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The Dynamic Aspect of Product Development Capabilities: An International Comparison in the Automobile Industry

(first draft, not edited)

by

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1. Introduction: Outline of the Industry and Its R&D

This chapter describes and analyzes how some of the Japanese auto makers built distinctive capabilities of new product development by the 1980s, how the western makers made efforts to catch up with the effective Japanese firms by systematically adopting some of their practices, and how the Japanese makers tried to respond to the new competitive challenges in the first half of the 1990s[1]. Thus, the focus of this chapter is the dynamic process of competition through capability building in product development. The evolutionary processes of creating, maintaining, transferring, overusing and renewing capabilities in product development will be explored.

After the introduction, section 2 illustrates product development capability and performance of the Japanese auto makers of the 1980s. Section 3 will briefly describe historical process of the capabilities in the Japanese firms. Section 4 focuses on the catch-up of the U.S. auto makers since the mid 1980s. Section 5 characterizes the problems that the Japanese firms are facing as those of over-using the development capabilities in an unbalanced way. Section 6 summarizes the discussions.

Before getting into details of the product development performance and capabilities, let us first outline the Japanese auto industry manly from the production and R&D's point of view.

<u>Production Scale</u>: Production scale of the Japanese auto industry grew rapidly and almost continuously from 30K in 1950 to 500K in 1960, 5 million in 1970, and to 11 million in 1981, when Japan became the world largest auto producer in units. Domestic production peaked at about 13.5 million units in 1990 (the peak so far). 7.8 million were domestic sales, and

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[1] Capability is defined here as a consistent pattern of a firm's activities and resources that brings about distinctive competitive advantages. See, also, Fujimoto and Tidd (1993) and Fujimoto (1994a, 1994b). For the concept of dynamic cpabilites, see, for example, Teece et al. (1992).

5.8 million were exports then. 10 million were cars and 3.5 million were commercial vehicles. Production volume then declined back to 11 million in 1993 due mostly to the "post-bubble" recession.

Relative Industry Size: The auto industry has played an important role in Japan's manufacturing sector. In 1990, the automobile and auto parts industries occupied about 13% of total manufacturing sector in production value (47 trillion yen), 7% in employment (0.8 million), 23% in export value (65 billion dollars), 22% in capital investment (2.3 trillion yen), and 14% in R&D expenditures (1.3 trillion yen)[2]. Thus, although the auto industry is not particularly R&D intensive, measured by R&D expenditure to sales ratio, the size of the R&D spending itself is significant in the Japanese manufacturing sector.

Pattern of R&D Expenditure: During the 1980s, R&D spending of the Japanese auto makers increased almost constantly. **Table 1** shows the ratio of R&D expenses to sales of those Japanese auto and auto parts makers with more than 10K employees reported in the government statistics, which is a rough approximation of the R&D expense of the major Japanese automobile assemblers[3]. The figure (both in disbursement and cost) roughly doubled from about 2% in the early 1970s to around 4% in the early 1990s. The level in the 1980s, 3% to 4%, roughly matched those of average US and European makers. According to International Motor Vehicle Program (Womack, et al. 1990), the level of aggregate R&D expenditure by the Japanese auto makers was similar to that of the US-based and Europe-based auto makers during the mid 1980s **(figure 1)**.

Despite the fact that the level of R&D spending of the Japanese auto makers was not particularly overwhelming, the pace of new product introduction of the Japanese makers was overwhelming: about 70 in Japan versus about 20 in the US. and about 40 in Europe between 1982 and 1987. Clark and Fujimoto (1991, 1992) pointed out, from the above data, that what made the inter-regional differences in the pace of new product development was not the level of R&D spending, which standard textbooks of economics tend to emphasize, but the level of product development productivity.

Finally, the patterns of R&D expenditure and capital investments are compared **(figure 2)**. Although the sample of the two data do not exactly match, the R&D spending is estimated to be over 50% of the capital

2 Nikkan Jidosha Shinbun. Jidosha Sangyo Handbook (Automobile Industry Hand Book), 1994 version (in Japanese). Note that the samples are not consistent across the statistics. The figures include motorcycles.

3 The figure is likely to be slightly biased upward, as it includes Nippondenso, whose R&D expenditure is higher than the average auto makers.

日経T1 R&D Expense 70-93

year	company	total number of employees (A)	number of person engaged in R&D (B)	regular researchers (C)	B/A (%)	C/A (%)	C/B (%)	sales (bil yen) (D)	Intramual R&D Expenditure disbursement (E)	cost (F)	R&D/sales E/D (%)	F/D (%)
1970	6	159,076	13,695	2,709	9%	2%	20%	2,151	43,082	39,384	2.00%	1.83%
1971	7	175,895	15,197	3,090	9%	2%	20%	2,658	56,972	50,616	2.14%	1.90%
1972	7	179,927	16,874	3,384	9%	2%	20%	3,102	70,846	64,838	2.28%	2.09%
1973	7	186,814	19,407	3,707	10%	2%	19%	3,524	89,684	77,115	2.54%	2.19%
1974	6	181,207	21,410	4,894	12%	3%	23%	3,889	123,213	105,852	3.17%	2.72%
1975	7	204,443	24,837	5,160	12%	3%	21%	4,843	148,053	141,419	3.06%	2.92%
1976	7	200,505	24,622	5,571	12%	3%	23%	5,830	142,524	143,008	2.44%	2.45%
1977	7	204,298	23,651	5,372	12%	3%	23%	6,675	170,322	168,971	2.55%	2.53%
1978	7	202,863	24,323	5,478	12%	3%	23%	7,732	209,833	202,622	2.71%	2.62%
1979	7	207,229	25,480	6,283	12%	3%	25%	8,426	258,744	231,543	3.07%	2.75%
1980	7	217,591	27,082	6,976	12%	3%	26%	9,625	291,608	262,811	3.03%	2.73%
1981	8	230,876	26,414	7,358	11%	3%	28%	11,503	330,343	303,596	2.87%	2.64%
1982	10	259,780	30,723	8,594	12%	3%	28%	13,416	440,811	395,121	3.29%	2.95%
1983	10	269,172	32,150	8,660	12%	3%	27%	14,198	485,656	471,157	3.42%	3.32%
1984	10	265,881	34,568	9,991	13%	4%	29%	15,571	496,355	491,303	3.19%	3.16%
1985	9	264,795	34,632	10,152	13%	4%	29%	16,654	546,817	532,452	3.28%	3.20%
1986	9	268,389	35,831	10,858	13%	4%	30%	18,521	622,227	604,548	3.36%	3.26%
1987	9	264,678	36,698	11,468	14%	4%	31%	18,118	659,842	615,071	3.64%	3.39%
1988	9	259,578	36,452	12,397	14%	5%	34%	18,250	628,565	604,727	3.44%	3.31%
1989	11	294,498	38,434	13,515	13%	5%	35%	20,352	732,639	711,679	3.60%	3.50%
1990	11	295,630	41,920	15,000	14%	5%	36%	22,402	875,505	849,219	3.91%	3.79%
1991	11	304,839	43,429	15,901	14%	5%	37%	24,445	1,017,238	976,399	4.16%	3.99%
1992	11	300,711	44,787	17,643	15%	6%	39%	25,594	1,031,368	1,000,267	4.03%	3.91%

Table 1 R&D Personnel and Expenditures at Auto and Parts Makers with 10K or More Employees

(subject to change)

		A	B	C	B/A	C/A	C/B	D	E	F	E/D	F/D
year surve	comp	total numb	number of	regular researcher		B/A(%)		sales(bil yen	Intramual R&D Expenditur disbursement	cost	R&D Expendit ~~D/C~~(%	E/C(%
1970	6	159,076		2,709		1.7		2,151	43,082	39,384	2	1.8
1971	7	175,895		3,090		1.76		2,658	56,972	50,616	2.14	1.9
1972	7	179,927		3,384		1.88		3,102	70,846	64,838	2.28	2.1
1973	7	186,814		3,707		1.98		3,524	89,684	77,115	2.54	2.2
1974	6	181,207		4,894		2.7		3,889	123,213	105,852	3.17	2.7
1975	7	204,443		5,160		2.52		4,843	148,053	141,419	3.06	2.9
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1979	7	207,229		6,283		3.03		8,426	258,744	231,543	3.07	2.8
1980	7	217,591		6,976		3.21		9,625	291,608	262,811	3.03	2.7
1981	8	230,876		7,358		3.19		11,503	330,343	303,596	2.87	2.6
1982	10	259,780		8,594		3.31		13,416	440,811	395,121	3.29	3
1983	10	269,172	32,150	8,660	11.94%	3.22	26.94%	14,198	485,656	471,157	3.42	3.3
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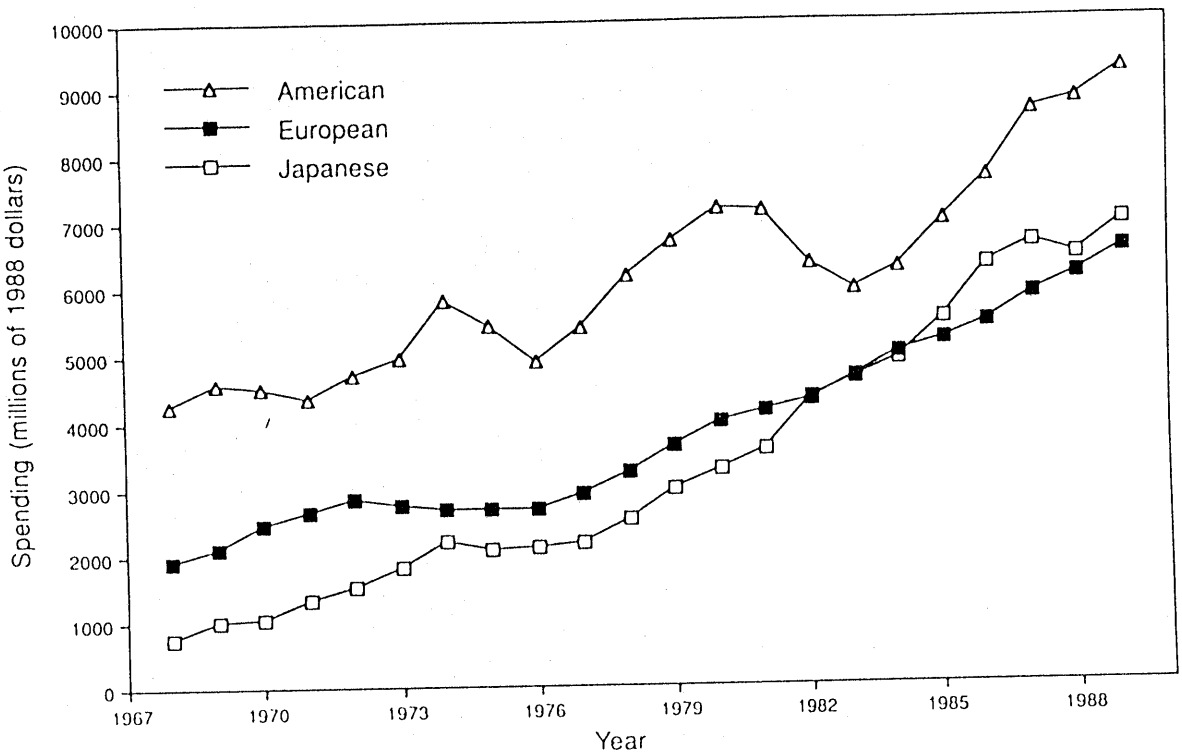
1992	11	300,711	44,787	17,643	14.89%	5.86	39.39%	25,594	1,031,368	1,000,267	4.03	3.9

