine the timing of technological innovation.

It was in 1977 that Japanese automakers, who lagged behind their US and European competitors in technological prowess, came to develop the three-way catalytic converter system to meet the most stringent emission-control standards in the world. This was an achievement that was believed to be impossible in the mid-1970s. The three-way catalytic converter system is a device to significantly reduce the amount of three types of pollutants: hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) from emissions. After thirty years, this technology still remains as the dominant emission control technology for gasoline engines in the world auto industry. It is also arguable that this technological achievement gave the Japanese auto industry the impetus for subsequent competitive momentum.

However, in 1973 (just four years before the development of the technology), at a hearing of the U.S. Environmental Protection Agency (EPA), major automobile manufactures of the world, including the Big Three, asserted that the catalytic converter system was premature and far from completion and requested that the enforcement of the 1970 Clean Air Act Amendment (CAA) be suspended. The 1970 CAA was proposed by Senator Muskie and enacted in December 1970 (in Japan, this 1970 CAA is well known as the Muskie Laws). The act specified a 90% reduction in the level of HC and CO emissions from the 1970 levels by Model Year (MY) 1975, followed by a 90% reduction of NOx from the 1971 level by MY 1976. It was a very stringent environmental regulation, requiring that HC, CO, and NOx all would have to be reduced by 90% of the prior standard less than six years.

Given the necessary lead time to go from technological development to mass production, less than three years was available to develop new emission controls for automakers as of December 1970, when the 1970 CAA was enacted. While most automakers paid serious attention to catalytic converter devices as a possible solution, they believed that it would take much longer to develop reliable catalytic converter systems to be applied for a wide variety of engines. Asserting that the timeline to completion of three years was unfeasible, major automakers waged concerted lobbing efforts at Congress and EPA for postponement, sometimes appealing to the courts.

The catalytic converter technology was also criticized as “most disadvantageous with respect to cost, fuel economy, maintainability, and durability” by the National Academy of Sciences (NAS), one of the most notable scientific organizations in the U.S. In its report in 1973, NAS concluded that the provisions of the 1970 CAA were unlikely to be attained on the established schedule and would even harm the industry’s ability to develop better solutions. Finally, recognizing that it would be imperative to suspend the original 1975/1976 timetable after the hearing in 1973, EPA granted a one-year postponement to the 1975 standard and declared a 1975 interim standard.

Subsequently, as further amendments to the 1970 CAA and reviews by EPA continued, implementation of the original 1970 CAA was suspended repeatedly and the standards were relaxed frequently. Throughout these years, resistance from the industry was vehement. In 1976, for example, Mr. Estes, President of General Motors at the time, expressed his views during an interview with the New York Times: “They [the Federal Government] can close the plants, put someone in jail, maybe me, but we’re going to make [1978] cars to 1977 standards.” Ultimately, the original 1970 CAA standards were first achieved in California in 1981 and not nationwide until 1994.[3]

However, it was June 1977, just eight months after Mr. Estes statement that the three-way catalytic converter system was realized and installed in new models in Japan by Japanese automakers. Why was the most stringent emission control standard enacted and met successfully in Japan, leaving the U.S. far behind, despite the fact that the U.S. was initially far ahead in policy formation as well as technological capabilities for emission control? This is the question for our case analysis.

4.2. Previous Studies: Three Explanations

Previous studies on this topic have pointed out three major reasons why Japan was a pioneer in this remarkable technological innovation in automobile emission control.

First, an OECD report emphasized the role of the Japanese government (OECD, 1977). In contrast with successive delays in the U.S. regulations, the Japanese government rejected automaker’s request for suspension and implemented the most stringent NOx standard of 0.25 g/km beginning in fiscal year (FY) 1978. The report asserted that it was the strict environmental policy adhered to by the Japanese government that triggered the innovative activities of the industry.

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[3] The EU introduced in 1992 the emission control equivalent to that of the U.S.

Second, two studies (Miyashita and Takeuchi, 1982; Mutou, 1984) suggested that the market structure in the Japanese automobile industry made a difference. Differing from the oligopoly structure of the U.S. automobile market where the Big Three dominated, the Japanese market structure was more competitive in that nine automakers, including small ones, were intensively competing with each other. According to these studies, it was the healthy competition between automakers that stimulated the technological innovation. Particularly important was the role of Honda. Differentiating itself from leading Japanese automakers, which focused their engineering efforts on catalytic converter technologies, Honda, the late-comer to the industry in Japan, focused on engine modifications and developed the CVCC engine in 1972. As the first technology to have successfully passed the test of the 1975 standard of the original 1970 CAA, the CVCC engine drew much attention as a possible solution to emission control. The CVCC engine had its limitations to comply with ever more stringent standards, and the final solution was provided by the three-way catalytic converter system developed by Toyota and Nissan. Nevertheless, these studies pointed out that competitive pressure from small makers prompted major manufacturers to work much harder.

Third, another study emphasized that the social movement outside the industry played an important role (Kajita, 1988). In this view, it was the left-wing municipal governments that played a key role by politically demanding the conservative Japanese government to push hard for strict emission control, which the industry had expected to be postponed, as in the case of the U.S.

These explanations provide us with important factors (government regulation, competition, social movement) behind the unexpected timing of the development of the catalytic converter system in 1977. In particular, the first explanation gives us a direct answer to the research question of this paper. It was the Japanese government’s imposition of the NOx reduction regulation from FY 1978 that compelled the Japanese auto industry to come up with the technological solution in 1977. There is no doubt as to the important role of the Japanese government, but a question still remains: why were the strict emission control standards, which had been judged unfeasible and thus postponed in the U.S., maintained and implemented in Japan? The first explanation does not provide a satisfactory answer to this question.[4] Neither of the other two explanations addressed the timing of the technological innovation directly and our research question is still left unexplained. Building on these previous studies, this paper aims at providing a new explanation of the particular timing of the innovation. As will

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[4] Indeed, OECD (1977) was astonished that the Japanese government enacted the most stringent NOx standard, despite strong protests from automobile manufacturers.

be revealed later, the three explanations will be combined in our analysis.

5. Process towards the Innovation

Having defined our empirical question, we now move to our case description. Based on the analytical viewpoints, we trace the socio-political process toward the development of the three-way catalytic converter in 1977, taking both successful and unsuccessful technologies into account and paying attention to different interpretations of emission control technologies by various social groups[5]. The case draws on historical archives and interviews with those engineers involved in the technology development in the 1970s.

5.1. Emission Control in Japan

Shortly after the U.S. Congress passed the 1970 CAA in 1970, the Japanese government formed the Environment Agency (EA; now Ministry of the Environment) and set emission control standards in 1972 that were equivalent to those of the US. The standards in the original plan required the 90% reduction of HC and CO emissions by FY 1975, and 90% reductions of NOx, which was more difficult to achieve, by FY 1976. It meant that emissions of HC, CO, and NOx should be reduced to 2.1, 0.25 and 0.25 g/km, respectively, less than four years.

As in the U.S., Japanese automakers asserted that it would be technologically unfeasible to achieve these standards, especially the NOx reduction, within a short period of time and demanded a suspension. However, unlike in the U.S., where the standards were delayed and relaxed year by year, in Japan the government decided at the end of 1974 to set an interim reduction of NOx to 0.6 g/km for FY 1976, and then enforced a full 90% reduction to 0.25 g/km from FY 1978, constituting the most stringent emission control in the world. As we have already mentioned, a direct reason for the development of the three-way catalytic converter system in 1977 is due to the enactment of the 1978 NOx standards. However, we would like to go further in our analysis. What we would like to know is why, in the first place, such a stringent emission standard was enacted in Japan. For this investigation, we pay special attention to the role played by Honda's CVCC engine in the process toward the government's decision.

5.2. CVCC and Its Evaluation

Whereas major automakers in the world put their resources to develop catalytic

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[5] The table in the Appendix provides a brief history of the case.

converter technologies, Honda sought for a different technological solution. Honda focused on engine modification, and came up with the CVCC (Compound Vortex Controlled Combustion) engine.

A catalytic converter receives exhaust from an engine and reduces the pollutants through chemical processes. In contrast, CVCC modifies the conventional engine to achieve a lean-burning system. For gasoline internal combustion engines, the three pollutants (CO, HO and NOx) exhibit trade-off relations near the ideal fuel-air ratio (15:1), which is the best combination of gasoline and air for power and fuel economy. In order to reduce the three pollutants simultaneously from combustion, a lean-burning system is required, with a fuel-air ratio of 20:1. Usually the combustion process is unstable and slow in a lean-burning system. In the system of CVCC, however, Honda developed a dual-chamber, in which a fuel-rich mixture was admitted to the small chamber, while a fuel-lean mixture was admitted to the main chamber. Therefore, the burning jet issuing from the small chamber after the spark plug discharge ensured good ignition of the very lean mixture in the main chamber.

A reason why Honda probed the engine modification (CVCC engine) approach lied within the engineering philosophy of Mr. Honda, the founder of the company. He strongly believed that emission should be cleaned up at the source, that is, in the combustion process, rather than by any additional devices such as catalytic converters. There were other reasons. Honda trailed other automakers in catalytic converter technologies and was more willing to modify its engines because they were a small automaker with few small car models at the time. The amount of investment necessary for engine modification was not large compared with larger automakers with a wide variety of engines. Furthermore, Honda, which was a late-comer in the Japanese auto industry, suffered serious damage from recalls of its main model, N 360, in 1969. Honda considered the development of the CVCC as a great opportunity to restore and gain its reputation in Japan and abroad.