Figure 1 Annual Spending on Motor Vehicle R&D by Regions

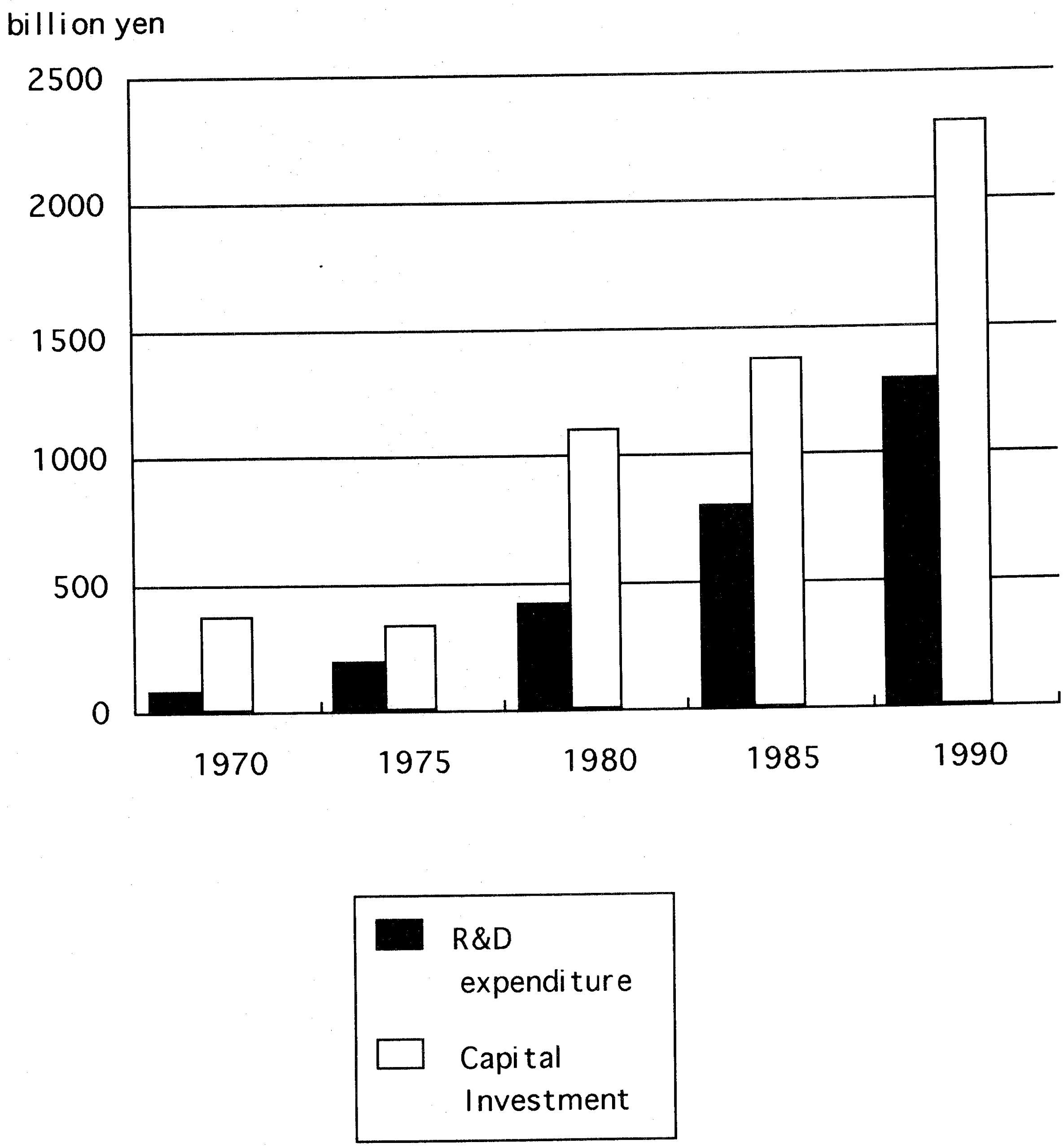


Note: The figures are for worldwide spending on research and development by firms in the motor vehicle industry grouped by headquarters region. Thus General Motors' worldwide spending is consolidated under "American" and Volkswagen's worldwide spending is grouped under "European."

Figures are constant 1988 dollars at 1988 exchange rates.

Source: Womack et al (1990), p. 133.

Figure 2 Capital Expenditure and R&D Expenditure of the Japanese Auto Industry



Source: Nissan and Nikkan Jidosha Shinbun, Jidosha Sangyo Hand Book expenditure in 1987-91. Capital investment tend to fluctuate depending upon the business cycle, but the pattern of R&D expenditure has been more stable.

Manufacturers: There are 11 motor vehicle assemblers with their own brands, in-house engines, dealer networks and product development function. This is an unusually large number among the major auto-producing countries, which implies the intensity of the domestic competition. Of the 11 motor vehicle makers, 9 are passenger car makers (including recreational vehicles), 4 are large truck makers, and 6 are micro mini makers (with duplication). Toyota is the leading company with the domestic production share of about 30% (about 4.2 million units in 1990), followed by Nissan (2.4 million in 1990) and three other smaller full line car makers, Mitsubishi, Mazda and Honda (1.3 to 1.4 million respectively). The other makers are focusing on particular market segments or niches.

There are also many companies that have both automobile assembly and product development functions, producing cars under OEM consignment agreements. Including such consigned assemblers, there are about thirty companies that have volume assembly lines in Japan, forming assembly networks[4].

Product Technologies: Automobile product development activities in Japan before the 1930s were nothing but sporadic prototype making by small venture businesses. Over 90% of the domestic market was occupied by Ford and GM products (mostly trucks), but they were forced out of the market by a powerful protectionistic law of 1936. The two major companies replacing the U.S. makers lacked capability of developing cars of purely original designs: Toyota reverse-engineered major American car and truck models; Nissan bought a package of engineering drawings for a truck from a minor American company.

In the 1950s, when commercial production of passenger cars started in addition to that of trucks, some of the Japanese auto makers introduced packages of car designs and technologies from European makers under licensing agreement (e.g., Nissan-Austin). Imports of component technologies from US and European makers to first-tier suppliers also increased in the late 1950s.

First oil crisis and emission control regulations in the 1970s created a pressure for the Japanese auto makers to dramatically improve their product and component technologies. Facing the strict domestic emission regulations and higher oil prices, the Japanese auto makers shifted resources from

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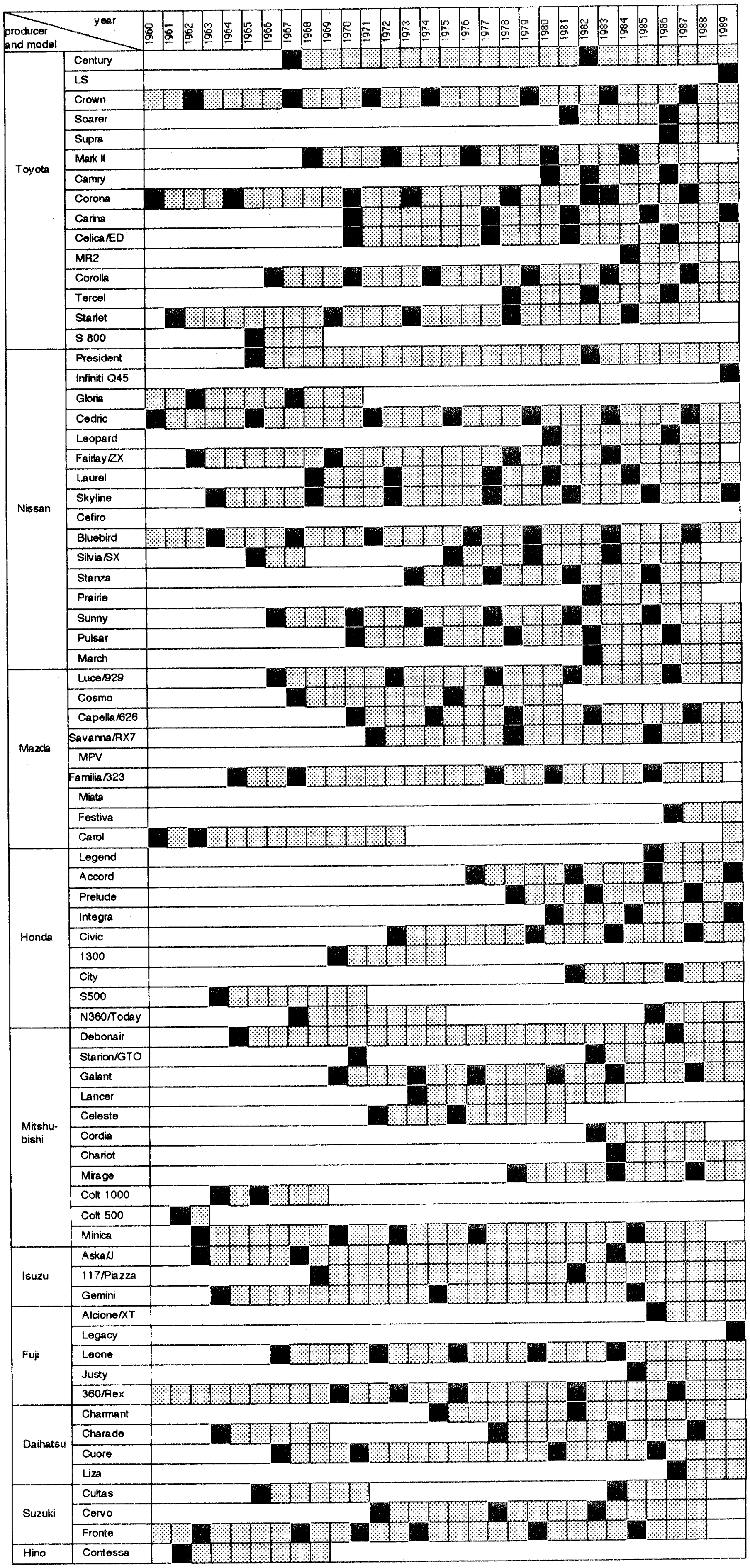
4 Shioji (1985) and Shiomi (1994).

vehicle development to engine technologie throughtout this era. It is said that the Japanese auto makers became world class players in small combustion engine technology during this period. In the 1980s, the advancement of product technology was accelerated by application of electronic controls and new materials, but no radical changes of the product (e.g., alternative engines or drastic changes in material composition) were observed. In other words, the patterns of automotive innovations in this period may be characterized as "rapid incrementalism" rather than "reinvention of the automobile" or "technological dematurity (Abernathy, et. al., 1983)." The Japanese cars has become more sophisticated in terms of total product integrity without break-through innovations in component technologies.

Model Change History: The commercially produced models from Toyota and Nissan between the 1930s and 1950s were mostly trucks. After the early period of car development in the 1950s, including the licensed foreign models, the motorization in the 1960s triggered proliferation of Japanese original car models **(figure 3)**. It should be noted here that the 4 year model change cycles that we observe today in Japan had already been established in early 1960s for main models of Toyota and Nissan that were rivals against each other. This practice prevailed in other companies subsequently. Thus, intense domestic competition seems to have forced the companies to introduce new products frequently, and thereby to build capabilities for rapid product renewals. In other words, it is likely that the competition shaped up development capabilities of the firms, rather than vice versa.