In 1972, at an EPA hearing in the U.S., Honda testified that CVCC engine would be able to pass the 1975 emission levels (0.41 and 3.4 grams per mile for HC and CO). In December of that year, the CVCC engine indeed passed the EPA certification for the first time in the world and drew much attention internationally. NAS immediately published a report that praised the CVCC engine highly and suggested that other manufacturers also implement this solution (NAS, 1973).

Yet, in the end, the CVCC engine did not prevail as a dominant technology. CVCC had serious drawbacks in fuel economy and engine power. In order to overcome such a weakness, Honda made great engineering efforts, but the CVCC barely passed the EPA test for the 1975 emission standards with delicate adjustments, fine-tuned for the test with its small-sized engine. In contrast to Honda, which manufactured only small-sized cars at the time, the CVCC couldn't be an effective solution for other leading automakers. Since the other auto makers manufactured a wide variety of cars with several different engine sizes, it was much more risky and expensive for them to put the new engine technology into mass production within the required timeframe. Furthermore, it was even more difficult for the CVCC engine to meet the original 1976 emission standards in which not only HC and CO but also NOx should have been reduced by 90%[6].

Although initially the CVCC engine was in the spotlight as a seemingly promising solution to emission control, the perception that it could not be a viable solution for the auto industry eventually prevailed. Nor were catalytic converter systems seen as viable within a foreseeable future. Leading automakers in both the U.S. and Japan commonly viewed that 1970 CAA should be postponed[7]. This was why the original 1975/1976 standards had been suspended several times in the U.S., as we have seen. The situation in Japan, however, unfolded differently.

5.3. Left-Wing Forces and Social Pressure

In June 1974, the Environmental Agency gave a hearing to Japanese automakers on the technological feasibility of 90% reduction of NOx, which was scheduled to start two years later in FY 1976. Major automakers testified that the standards would be technologically unfeasible and requested a relaxation and suspension. In contrast, Honda suggested an interim standard for NOx reduction because unconditional postponement would deny the opportunity for the company to showcase its new low-emission engine. While major automakers insisted on their claims, the CVCC engine was increasingly covered by the Japanese mass media. Eventually, left-wing municipal governments, which had been heavily involved in anti-population activities, began to pay a great deal of attention to the CVCC engine.

Two months after the hearing, in August 1974, governors from the seven largest

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[6] For a report that pointed out the CVCC's weakness, see Grad et al (1974). Since the CVCC engine could not reduce NOx by 90%, Honda later added thermal reactors for NOx reduction. CVCC's limitation was also recognized by Toyota. Toyota asked Honda for the license of the CVCC technologies in 1972 and developed an engine model based on Honda's license in 1975. In 1976, Toyota then developed its original lean-burn combustion engine (TGP). Due to its limitation, however, Toyota discontinued the production of these engines after one year.

[7] Similarly, Mazda developed the rotary engine, which was another promising solution to the emission control, but because of its weakness in fuel economy, this technology could not succeed either.

cites, including Tokyo, Osaka, Kyoto, Kobe, Yokohama, Nagoya, and Kawasaki convened and declared their “statement to promote the emission control.” At the time, these largest cities in Japan were all under the control of the left-wing forces. For those cities, automotive pollution was one of the major issues to fight with the Liberal-Democratic Party (LDP) in the central government. Because photochemical smog increasingly aggravated metropolitan residents and automotive emissions were indicated as the major contributor, emission control was a decisive policy issue for the governors on which there could be no compromise. The statement criticized automakers’ philosophy of maximizing profits without consideration of public health, stating, “the automakers should make their maximum effort to accomplish the emission standards.” The seven cities then established a committee to investigate and evaluate Japanese automakers’ efforts on emission control.

The committee held a hearing in September and questioned automakers about technological possibilities. Toyota and Nissan asserted that the 1976 NOx standards should not be executed without confirming the reliability and safety of the catalytic converter system. The committee members argued that since potential solutions like the CVCC and rotary engines had been already developed, and both Toyota and Nissan had been developing similar technologies, the interim standard based on Honda’s proposal should be attainable[8].

The committee report issued in October avowed that “the 1976 NOx standard, or the approximate to the original one, is fully attainable, and since the CVCC engine needs only one year to get ready for mass production, the prospect to meet the original emission control standards within the planned timeframe is convincing.” The report stated, “technological advancement is possible only under strong pressures from the government,” intending to restrict major automakers’ efforts to postpone the regulation. The committee hearing and the report fueled coverage from the mass media, and citizen activities in anti-pollution spread throughout the country[9]. Large automakers were denounced for their lack of efforts and faced harsh public criticism.[10].