As a result, In the 1980s, the Japanese overwhelmed the US and European makers in the number of new model introduction per period, which contributed to freshness of models and expansion of model varieties (Sheriff, 1988; Clark and Fujimoto, 1992).

Suppliers: The Japanese auto suppler system of the 1980s, which gradually evolved mostly during the post-war era, has had many characteristics that contributed to competitiveness of the industry, including multiple-tier supplier networks, stable contractual relations, tight supplier control with technical-financial assistance, and so on. Each auto maker handles a relatively small number of first-tier suppliers, most of which are large makers (over 1000 employees) with sub-assembly and component engineering capabilities. According to a survey on the first-tier suppliers by the author (in 1993; N = 201), R&D expenditure is 2.6 % , and capital expenditure is 6.2 % of sales on average respectively. Roughly 9 % of their employee are product engineers; 15 % are process engineers.



Note: Models with extremely small volume and short life are excluded. Jeep-type models and cab-over vans are also excluded. Only the most common name plates are shown.

■ New model or major model change ▒ In production

In most cases, a first tier maker supply parts to multiple auto makers, while an auto makers purchase the same parts category (if not the same parts design) from multiple suppliers. For a given component drawing, though, there is usually only one suppler (single sourcing). Reflecting the involvement of the suppliers in automobile product development, competitions among the suppliers takes the form of competition by results and potentials of component designs (i.e., development competition), rather than simple price competition (i.e., bidding)**(figure 4)**.

In any case, the engineering capabilities of the suppliers seem to have been built by the rapid growth of production volume with rapid product proliferation during the post war period (Fujimoto, 1994a, 1994b).

<u>Product Development Personnel and Organizations:</u> In many cases, the Japanese auto makers (e.g., Toyota) started with a simple product development organization that reverse-engineered foreign models and made prototypes. The R&D organization became gradually large and structured since then **(figure 5)**. In 1992, roughly 15% of the total employees at the auto companies larger tan 10K employees, or about 45K, were engaged in their R&D organizations **(table 1)**. The top group auto makers now hire over 10K employees in their R&D groups. Over a third of them were engineers, whose share has gradually increased **(table 1)**. Many of the first-tier parts suppliers established formal product engineering departments or sections during the 1950s (Fujimoto, 1994a).

Having outlined the Japanese auto industry from R&D's point of view, let us now focus on product development performance and capabilities of the Japanese automobile development projects in the 1980s.

2. The Product Development Performance and Capabilities of the 1980s

2.1 Product Development and Competition

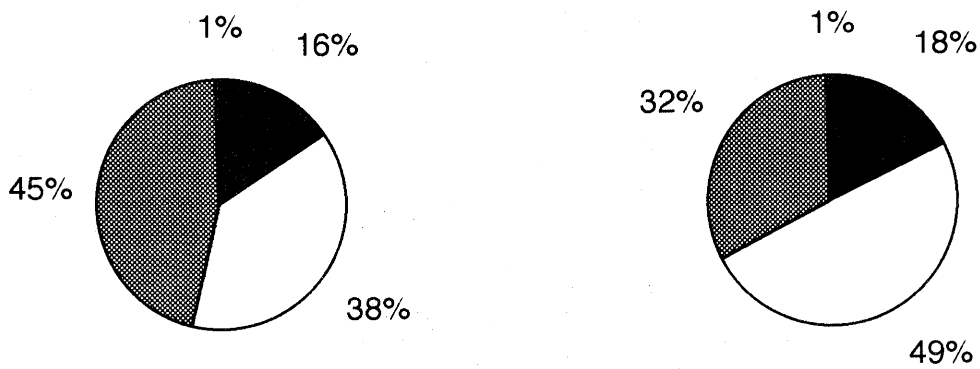
Product development has always been an important factor of inter-firm competition in the history of the world auto industry, but it has increased its importance in the 1980s and 90s. Why has product development become even more important? At least several factor has been observed as stylized facts.

<u>Diversity</u>: As lifestyles of the car-owning households became diversified, and as the cars become closely linked with their lifestyles, consumers as a whole requested more varieties of cars at the fundamental (i.e., basic model) level. This means that the competing firms need to achieve

Figure 4. Types of Competition among Japanese Parts Suppliers

a. The Case of Model Changes
(N = 201)

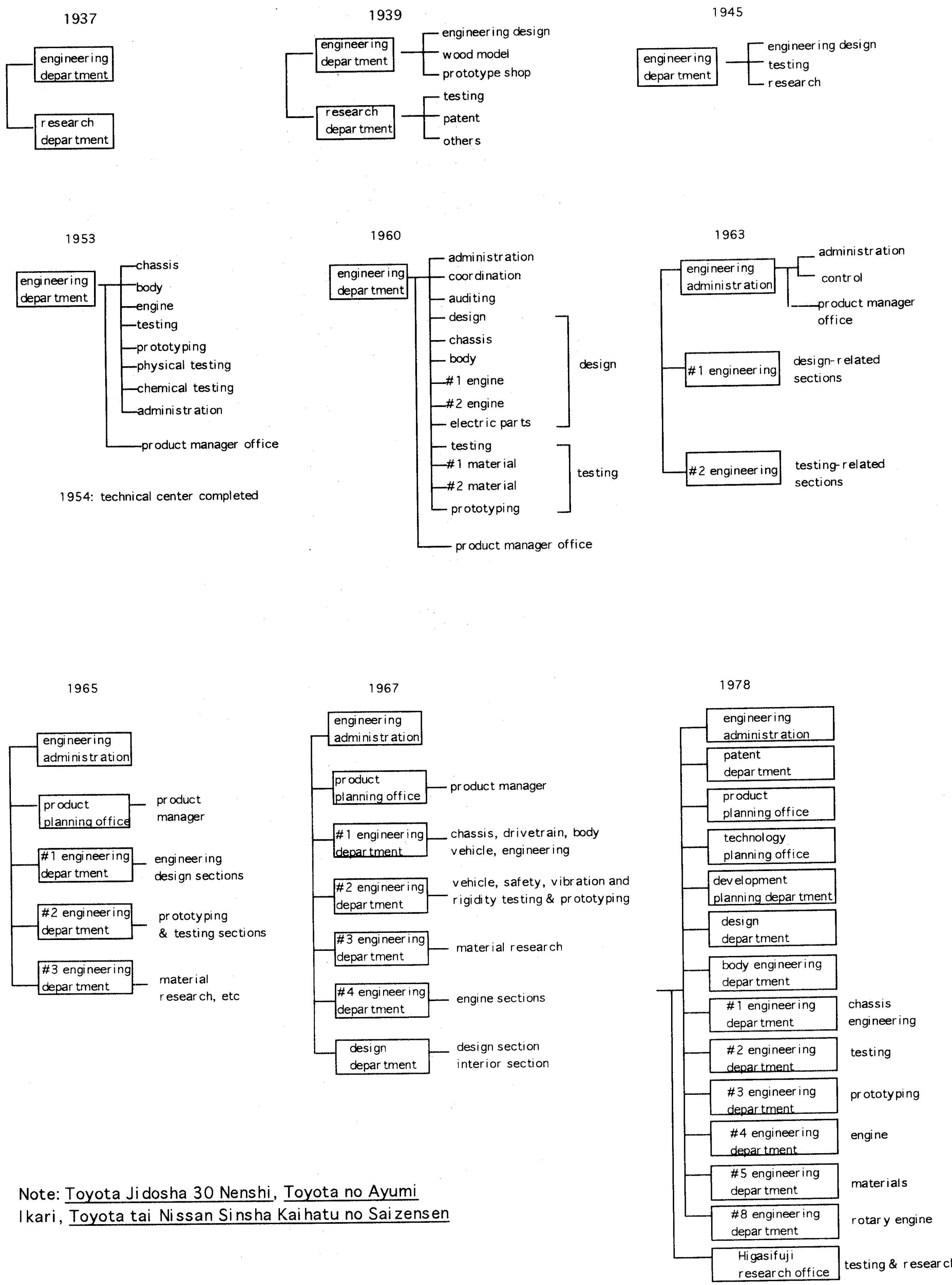
b. The Case of Completely New Models
(N = 201)



Key:
- ■ bidding based on detailed parts drawings provided by the car maker
- □ development competition among more than one parts suppliers based on specifications provided by the car maker
- ▩ selection of a particular parts supplier by the car maker at the stage of product concept, product planning, or specification development
- ▩ others

Source: A questionnaire survey by the author in 1993. Almost all of the respondents are first-tier suppliers belonging to the Japan Auto Parts Industries Association.

Figure 5 History of Toyota's Product Development Organizations



Note: Toyota Jidosha 30 Nenshi, Toyota no Ayumi
Ikari, Toyota tai Nissan Sinsha Kaihatu no Saizensen

a high productivity of product development, other things being equal, in order to match the required model variety.

Changes: As both state-of-the-art technologies and market needs changed rapidly, and as competing products were also renewed frequently, the Japanese auto firms had to give major changes to their products frequently. Other things being equal, this also meant an competitive pressure toward high productivity of product development.

Uncertainty: Market needs and trends of product technologies have become not only rapidly changing but also difficult to forecast, as the customer expectations for the cars became complex, equivocal and holistic. In this situation, shorter lead time of product development became more important for better forecasting of the future customer needs.

Sophistication: Customers' capabilities of evaluating the products tend to evolve over time toward higher sophistication. The customers, as they accumulated product experiences, shifted attentions from catalogue performance and individual component technologies to overall balance and total vehicle integrity of the cars. As the process of product development mirrors the nature of the products, total product quality and organizational integration tend to become a key to the product success.

Global Convergence: Basic product concepts of the automobiles were significantly different between the American and the European (and the Japanese to a lesser extent) manufacturers. Typical American cars were large general-purpose cruisers that emphasized comforts, while the typical European cars were compact driving machines that emphasized handling. The Japanese cars were more or less eclectic. After the second oil crisis, however, the American, European and Japanese models started to converge in size, packaging concept, styling, drive feel, and so on. As a result, the international competition became more direct in that individual models from different firms and regions started to compete against each other within the same global segment of the market. In other words, international convergence in basic product concepts caused direct competition among individual products during the 1980s.

To the extent that the international mass market was characterized by diversity, change, uncertainty, sophistication and convergence, three performance criteria of product development became critical for product success in the market: productivity of development, lead time of development, and total product quality. The successful volume producers of this era needed to outperform the others in all three at the same time. In fact, a small number of Japanese auto makers, generally recognized as highly successful ones of the 1980s, enjoyed the world class performance in all three criteria.

2.2 Product Development Performance in the 1980s

In order to examine the relationships between patterns of product development management and its performance, Clark and Fujimoto conducted an international comparative study of 29 product development projects at 20 auto manufacturers in Europe, America and Japan in the late 1980s. The following section is a summary of this empirical study (Clark and Fujimoto, 1989, 1991, 1992; Fujimoto, 1989, 1991, 1993b, 1993c). It will present results in both performance and processes of product development. Let us first focus on the international comparison of product development performance in lead time, product development productivity and total product quality. The key findings in product development performance were as follows:

(1) significant advantages of the Japanese in both lead time and productivity of product development **(figure 6)**.

(2) significant inter-firm differences in total product quality among the Japanese **(table 2)**.

(3) consequently, only a few Japanese auto makers achieved high performance in all three criteria.

On the one hand, the Japanese makers as a group demonstrated significant competitive advantages in productivity and lead time. In development productivity (measured by hours worked per project, adjusted for project content by multiple regressions), the average of the Japanese projects (about 1.7 million person-hours) were on average nearly double as efficient as that of the U.S. and the European projects (about 3 million person-hours). In development lead time (measured by time elapsed from concept study to start of sales, adjusted for project content), also, the Japanese projects were on average about year faster to complete a project than the Western cases (about 4 years in Japanese average versus 5 years in Europe and America). The regional differences were statistically significant even after the adjustment of project content factors such as product complexity and variety, innovativeness, ratio of carry-over parts, involvement of parts suppliers, etc.

Table 2 Ranking of Organizations in TPQ Index

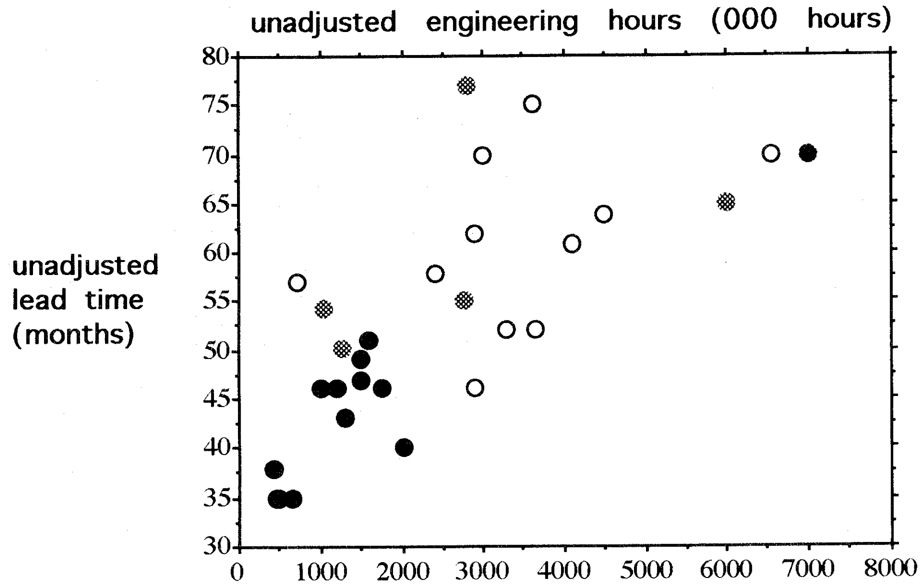
ranking	regional origin	score
1	Europe (high-end)	100
1	Japan	100
1	Japan	100
4	Europe (high-end)	93
5	Japan	80
6	U.S.	75
6	U.S.	75
8	Europe (high-end)	73
9	Europe (high-end)	70
10	Japan	58
11	Europe (volume)	55
12	Europe (volume)	47
13	Japan	40
14	Europe (volume)	39
15	Europe (volume)	35
15	Japan	35
17	Europe (volume)	30
18	Japan	25
19	U.S.	24
20	Japan	23
21	U.S.	15
22	U.S.	14

Note: Based on ranking in Table 3.X.
Weghts = 0.3 for total quality; 0.1 for conformance quality 0.4 for design quality; 0.2 for customer share.
Scores = 100 for top 1/3; 50 for middle 1/3; 0 for bottom 1/3; 100 for share gain; 50 for share loss; 75 for border case.

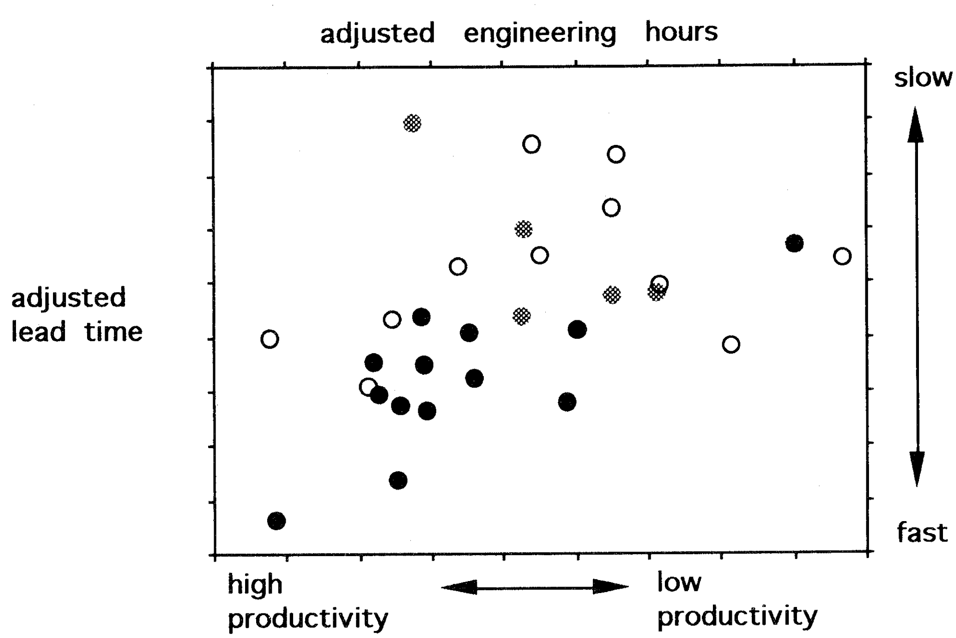
Source: Clark and Fujimoto (1991)

Figure 6 Lead Time and Engineering Hours - Unadjusted and Adjusted -

A. Unadjusted



B. Adjusted for Project Content



Note: 1 segment in panel B stands for 0.5 million hours (horizontal) and 5 months (vertical)respectively.

● Japan ◍ U.S. O Europe (volume) O high-end specialist

At the same time, rapid product renewal and expansion of product varieties have been recognized among the Japanese firms (Sheriff, 1988). High development productivity seems to have contributed to this frequent changes in product designs (Clark and Fujimoto, 1992). In other words, the capability of high development productivity tended not to be used directly for cost reduction, but to increase the pace of product changes while matching the unit R&D cost with the competitors.

On the other hand, performance differences within the regional group were also identified: In product integrity (measured by total product quality index, or TPQ, which is a composite of such indicators as total quality, manufacturing quality, design quality and long-term market share), no clear regional pattern was detected, unlike productivity and lead time. A few Japanese companies appeared in the top-rank group in total product quality, but there were other Japanese found at the bottom. Similar patterns were observed in the European and American groups.

Thus, both regional effects and individual company effects were clearly observed in performance of product development during the 1980s. There were a few Japanese makers which did achieve high competitive performance in all three criteria mentioned above, but not all of the Japanese enjoyed this kind of overall advantage. After all, what mattered eventually was firm-specific capabilities of individual auto makers.

2.3 Product Development Capabilities in the 1980s

Clark and Fujimoto also found that, apparently corresponding to the presence of both region-specific and firm-specific effects in product development performance, both region-specific and firm-specific patterns existed on the side of product development capabilities (i.e., stable patterns of processes and activities that creates competitive advantages of a firm). Through our data analyses, we identified the following capabilities at high-performing form in product development[5]:

(1) technological capabilities of the first-tier suppliers (black box parts system);

(2) manufacturing capabilities that enables better performance in product development;

(3) capabilities in intensive communication and stage overlapping between product and process engineering;

[5] For the concept of firms' capabilities, see, for example, Chandler, 1990; Grant, 1991; Teece, Pisano and Shuen, 1992, Leonard-barton (1992).

(4) capabilities of product development engineers to carry out a relatively broad range of tasks;

(5) capabilities of product managers to act as strong concept champions and strong project coordinators at the same time (heavy weight product manager).

(1) Suppliers' Engineering Capability: The Japanese companies tended to subcontract out a larger traction of product development tasks, particularly in detailed component design, prototyping and testing, to their first-tier parts suppliers, and thereby keep the in-house project compact[6]. The compactness of the projects, in turn, contributed to shorter lead time and higher development efficiency by simplifying the task of project coordination to a manageable level. Clark and Fujimoto (1989, 1991) identified statistically significant positive effects between the degree of supplier's participation and overall speed or efficiency of the projects. The Japanese makers also enjoyed lower component cost by letting the suppliers pursue design for manufacturing. Although some predicted that suppliers might take this opportunities to seek monopoly rents and raise component prices, the actual competitive results indicates that the effect of cost reduction by design-for-manufacturing outweighed the monopoly effects.

The U.S. auto makers of the 1980s, by contrast, apparently tried to keep the project compact by using existing component designs developed by other projects, but excessive use of common parts tended to deteriorate product integrity and distinctiveness. While depending upon traditional bidding, the U.S. makers apparently failed to exploit the potential of cost reduction by letting the suppliers design the parts they make. Thus, engineering capability of Japanese parts supplier systems seems to have benefited the Japanese auto makers.

(2) Manufacturing Capability in Product Development: There are many "hidden" manufacturing activities in product development processes, such as prototyping, die making, pilot run and production ramp-up. Unless a firm do such manufacturing jobs speedily and efficiently, it cannot achieve high performance in product development. Thus, the famous dichotomy of R&D capability versus manufacturing capability does not apply to the case of automobile product development: Effective firms in product development have also to be good at production.

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[6] For the concept of black box parts, design -in or approved srawings (shoninzu), see Asanuma (1989), Mitsubishi Reserach Institute (1987), Clark and Fujimoto (1991), Fujimoto (1994a).

The Japanese auto makers tended to apply their capabilities in manufacturing to critical activities in product development, which, in turn, contributed to improvement in overall performance of product development. For example, application of just-in-time philosophy to body die shops seem to explain part of the reason why die development lead time of the average Japanese projects was much shorter (about 1 year) than that of the Western projects (about 2 years). Their capabilities of managing prototype parts procurement, mixed model assembly, and quick shop-floor improvements also helped the Japanese makers carry out fast and effective prototyping, pilot run and production start-up.

(3) Capability of Inter-Stage Overlapping and Coordination: The Japanese projects tend to overlap upstream stages (e.g. product engineering) and downstream stages (e.g. process engineering) more boldly than the American and European projects in order to shorten overall lead time **(figure 7)**. The Japanese practices indicate that the overlapping approach can effectively shorten lead time only when it is combined with intensive communications between the upstream and the downstream. Effective overlapping also needs capabilities of both upstream and downstream people to cope with incomplete information, as well as flexibility, mutual trust, and goal sharing between the two stages (Clark and Fujimoto, 1991). Without such conditions, stage overlapping is likely to result in confusion, conflict, and deterioration in product development performance .

(4) Wide Task Assignment: The empirical result of Clark and Fujimoto also indicates that the lower the specialization of individual product engineers (i.e. the broader the task assignment of each engineer), the faster and more efficient the projects tend to be **(figure 8)**. Many development organizations (mostly Western) seem to be suffering from the over-specialization syndrome, while some others (mainly Japanese) appear to benefit from lower levels of specialization without losing technological expertise.