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[8] One member in the investigation committee noted, “Japanese top two makers were incomparably larger than Honda and Mazda not only in the sales but also in their manpower. It is suspicious to believe that they could achieve only 1.0～1.1 g/km of NOx [Honda proposed an 0.6g/km for an interim standard].”

[9] In the Asahi Shimbun, a leading newspaper in Japan, the number of articles on emission control reached about 150 per year during 1974 to 1975, when the debate on the regulation was heating up. It was about 20 in the late 1960s, and 50 in the early 1970s.

[10] Eiji Toyota, President of Toyota Motor at the time, recalled, “Since the final target of NOx of 0.25 g/km was unlikely to be attainable within the timeframe, we suggested an extension. But I was called to the Diet and unjustly accused. It was an ordeal. Also, the mass media denounced us, saying “stop quibbling, just make our air clean.” Attacks from outside the industry were savage. The media

5.4. A New Prime Minister and Policy Decision

While the pressure continued from the local governments, supported by citizens, to preserve the original regulation and press coverage on the issue further heated up, the Central Council for Environmental Pollution Control (Central Council, hereafter), an important formal council to recommend environmental policies to the government, submitted an interim report early in December 1974. The report admitted that enforcement of the 0.25 g/km NOx standards that were to go into effect in 1976 was probably impossible, and suggested a provisional standard of 0.6 g/km for the year. The report vaguely stated that it was not yet possible to predict when the final target (0.25g/km) would be met, thereby hinting at additional extensions in the future.

Yet, harsh criticism to the central government's environmental policy from the local governments and aggressive mass media didn't fade away at all. Grumbling voices, demanding a reexamination of the Central Council's interim report, were mounting. It was at this juncture, with great national tension, that the political landscape changed suddenly and significantly in the central government.

On December 10, 1974, Kakuei Tanaka resigned as Prime Minister because of his money scandal, and Takeo Miki took over and formed a new cabinet. This happened just four days after the Central Council issued the interim report. Shortly after taking office, opposition parties blamed Miki in the Diet for relaxed environmental policies. Miki stated that his cabinet would make efforts to supervise automakers in order to shorten the lead time to achieve the standards. Miki was a former Director General of the Environmental Agency in the Tanaka cabinet, but resigned in the middle of 1974 because of his political opposition to Tanaka. As a new Prime Minister, Miki was pushing "cleanness" as his cabinet's slogan to differentiate himself from Tanaka and save the LDP. Emission control naturally became one of the most critical issues to test the will and commitment of Miki. As public concern on the issue was growing, he could hardly back away from it.

After Miki ordered "deliberate reconsideration," the Central Council held a special meeting on December 27 and made the final decision on the much debated issue of whether any suspension was needed or not. The final recommendation, which was reached by breaking down some strong opposition in the council, was very different from that of the interim report issued just three weeks prior. It declared unambiguously that efforts must be made to meet the final target of 0.25 g/km level in FY 1978. It

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accused us, "It is suspicious that the Japanese top maker, Toyota, cannot do what Honda and Mazda say they can do" (Toyota, 1985).

stated that the provisional standard of 0.6 g/km would last no more than two years after FY 1976. It was in this manner that the most stringent NOx standard in the world was determined to go into effect definitively in FY 1978 in Japan.

With no chance of further suspension, automakers were forced to develop immediately the catalytic converter system to meet the standards. They poured significant resources and engineers into the development of emission control, putting aside other projects, including new model development. Intense efforts continued without success[11] until both Toyota and Nissan succeeded in developing the three-way catalytic converter system in 1977. Toyota's new model with the system passed the certification testing for the 1978 emission standards by the Ministry of Transportation in February 1977, and Toyota started selling the model in June 1977. A month later, Nissan also started selling a new model with a three-way catalytic converter system that met the standards. To reiterate, this breakthrough was achieved less than one year since GM's Estes denied the technological feasibility of meeting the 1970 CAA standards in the U.S.

6. The Mechanism to Prompt the Development of Three-way Catalytic Converters

Drawing on our analytical viewpoints, we have traced the process by which the three-way catalytic converter system was developed unexpectedly earlier in Japan. As depicted in Figure 1, an unsuccessful technology (CVCC engine), which was interpreted differently by different social groups (Honda, major automakers, left-wing municipal governments, citizens, the mass media, politicians, and bureaucrats), mobilized socio-political processes (opposition between the LDP and left-wing forces, overt anti-pollution movements, political stances of Miki to differentiate him from Tanaka). These processes intensified social and political pressures to prevent the most stringent emission controls from further suspension. Under the firmly-fixed timetable, the development of the dominant (successful) technology (the three-way catalytic converter system) was prompted and completed in 1977, earlier than widely expected. To summarize, the result reveals a mechanism that determines the timing of technological innovation — an unsuccessful technology prompts the development of a successful one and it is realized at a particular point in time through socio-political processes

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[11] "We worked seven days a week from early morning till midnight. Due to the overtime work every day I usually got home the next morning. Quite a lot of engineers involved in the painstaking development and test works burst themselves. Some of them, even today, still keep going to the hospital," said Kiroku, Shimura, a former project manager of Engine System Development Division at Toyota (interviewed by the authors on December 14, 2000).

among various relevant social groups, each of which interprets the technologies differently.