(5) Heavy-Weight Product Manager: By introducing the concepts of internal and external integrators, Clark and Fujimoto also examined how patterns of product development organizations affected product development performance (Fujimoto, 1989; Clark and Fujimoto, 1991). The statistical results indicated that both internal and external integration was a significant driver of product development performance. First, the stronger the internal integrator (i.e., project coordinator), the faster (and somewhat more efficient) the project tend to be. This result seems to be reasonable, because reduction of lead time would call for stage overlapping with intensive communication between the stages, which, in turn, would be facilitated by

Figure7 Simultaneity Ratio and Engineering Lead Time

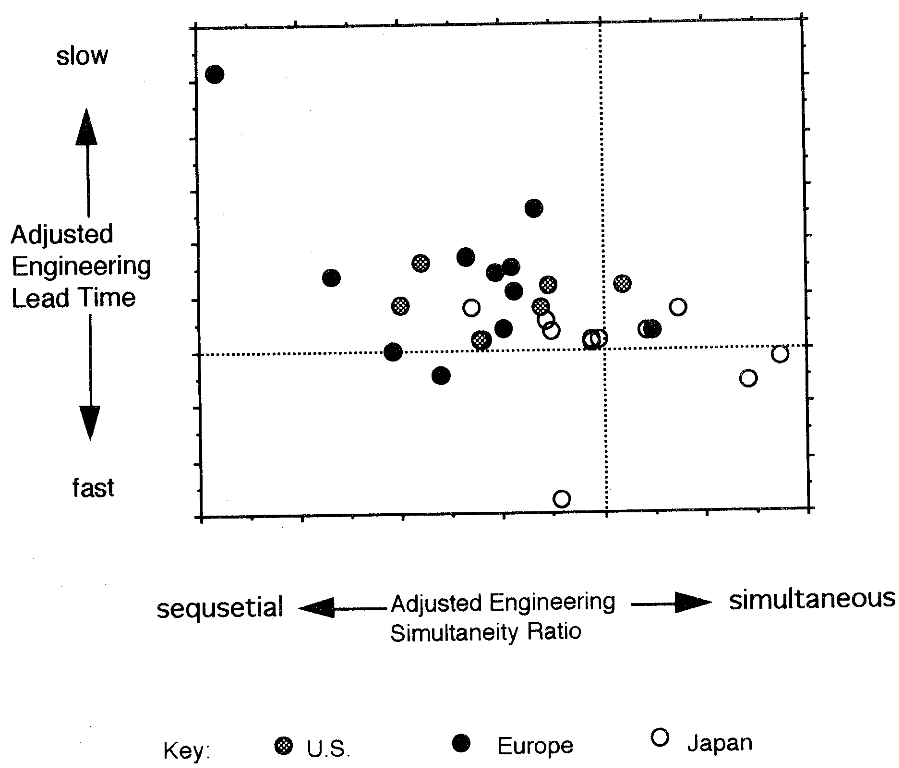
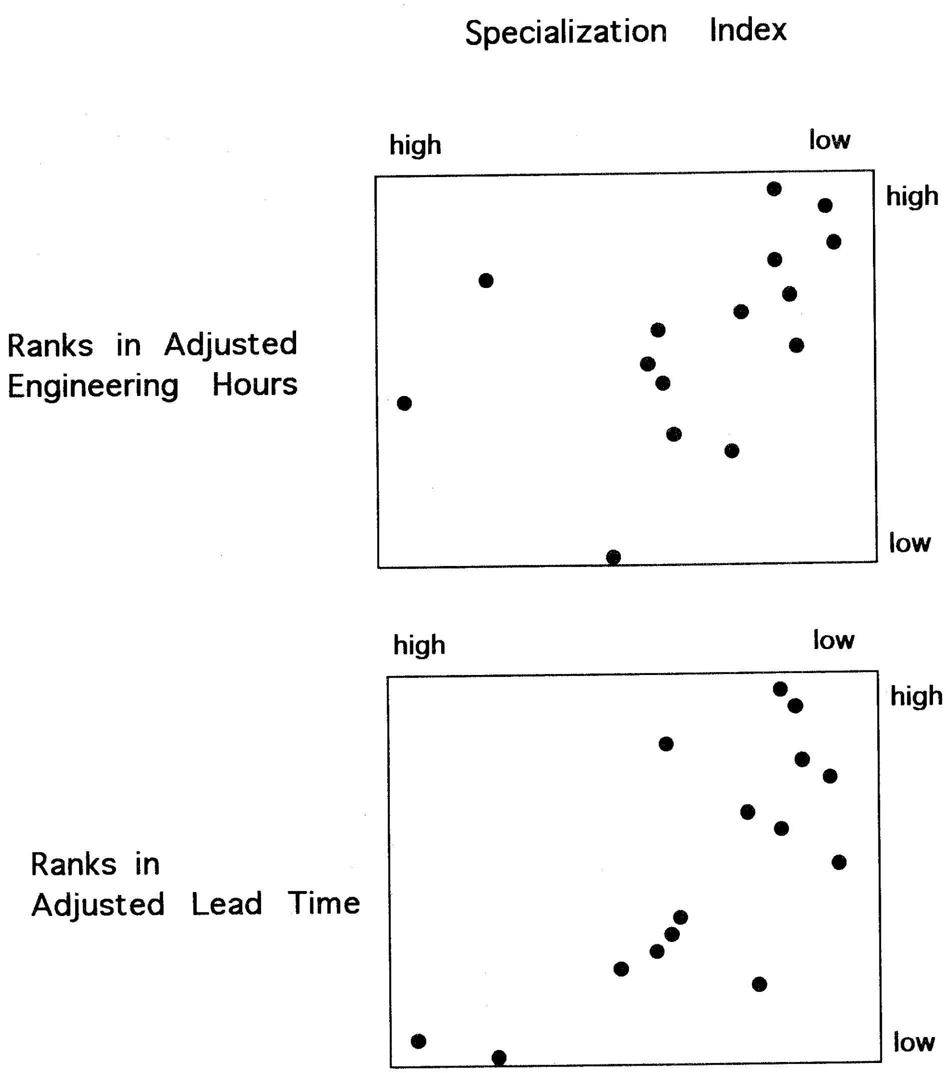


Figure 8 Specialization, Integration, and Development Performance



Note: Spearman rank order coefficient is significant at 5% level.

powerful project coordinators. Again, however, internal integration was not correlated with product integrity. Second, the stronger the external integrator, the higher the TPQ scores, and the higher the product integrity. This correlation seems to indicate that a powerful champions who create and realize distinctive product concepts might be a key to product integrity and market success.

As a result, in the auto industry of the 1980s, the development organizations which achieved high performance in lead time, productivity and product integrity simultaneously tended to be those which combined powerful internal integrator and external integrators in one role. We called this role "heavyweight product manager" -- a combination of strong project coordinator and strong concept leader **(figure 9)**. Our statistical result, using certain indices of organizational patterns, indicated that heavyweight product manager system tended to result in high scores in all three dimensions of product development performance, as far as volume producers of the 1980s were concerned **(figure 10)**.

To sum up, Clark and Fujimoto found both inter-regional and within-regional differences in product development performance, as well as development capabilities. The study also identified some patterns that might challenge traditionally believed propositions, such as "there is a trade-off between R&D cost and lead time," "involving parts suppliers in the early stage of development will result in higher component cost through monopoly rent seeking," "there is a dilemma between firm's capability in R&D and that in manufacturing," "task specialization is generally good for better R&D," and so on.

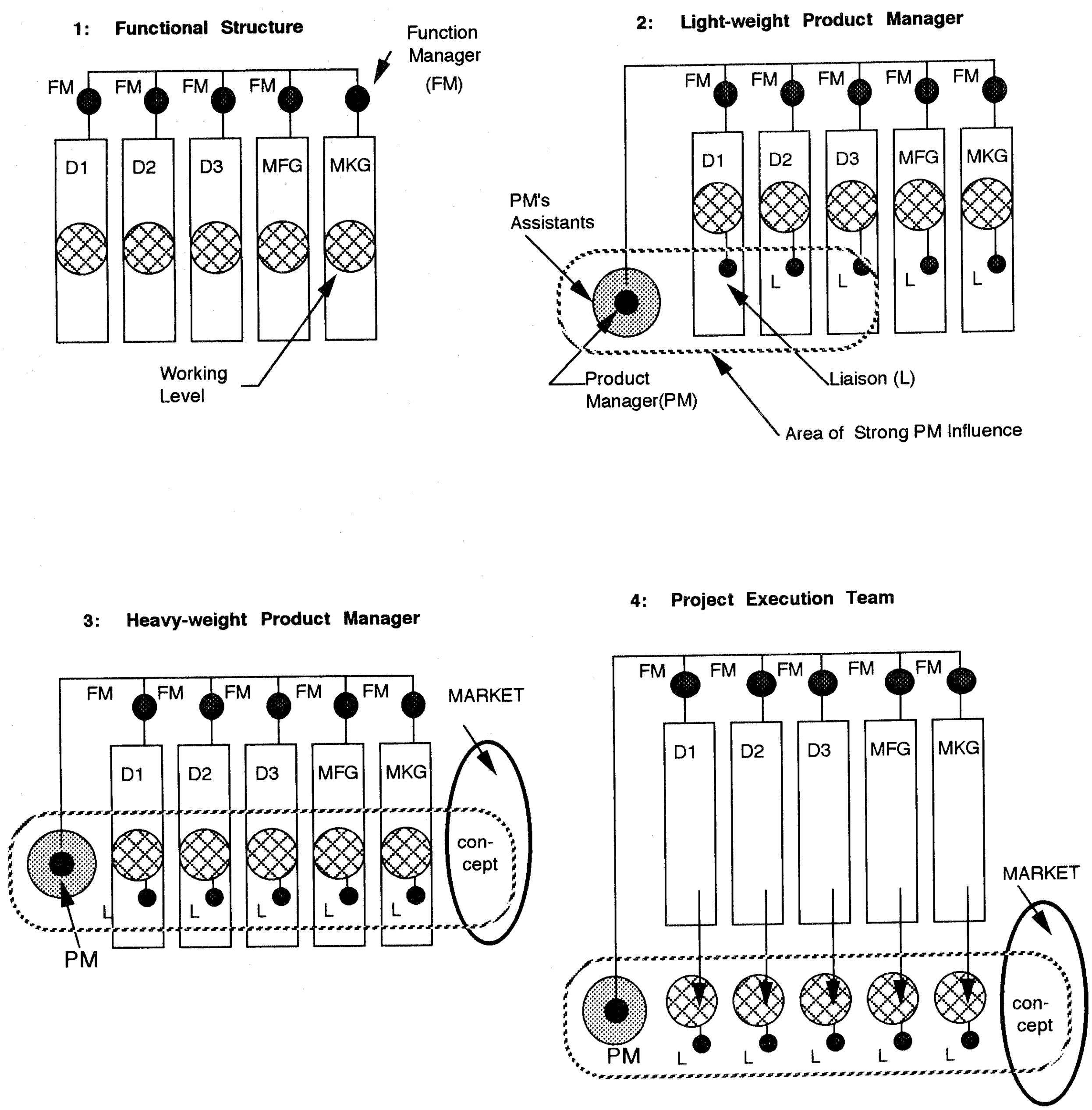
3. Historical Evolution of the Product Development Capabilities

3.1 Why Do Region-Specific and Firm-Specific Patterns Coexist?

When we observe that product development capabilities of the 1980s were partly region-specific and partly firm-specific, how can we explain this phenomenon? There are multiple ways of analyzing the process

For example, to the extent that the Japanese and Western markets and domestic competitive environments were different, each firm adapted itself to its own domestic market (i.e., the home ground), which may have shaped the firms' region-specific capabilities. Now that the world auto markets became more or less converged, the Japanese in general got natural advantages, because their past domestic environments (many rivals, many