As Bijker (1995) indicated earlier, the success or failure of a particular technology may not be evaluated on an objective criterion. Especially in the "fluid phase", in which the appropriate configuration of the technology is not commonly shared and the evaluation criteria are not well established, a wide range of interpretations are possible (Table 1). Engineers of major automakers and some bureaucrats interpreted the CVCC engine was an unsuitable solution for emission control technology, in particular, to satisfy the goal of reducing by 90% the levels of NOx within a few years and the development of catalytic converter systems would require much longer than originally planned. But their interpretation was not shared unanimously. As for the CVCC engine, an unsuccessful technology that was destined to fade way in the end, not only Honda but also left-wing forces, environmental activists, and some of the mass media interpreted it as a positive solution. This interpretation served as the motivation to stimulate the socio-political pressure against postponement and, in effect, prompted the development of the dominant emission control technology (the three-way catalytic converter system) [12].

As mentioned earlier, previous studies indicated that three factors played important roles in the process: government regulation, competition, and social movement. For this paper's stated purpose to explain the particular timing of technological innovation, we have shown that all of these factors were indeed important (Fig.1). The CVCC engine, which stemmed from the "competition," inspired the "socio-political movement" of the left-wing local governments and accidentally coincided with a significant change in the political climate in the central government, with the government deciding to enforce the stringent "regulation," despite strong resistance from major automakers.

What we have found intriguing in the process is that, in hindsight, every group was wrong in their evaluation. Major automakers' assertion (and NAS's report and EPA's evaluation as well) regarding technological unfeasibility was defeated in the end. Honda's bet on the CVCC engine was also lost. The argument by left-wing local governments and some mass media that the CVCC engine provided the evidence for

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[12] It seems that the CVCC engine made little impact on policy making in the U.S. But it does not necessarily mean that the technology was more objectively and accurately evaluated in the U.S. One may argue that President Nixon was supportive of automakers' desire for the postponement. The EPA first rejected the Big Three's request for postponement in 1972, but quickly changed its decision and granted a one-year suspension in 1973, shortly after Nixon's reelection. Also, changes in political priorities from emission control to fuel economy after the first oil shock in 1973 might have affected the U.S. policy on emission control.

technological feasibility of the stringent emission control was without merit. It reveals how difficult it is to properly evaluate and forecast technological development before a dominant design emerges.[13] Indeed it was the difficulty of *ex ante* evaluation of technologies that allowed multiple interpretations and unexpectedly prompted the development of the three-way catalytic converter.

To eliminate misunderstanding, we would like to emphasize the importance of technology. This paper does not insist that the development was prompted only by socio-political factors. The three-way catalytic converter could not have been realized until automakers could develop the technology that met the standards in a commercially viable way. The technology was not developed hastily after chances for further regulatory suspension disappeared at the end of 1974. Toyota, for example, started R&D on catalytic converters during the latter half of the 1960s. Also, in order to have the three-way catalytic converter work effectively, very precise control of fuel injection was crucial. Without technological progress in the mid 1970s in O2 sensors, which detect the oxygen density in the exhaust gas, and electronic fuel injection systems, the three-way catalytic converter system would not have been realized.[14] Just as Mr. Estes stated correctly, however stringent the regulation might be, it would be meaningless unless the technology to meet the regulations was available.

This paper doesn't intend to deny the value of the CVCC engine, either. As Honda itself shifted to a catalytic converter system later, the CVCC engine only existed as a short-lived technology and couldn't become a dominant design. Yet, it was a remarkable innovation that met the 1975 standards for the first time. The CVCC engine could drive the social-political process, and eventually prompted the development of the three-way catalytic converter system within a short period[15] because it was a superior, although limited in hindsight, technology. Again, in this sense, technology was an important

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[13] Although the evaluation and forecasting was incorrect, the result was desirable to each group. Both central and local governments in Japan could enforce the most stringent, yet technologically feasible, emission standards and improved air quality and public health. Toyota and Nissan could develop the three-way catalytic converter system for the first time in the world, a great experience for these companies that would subsequently lead to their further success in the world's auto industry. Also, Honda could gain a reputation for its technological capability with the CVCC engine, and then could continue to succeed by shifting from the CVCC engine to the three-way catalytic converter later.

[14] To draw an overall picture of how the three-way catalytic converter was developed in 1977, we need to look inside the automakers. However, since this paper focuses on the role of socio-political factors, and also because of limited space, we chose not to. For details of technological development from the late 1960's to 1977, see Zhu (2002).

[15] On a popular Japanese TV program [Project X] (July of 2000), the CVCC engine was highly praised as a historical innovation. Although the production of CVCC engines discontinued after 1980, it was a sensational technology in the 1970s. If the CVCC engine had been less successful, the subsequent social movement would not have been continued.

driver. Technology is embedded within society, but society cannot be mobilized without technology.

We are not arguing that inferior technology survived because of socio-political factors. Since most automakers considered catalytic converters as the best choice for emission control technology, the advent of the catalytic converter system as a dominant emission control technology would be most probable in the end, although perhaps not as soon as it actually occurred[16]. Nor do we argue that socio-political factors affected the direction of technology development or the evaluation criteria for technologies. We simply argue that the particular timing of the technological innovation was socially constructed.

7. Conclusion

This paper is grounded on the SCOT perspective. If the advent of a dominant technology is embedded within the social context, both in the reason for its emergence, as well as in its consequences, exploring why a particular innovation came about at a particular point in time deserves research, for which social factors should be taken into account. This is the premise of our paper and the conclusion of our analysis.

In this paper, we have demonstrated the value of the SCOT perspective in understanding the timing of a technological innovation. While the viewpoints of "interpretative flexibility" and "symmetrical analysis" were both proposed by Bijker and his colleagues, this paper is the first attempt, to our knowledge, to apply these viewpoints to understand the timing of technological change. This paper has demonstrated that there could be a mechanism wherein the timing of a technological innovation is affected by socio-political interactions among various social groups, each of which have different interpretations on successful and unsuccessful technologies.

The mechanism presented here shows that an "unsuccessful technology" can have a significant influence on the timing of the emergence of a "successful technology". We think this indicates another value for "symmetrical analysis" in innovation research. [17] More generally, this identifies a pattern of interactions between technology and society in which a technology can dictate the timing of the development of another technology

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[16] It would be interesting to think of what could have happened if the emission control had also been postponed in Japan. If latecomers face difficulty taking over the leader due to, for example, "learning by doing" (Arthur, 1992), the realization of the three-way catalytic converter might have eliminated chances for other technological solutions to emerge.

[17] Based on "symmetrical analysis", Bijker (1995) explained the technological change in bicycles from ordinary to safety-oriented in the late 19th century. But his explanation left the possibility that the safety-oriented bicycles became successful because all relevant social groups found them superior.

via the socio-political processes.

Obviously the mechanism we have presented is one of a host of possible mechanisms, not a general framework to determine the timing of technological change. We need to explore other mechanisms and determine the conditions under which each mechanism works in determining the timing. More research with different empirical conditions is necessary.[18] Also, although this paper has focused just on the issue of timing, it would be interesting to deal with both the timing and the substances (possible choices, evaluation criterion, and the directions of changes) of technological changes together in an integrative manner.[19]

If the mechanism we have proposed has some external validity, there could be some managerial implications. Policy-makers who are designing a regulation that requires new technologies, or managers who are wrestling with incongruous technological innovations, should realize that under some circumstances, technological changes may not necessarily unfold around an objective evaluation.

Porter (1980) argued that the essence of formulating competitive strategy is relating a company to its environment. He then wrote, “Although the relevant environment is very broad, encompassing social as well as economic forces, the key aspect of the firm’s environment is the industry or industries in which it competes.” This argument seems valid if the technology is more or less stable. However, as our case suggests, in the era of technological change, in which uncertainty and ambiguity surround the industry, it would be important to pay close attention to social forces outside the industry. A technology that is seemingly inferior in eyes of most engineers and managers in the industry could have an unexpected impact through social forces.

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[18] On one hand, Tushman & Rosenkopf(1992), Dosi(1982), and Kato(1999) argued that socio-political factors are more relevant for the period of technological discontinuity or the fluid period. On the other hand, Bijker stressed that social factors are important at every stage of innovation and Henderson (1991) made a similar argument. Although we have taken the former position in this paper, further investigation is needed.

[19] For instance, if a particular technological solution was selected at a particular point in time, the choices available at the time, as opposed to others, were taken and subsequent directions of technological development would be affected (see footnote 16).