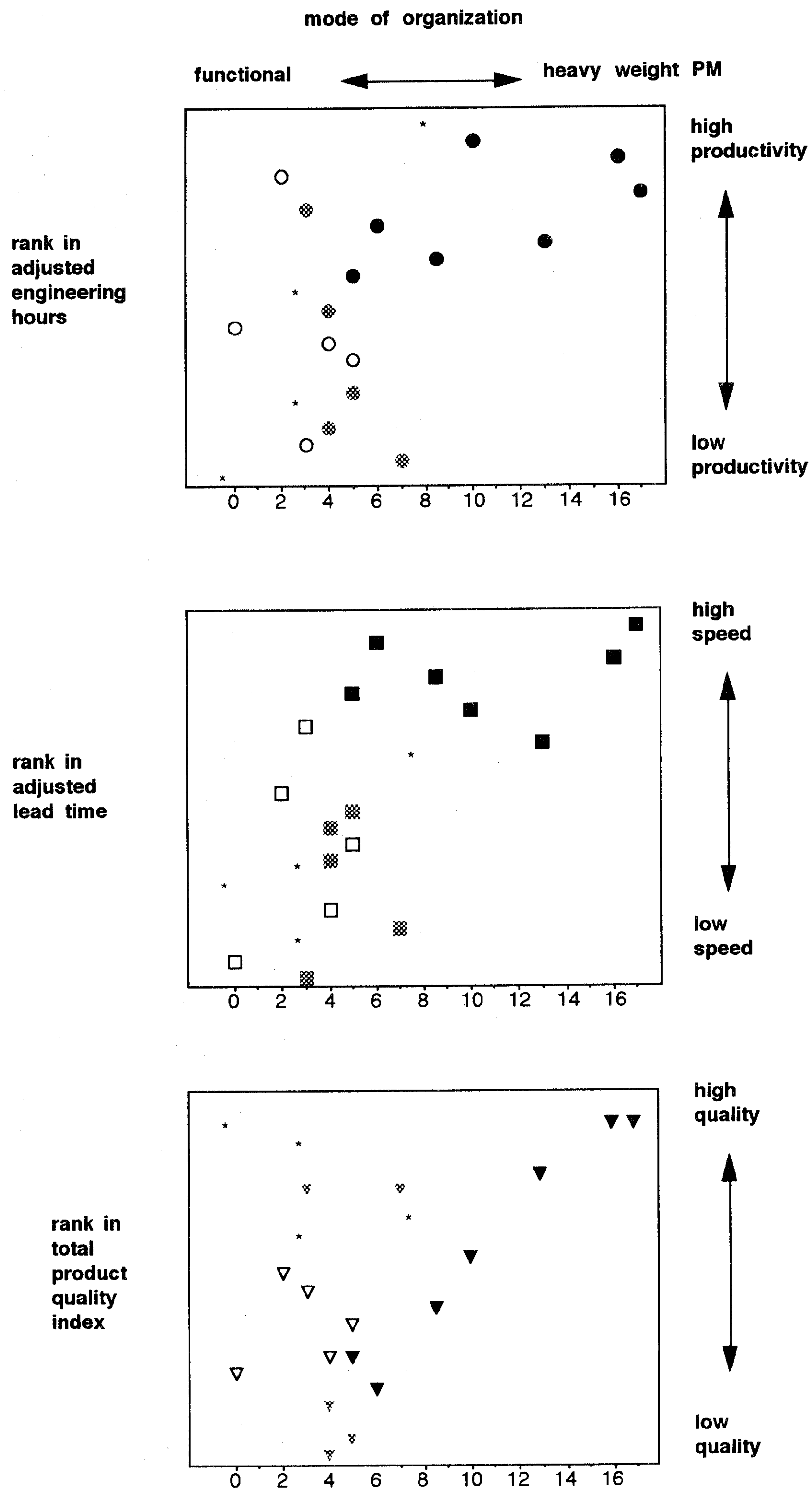
Figure 9 Four Modes of Development Organization



Note: D1,D2 and D3 stand for functional units in development. MFG stands for manufacturing; MKG for marketing.

Source: Fujimoto (1989), Clark and Fujimoto (1991).

Figure 10 Mode of Organization and Development Performance



Note: ■ = Japan ▩ = U.S. □ = Europe * = high-end specialist

One Japanese volume producer with incomplete data was omitted from the diagram.

Source: Clark and Fujimoto (1991)

products, rapidly changing market needs, etc.) turned out to be similar to the current global environments. Thus, the companies that could adapt themselves to the Japanese competitive environment tended to perform well in the global market of the 1980s as well. This hypothesis seems to be able to explain at least a part of the "Japan effect." (Clark and Fujimoto, 1992).

In this way, competitive rationality may explain why the system continues to exist, but it may not explain why the system emerged in the first place. First of all, some aspects of the system were created long before its competitive advantages were revealed. In other words, the firms apparently built some of product development capabilities without knowing their competitive consequences. Even when the system is ex-post rational in terms of competitiveness, it does not have to be ex-ante rational. Historical imperatives often force the firms to adapt themselves to certain constraints of the competitive environments, and then this move may subsequently bring about unintended contributions to their competitiveness.

This, however, does not mean the environmental determinism. While the effects of environmental imperatives and inadvertent trials may be an important element of the evolutionary process, individual firms may still be able to outperform their rivals by making better use of the imperatives than the others.

There are also historical evidences that the whole system of capable product development was not created by one big and strategic decision making, but rather emerged gradually since the 1950s. Thus, we have to examine the historical evolution process of the product development capabilities.

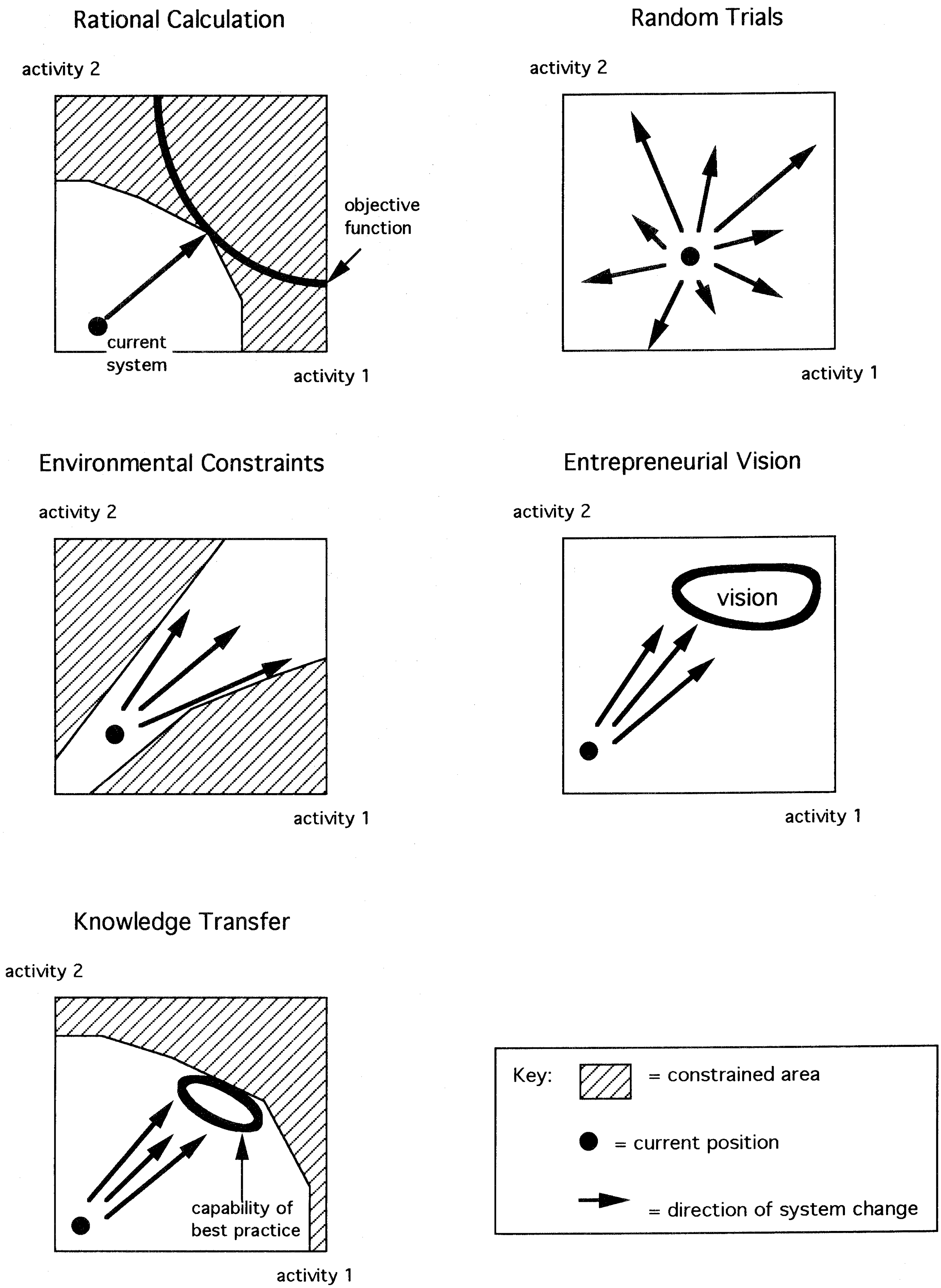
Generally speaking, there are several ways to describe the emergence of new systems and capabilities (**figure 11**; Fujimoto, 1994a, 1994b):

- *Rational calculation:* A firm deliberately chooses a new course of action that satisfies or maximizes its objective function by examining a feasible set of alternatives based on its understandings of environmental constraints and limits of capabilities. Rational decisions may be made before the trials are made (ex-ante rationality) or after the trials (ex-post rationality).

- *Random trials:* This logic assumes that it is a matter of pure chance for an organization to choose a particular trial. A lucky one gets a better system, an unlucky one gets a poor one.

- *Environmental constraints:* A firm limits its range of trials, voluntarily or inadvertently, because of certain constraints imposed by *objective* or *perceived* environments (i.e., historical imperatives).

Figure 11. Some Generic Hypotheses of System Emergence



- *Entrepreneurial vision*: A desirable set of activities is directly chosen by entrepreneurs of the organizations on the basis of their visions, philosophies, or intuitions, without much analysis of the capabilities and constraints of those activities.

- *Knowledge transfer:* A certain pattern is transferred from another organization to the one in question. The transfer may happen within the industry (competitor, supplier, customer, etc.) or across industries.

The coexistence of firm-specific, region-specific, as well as universal patterns of performance and capabilities may be explained by an interrelated combination of the above logic. First, region-specific patterns of product development capabilities may have emerged by rational adaptations to region-specific constraints and or objective functions (e.g., multiple equilibria, each of which is region-specific), knowledge transfers among firms of the same region, or imperatives of region-specific environmental constraints. Second, firm-specific patterns of capabilities may evolve over time through a combination of uneven distribution of rationality among firms, entrepreneurial visions, and the lack of inter-firm knowledge transfer. And finally, universally observed capabilities may emerge as a result of rational adaptations to (or historical imperatives of) a uniform competitive environment worldwide, many random trials by the firms, or inter-regional knowledge transfers.