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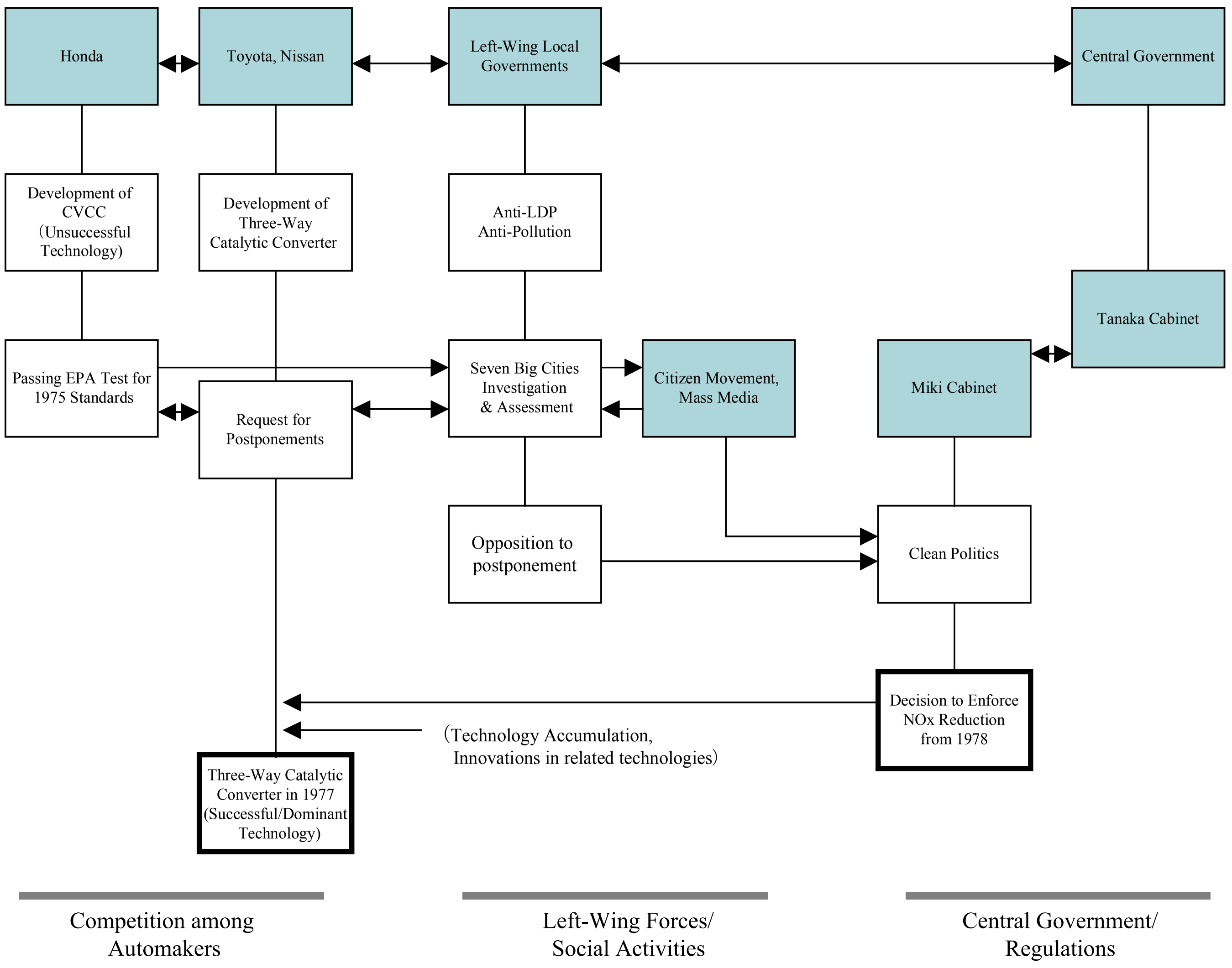
Table 1. Relevant Social Groups and their Interpretation of Emission Control Technologies (as of mid- to late-1974)

	CVCC Engine	There-way Catalytic Converter
Honda	Most proper solution through engine modifications	Improper solution through additional device
Toyota, Nissan	Limited solution; infeasible to reduce NOx by 90% to the original target of 0.25 g/km; ineffective for large-sized cars	Best solution but takes longer time to be commercialized
Left-wing local governments, citizen movement, the mass media (some)	Superior solution for emission control, which is one of the most important issues for citizens.	Poor excuse for postponement
Central government (Tanaka cabinet), Bureacrats	Solution limited to small-size cars	Premature; prospect is still unknown
Central government (Miki cabinet)	Has some potential	Hard to achieve, but the regulation schedule should be maintained by all means