In any case, it is important to note that, even if the capabilities which some Japanese auto makers had built by the 1980s were ex-post rational from international competition's point of view, it does not necessarily mean that the first trials of the new system were made through ex-ante rational decision making. In this sense, we often have to distinguish the logic of system stability and that of system emergence (Fujimoto, 1994a, 1994b).

3.2 Examples of the System Emergence

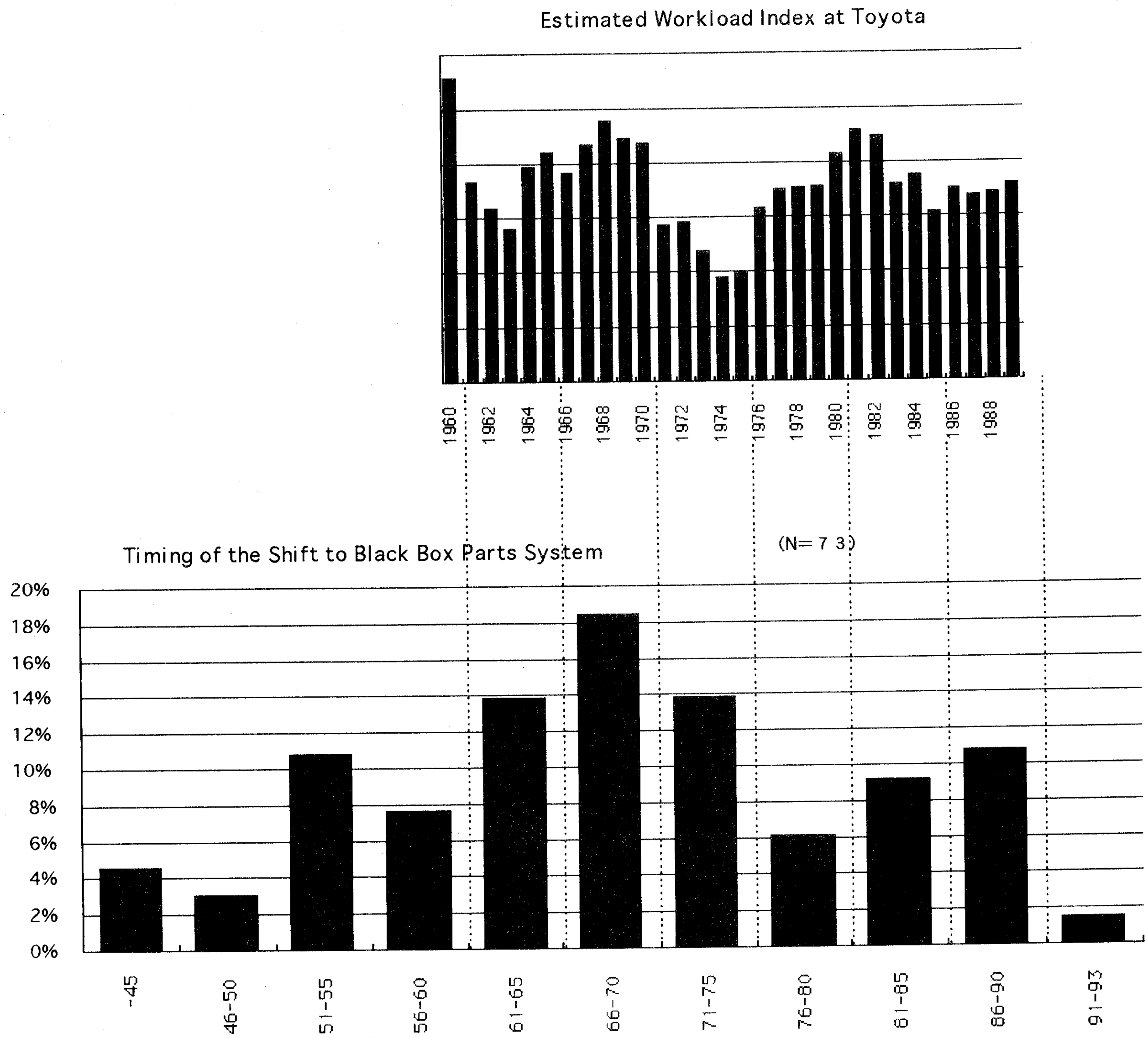
Based upon the above framework, let us now examine the system emergence of some of the development capabilities identified in the previous section.

Black box parts system: There was a transfer of the black box practice from the prewar locomotive and aircraft industries to the auto industry. Separation of Nippondenso from Toyota in 1949 may have been another source of the practice (Fujimoto, 1994a). However, the most important driving force for the diffusion of this practice appears to be the workload for creating a wide product variety. During the 1960s, rapid model proliferation due to the domestic motorization created a heavy workload for car makers' in-house product engineers, which facilitated subcontracting of not only manufacturing and subassembly but also detailed deign of the parts **(figure 12)**. In this way, the Japanese auto makers were almost forced to rely on black box parts. The competitive advantage of the system may not have been clearly recognized by all of the auto makers of those days. In fact, there are some historical evidences that Toyota recognized competitive rationality of this system earlier than Nissan and refined it accordingly, despite the fact that both companies were facing similar historical imperatives (Fujimoto, 1994a).

Manufacturing Capabilities: Manufacturing capabilities of the effective Japanese auto makers of the 1980s, including Just-in-Time (JIT), Total Quality Control (TQC), multi-task work assignment, small lot production, etc., gradually emerged as a complex result of historical imperatives, entrepreneurial visions, management knowledge transfers, rational calculations, and pure chances (Fujimoto and Tidd, 1993; Fujimoto, 1994b). It is important to note again that the competitive consequences of a given manufacturing capability were not always recognized clearly by those who adopted the system prior to the system trials. In many cases, historical imperatives or environmental constraints forced the firm to accumulate a certain capability, which turned out to be competitive only after the actual adoption. For example, small and fragmented market in the post war Japan forced the firms to adopt flexible work designs and equipment with limited specialization, but it was long after the adoption when the companies clearly recognized the system as a competitive weapon. Similarly, self restraints on the growth of permanent workers in the fear of labor conflicts in the 1950s almost automatically created continuous pressures for the companies to improve productivity and to make the most of the suppliers when they faced rapid growth of the output subsequently. The constraints in inputs were not deliberately planned, though.

In summary, historical analyses of evolution of the Toyota-style manufacturing capabilities indicate that rational calculations on the competitive effects of the new system prior to the actions did not necessarily play a critical role in building the manufacturing capabilities. At the same time, it should be noted that, once the new systems or processes were tried for whatever the reasons, some companies could comprehend their competitive implications and systematize the trials more effectively than others. Thus, the actual process of manufacturing capability building were often made by a combination of unintended environmental constraints, ex-post ability of making use of the trials, and entrepreneurial visions interacting

Figure 12 Toyota's Estimated Development Workload and the Shift to Black Box Parts



with each other. The result was a mixture of firm-specific and region-specific capabilities in manufacturing.

Overlapping Problem Solving: As for the case of simultaneous engineering, it seems to be requirements for product development performance that created product development capabilities, rather than vice versa. The four year model change cycles for main car models started as early as the early 1960s between Crown and Cedric, Corona and Bluebird, as well as Corolla and Sentra. Assuming that lead time should be equal or shorter than model change cycles, and considering that product and process engineering took two years each in the 1960s as they do now, it would be natural to assume that the four year model change cycle existed first, and this forced the Japanese auto makers to build capabilities of simultaneous engineering and intense inter-stage communications. Why did 4 year cycles emerge in the first place? The evidence is not clear. However, we can at least say that the short lead time was not designed for winning international competition (it barely existed in Japan in the 1960s), but for competing in the domestic market.

Small Team and Broad Task Assignment: It is likely that chronic shortage of the engineers in the post-war auto makers forced the makers to make a compact project team, which forced each individual engineers to keep their skill ranges wide. The Japanese firms of those days might have regarded as a disadvantage because it implied lack of specialization and technical expertise.

The broad task assignment turned out to be a source of productivity and lead tie advantages, though. As a circumstantial evidence is observed in the case of Mazda Miata, in which the company lacked sufficient resource allocated to this "minor" project, which forced Mazda to make the project slim and compact. The inadvertent result was an unusually small project team, wide task assignment for each engineer, shorter lead time, and high development productivity. Again, this was not a strategically intended result. Historical imperatives of the shortage of engineers throughout the product proliferation period may have been a main cause of the compactness of the product development teams.

Heavy Weight Product Manager: There is a historical evidence that the origin of the heavy weight product manager was the prewar aircraft industry, which attracted best and brightest college graduates. After the war, the aircraft industry collapsed and many young and talented engineers were forced to seek jobs in related civilian industries, including locomotives and automobiles (Maema, 1993, Ikari, 1985, 1993). Because of this "forced technology transfer" technological capabilities in aerodynamics, structural analyses , and so on prevailed in the auto industry. Also, at Toyota, the product manger system was transplanted by an ex-aircraft engineer, Hasegawa (first PM of Corolla). Interestingly enough, it was much later, the late 1970s or early 1980s, that the advantages of the Heavy Weight PM system became apparent and other companies started to adopt similar systems. Again, competitive rationality cannot explain the origin of the system..

Overall, the brief analysis of the origin of the product development capabilities reveals that ex-ante rationality alone cannot explain their origins and evolution. The competitive rationality may explain why the system was sustained once it was established, but it may not be able to explain why the capability emerged in the first place. Unintended effects, such as historical imperatives and forced technology transfers, may play a major role here. The competitive consequences of a system may not have been recognized by the firms when they were first introduced.

Although historical imperatives played an important role in capability building of some Japanese firms, environmental determinism cannot explain the whole picture, either. Significant inter-firm differences in capabilities do exist among the Japanese firms, for example. The source of the inter-firm differences may be entrepreneurial visions (e.g. Soichiro Honda), but some kind of "ex-post capabilities", or the capabilities of making the most of unintended or forced trials, may be even more important. Examples are: differences of black box parts systems between Toyota and Nissan; Product manager system at Toyota versus other firms.

To sum up, a combination of region-specific historical imperatives and firm-specific capabilities for building capabilities may explain why both region-specific and firm-specific results were observed in product development capability and performance of the Japanese auto makers.

4. The US Catch-up

4.1 Adopting the Japanese Practice: Top-Down Approach

Once the competitive advantages of the product development capabilities of better Japanese firms became obvious in the 1980s, the Western auto maker started to transfer certain modified versions of the

Japanese product development systems. The U.S. makers, facing a stronger pressure of international competition, moved on this direction earlier[7].

For example, Ford has introduced a system of stronger product managers and coherent cross-functional project teams, following mainly Mazda and Toyota since the early 1980s. The period of the changes in Ford's product development organization roughly coincides with the period of its new product success, including Taurus. Chrysler, on the other hand, is said to have followed mainly the practices of Honda in product development, production and product designs. Chrysler also thoroughly changed its supplier management system, increased both production outsourcing and component design outsourcing ratio, reduced the number of first-tier suppliers (consolidated supply base), let them become system suppliers (specialist makers of sub-assembled components), built up a multi-layer procurement hierarchy, involved the suppliers into product development process (black-box parts), shifted from competitive bidding to collaborative cost reduction, introduced a market-driven cost planning method, and strengthened ties with the suppliers in terms of knowledge sharing and technical assistance[8]. Many of the purchasing practices that Chrysler adopted in recent years were virtually what some of the Japanese makers gradually acquired between the 1950s and 1970s. Reflecting this trend, the data that Clark, Ellison and Fujimoto collected in 1993 shows that the ratio of black-box parts in total procurement cost at the sample U.S. projects jumped from 16% on average in the 1980s to 30% in the early 1990s (The equivalent number in Japan is about 50 to 60%).