Figure 1 Mechanism to Prompt The Development of Three-Way Catalytic Converter



Appendix. Chronology of Automotive Emission Control in the 1970s

Year	Month	In the U.S.	In Japan (Social and Political Events)	Behavior of Japanese Automakers
1970	7		In Suginami-ku, a town in Tokyo, more than 3000 high school female students suffered from photochemical smog (21 fell down on the ground)./ Tokyo Municipal Government established a special task force to deal with photochemical smog and started warning system.	
	12	The 1970, the CAA was passed by the US Congress (0.41 g/m for HC, 3.4 g/m for CO from 1975, NOx 0.4 g/m from 1976).		
1971	5	Automakers testified that a 90% reduction was impossible during an EPA hearing.		Toyota and Nissan testified on the EPA hearing that 90% reduction was impossible.
1972	4	Big 3 requested a postponement to EPA regulation.		
	5	EPA declined Big 3's request for one-year postponement.		
	6		Governor of Tokyo, amended the city regulation on air pollution	
	10		EA (Environmental Agency) enacted emission control standards(2.1 g/km for CO, 0.25 g/km for HC from 1975, and 0.25 g/km for NOx from 1976）	
	11	Nixon was re-elected		
	12	Honda's CVCC engine passed the EPA certification of the 1975 CAA (0.41 g/m for HC, 3.4 g/m for CO), which was announced by the EPA in Feb the following year.		Honda's CVCC engine passed the EPA certification of 1975 CAA (0.41 g/m for HC, 3.4 g/m for CO), which was announced by the EPA in Feb next year./Honda licensed CVCC technology to
1973	2	EPA announced CVCC engine passed 1975 CAA certification./Mazda's rotary engine passed 1975 CAA standard (0.41 g/m for HC, 3.4 g/m for CO)./Washington High Court commanded EPA to re-examine the regulation/In NAS report, CVCC was highly	Tokyo Metropolis organized a special project team for measure against photochemical smog.	Mazda's rotary engine passed 1975 CAA standard (0.41 g/m for HC, 3.4 g/m for CO).
	4	EPA granted one year suspension to 1975 CAA and determined a interim standard (1.5 g/m for HC,15 g/m for CO and 3.1 g/m for NOx)	Tokyo Metropolis announced that photochemical smog was caused by automotive emission.	On a hearing held by EA,Toyota and Nissan testified that it would be impossible to achieve the 1975 standards within the timeframe, and Honda testified that it would be possible.
	6	GM requested postponement of NOx standard (0.4 g/m)./EPA announced that it is not necessary to reduce NOx by 90% by 1976.		
	7	EPA granted one-year suspension to 1976 NOx standard and submitted ammendement for NOx reduction (2.0 from 1977 to 1981, 1.0 from 1982 to 1989 and 0.4 from 1990)	Cumulative victims of photochemical smog reached over tens of thoundsands.	
1974	5	Congress passed the amendment to 1970 CAA（1.5 g/m for HC, 15 g/m for CO, 3.1 g/m for NOx）	EA held a public hearing on 1976 emission control standards	Honda licensed CVCC technology to Ford
	6	Congress enacted Energy Supply and Environmental Coordination Act of 1974		Toyota and Nissan requested an unconditional postponement of NOx reduction to 0.25 g/km, and Honda and Mazda propsed an interim standard (0.6 g/km) for NOx.
	7		Miki resigned Director General of EA	
	8	Nixon resigned due to the Watergate Affair, Ford was inaugurated.	Governors from the seven largest cities gathered, declared their "statement to demand the emission control", and established a committee to investigate the emission control	
	9		Seven cities' committee held a hearing	
	10		Seven cities' committee concluded that 1976 NOx reduction was feasible	On a hearing for the seven cities' committee, Honda testified that the interim standard would be possible to achieve, and Toyota and Nissan asserted that it would be impossible.
	12		Central Council for Environmental Pollution issued a report, suggesting an interim standard of 0.6 g/km for NOx from 1976 and a further postponement of the final target of 0.25 g/km for NOx./Tanaka Cabinet determined the interim standard for 1976./Tanaka resigned as Prime Minister, Miki took over/ Miki requested Central Council initiate a "deliberate reconsideration" of the interim report./ Central Council issued the final report that the extension period for 1976 interim standard would last no more than two years.	
1975	1			Toyota commercialized 19R engine based on the CVCC technology licensed by Honda (but the production continued for only one year).
	3	EPA postponed 1970 CAA until 1978 and announced interim standards for 1977 (2.0 g/m for NOx）		
1976	1			Toyota commercialized its original lean-burn engine, TGP, continued for only one year.
	9	Congress discuss a further postponement of 1970 CAA, including the proposal of 0.4 g/m for HC, 3.4 g/m for CO from 1979, and 1.0 g/m for NOx from 1981		
	10	Estes, GM's President denied technological possibility of achieving the emission control		
	11	Carter won the presidetial election		
	12		EA officially announced the enforcement of NOx reduction to 0.25 g/km from 1978	
1977	6			Toyota started the sales of a new model equipped with three-way catalytic converter system, which met the 1978 standards.
	7			Nissan started the sales of a new model equipped with three-way catalytic converter system, which met the 1978 standards.
	8	Congress enacted the standards of 0.4 g/m for HC from 1980 and 3.4 g/m for CO from 1981, 1.0 g/m for NOx from 1981 (the original standard, 0.4 g/m, for NOx was postponed for the time being).		

Note: The unit of emission control standards are grams per miles in the U.S. and grams per kilometers in Japan. Source: Compiled from Kadowaki(1990) and other sources.