The American makers did not follow the evolutionary path of the Japanese makers, though: They tended to introduce the system as a package from top down. Some of the Japanese practices, which they were using almost as tacit knowledge, were systematized, articulated, and given names by the American practitioners. For example, the Japanese auto makers, which had faced the competitive realty of the four year model change cycle in the domestic market, were forced to establish the practice of carrying out product and process engineering in parallel with intense communication, but the practice did not have a particular name, as it had been ingrained into the engineering organization. In the late 1980s, the American practitioners (SAE in particular), realizing the product development competition against the

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7 For further details, see Clark and Fujimoto (1994).

8 "Building Successful Supplier Relationships." Presentation by Thomas T. Stallkamp of Chrysler Corporation at the 1993 Global Automotive Conference "Megatrend and the Auto Industry," December 6-7, 1993

Japanese, focused on this practice as a key to shorten development lead times, described it as an explicit process, and gave a name to it: "simultaneous engineering." This term was re-exported back to Japan, and is widely used now [9].

Thus, many of the emergent practices and capabilities, which the Japanese auto makers gradually built up during the post-war era without recognizing as a system, were introduced into the American firms in the 1980s explicitly as a rational system[10]. A potential problem of such an analytical approach would be that some critical factors for success that still remain tacit might be overlooked by the adopting firms, but the approach would also have an advantage to the extent that the they can rationalize the practices and adopt them in a compressed process. This is often called "late comers' advantages," which the Japanese manufacturers are said to have enjoyed when they adopted the Western technologies in the past.

In addition to the fact that the U.S. makers adopted a parts of the Japanese-style practices through a different path, they introduced what even Japanese makers did not do regularly. For example, some U.S. makers organized so-called "dedicated-collocated" product development teams for each of the basic models, which helped them dramatically reduce product development lead times. Some of the Japanese makers did use this organizational structure in the past (e.g., Mazda Miata, Honda Today's minor change), but they never used this regularly. The regular project teams of typical Japanese makers consist of product engineers who are mostly assigned to multiple projects and work at the functional departments geographically while they belong to the projects organizationally. The Japanese practitioners agree that the collocation approach would shorten lead time, but they argue that using this approach regularly would result in duplication of engineering resources, insufficient accumulation of component technologies, and lack of inter-project knowledge transfers. Thus, the case of dedicated-collocated approach provides an interesting example of the U.S. makers that leapfrogged the Japanese as they departed from their traditional functional approach and shifted to the project team organizations.

To sum up, the U.S. makers, facing the competitive challenges from the Japanese makers, built up new capabilities of product development during the 1980s. The process was essentially the adoption of the Japanese style

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9 Many aspects of so called "reengineering" seem to have similar characteristics.

10 For the distinction between emergent and analytical formation of strategies, see, for example, Mintzberg (1987).

practices that they identified, but it was more than a simple imitation of best practices in that they articulated and systematized what the Japanese themselves did not explicitly recognized as a coherent system, and that they sometimes adopted even more radical approaches than the Japanese.

4.2 Narrowing the Performance Differences

As a result of the adoption of the high-performance practices, the Japan-US difference in product development performance started to narrow after the late 1980s. In order to examine this dynamic process of the Western catch-up, Clark, Fujimoto and Ellison replicated the survey of product development performance discussed above in 1993. The samples as of spring 1994 consist of 29 major product development projects (8 Japanese, 5 U.S., 12 European and 3 Korean) from 23 manufacturers (8 Japanese, 3 U.S., 9 European and 3 Korean). The preliminary results indicate that the average U.S. projects virtually eliminated the performance differences in development lead time and productivity[11] **(table 3, figure 13, forthcoming)**.

Product Development Lead Time: Adjusted lead time of product development from the beginning of concept generation to market introduction indicate that the U.S. makers dramatically reduced lead time from about 5 years in the 1980s to roughly 4 years in the early 1990s[12]. The Japanese average lead time, on the other hand, became slightly longer, as the auto makers emphasized upgrading of their products. The European average also remained almost the same as the previous cases (about 5 years). Thus, the lead time difference between the Japanese and the U.S. projects is estimated to have been totally eliminated by 1993. The equivalent unadjusted figures were 60 in Europe, 49 in America, and 51 in Japan.

Breaking down the lead time into its components, however, we found that the reduction of lead time by the U.S. makers came mostly from shortening planning lead time (i.e., from the beginning of concept creation to the approval of the product plans) rather than shortening engineering lead time (i.e., from the beginning of product engineering to the beginning of sales). That is, the U.S. average planning lead time was reduced dramatically by about half a year between the 1980s and the early 1990s, while the engineering lead time was almost unchanged (about 40 months)[13]. Besides,

11 For further details, see Ellison, Clark and Fujimoto (1994), persented at ORSA/TIMS meeting in April 1994.

12 The regressiion result of Calrk and Fujimoto (1991, page 386, table 6, specification LT6) was used for the adjusment of the lad time data for project content.

13 The data on the lead time components are all unadjusted for project content.

the U.S. auto makers increased the overlap period between planning and engineering from almost zero to about half a year between the two period. The concept creation stage length was shortened by about two thirds.

The average Japanese performance during the same period was quite contrasting. First, their engineering lead time (unadjusted) was almost unchanged at the level of about 30 months between the 1980s and the 90s. Second, their planning lead time (concept stage length in particular) was somewhat prolonged, which was a sharp contrast against the U.S. case mentioned above. Third, unlike the U.S. case, the average Japanese projects did not overlap planning and engineering periods.

Also, the Japanese projects on average maintained their advantages in lead times for core engineering activities such as prototype building and die development. Lead time for developing first engineering prototypes did not change much in both Japanese and American cases: about half a year in the former, about a year in the latter. European average improved, but the U.S. average did not. The Japanese also maintained significant advantages in die development lead times: the U.S. average was somewhat reduced, their die manufacturing lead time decreased particularly significantly, but the difference still remained.

To sum up, the U.S. auto makers made a dramatic reduction of total lead time to catch up with the Japanese, but it was achieved mostly by shortening lead time for planning, rather than that for hardware engineering. The average Japanese makers, by contrast, made concept and planning lead time longer. This may be partly because many of the Japanese models needed fundamental conceptual changes (e.g., conversion to luxury models, niche-oriented models, or simple product designs). Their performance advantage in engineering lead time still seems to exist, though.

Development Productivity: The U.S. makers also caught up with the Japanese in development productivity measured by adjusted person-hours per project. Adjusted engineering hours of average European projects remained basically unchanged, but US average was shortened to roughly half (1.5 million to 2 million person-hours) and thereby caught up with the Japanese average[14]. In short, product development productivity was essentially unchanged between the 1980s and the early 1990s in Europe and Japan, while the U.S. average was reduced to half. As a result, the estimated development productivity of the average U.S. projects became at least as

14 The regressiion result of Calrk and Fujimoto (1991, page 385, table 5, specification EH6) was used for the adjusment of the lad time data for project content.

high as that of the Japanese. The catch-up of the U.S. makers was dramatic. Also, the finding that the US makers focused on lead time reduction and achieved roughly 20% reduction in lead time and 50% reduction in engineering hours is consistent with the author's prediction that there is a positive correlation between lead time and engineering hours (as opposed to the trade-off relations that textbooks in engineering management tend to assume), and that lead time tends to drive productivity rather than vice versa.

5 Overusing the Capabilities: The Japanese in the Early 1990s

5.1 The Problem of "Fat Product Designs"

The Japanese auto makers on average lost much of their competitiveness that they enjoyed in the early 1980s by the early 1990s. Appreciation of yen, the US catch-up efforts, managerial resource transfer through cooperative international networks, slow down of the Japanese productivity increase all contributed to this trend.

Another important source of the Japanese problem in competitiveness was "fat product". Excessive product varieties, fast model change cycles, too few common parts, unnecessary options, over-specification and over-quality were all criticized first as a source of overwork of engineers before the post-bubble recession started, and was criticized as a competitive weakness of the Japanese cars after 1993 appreciation of yen.

The author do not interpret that these problems were created because the Japanese makers built a wrong set of capabilities, though. Quite contrary, it is argued here that "overuse" of the same capability that created competitive advantages in the 1980s has been the source of the new problem in the 1990s. Here is an important competitive dynamics: Firms tend to overshoot. They tend to overuse the capabilities that their competitive advantages once depended on. Thus, the US firms once became competitive through a mass production system of specialization, but subsequently they suffered from "over-specialization." The Japanese once enjoyed competitive advantages in product variety, but now they may be suffering from over-variety. History repeats in this sense.

<u>Causes of Fat Product Design</u>: Although the leading Japanese auto makers, particularly Toyota, were known for so called "lean production" (Womack et. al., 1990), as well as fast and efficient product development (Clark and Fujimoto, 1991), there was one area where they were not lean: the products themselves. Since the bubble economy collapsed in the early 1990s, many researchers and practitioners and union officials have criticized

that the Japanese companies developed too many product variations, replaced models too frequently, relied too little on parts commonalty between the models, and designed products with over-quality and over-specification.

It is true that, when the market is diversified, changing and sophisticated, the auto makers need to achieve a certain level of product variety, model change frequency, uniqueness of component designs, and rigorous pursuit of design quality and high functionality in order to stay competitive in the market. As mentioned in section 2, these were exactly the elements in which better Japanese makers outperformed their Western counterparts (Clark and Fujimoto, 1991).

Quite ironically, though, the Japanese makers have been criticized in recent years for the same reasons. It looks as if the Japanese companies have overused their advantages in capabilities of product development performance: if the Japanese auto makers had not had enough capability in product development efficiency, if it had not pursued product integrity and customer satisfaction to an extreme, and if their product managers had not been powerful enough, they would not have been criticized in this way, because it would have been impossible for them to develop too many variations too frequently in the first place. Fat design, or excessive product complexity of the Japanese products, can be thus regarded as the side effect of the very strength of the Japanese product development system.

Besides the "efficiency" of the leading Japanese makers that enabled them to create fat design, there are certain mechanisms built into the typical Japanese product development process that systematically creates fat design.

First, the Japanese makers have emphasized customer satisfaction, which in philosophy is an important thing to pursue, but this often meant pursuing high scores of Customer Satisfaction "Index" (CSI), which consisted of a long laundry list of "things to be done". If the engineers and designers emphasize such a list too rigorously and try to fill it in without a sense of priority, the result tends to be a fat design.

Second, when "product integrity" is recognized as the key to market success, product designers and engineers tend to start insisting that high price can be justified by improvements in product integrity. When this period coincides with economic booms, the notion that product integrity is sacred prevails, cost planning becomes less rigorous, and product cost increases. In other words, the period of reckless pursuit of product integrity may contribute to long-term evolution of the firms' capability, but it is also likely to result in cost increase in the short run.

Third, when lead time is short, the auto engineers tend not to have enough time to evaluate the relevance of the engineering standards, even when they represent over-quality from the customers' point of view. Today's automobile maker possesses engineering standards that as a whole are as thick as dozens of phone books. This huge accumulation of design rules facilitate quick and efficient execution of product engineering, but they also can become a bureaucratic procedures that tend to create fat design. For example, when only two bolts are enough to hold a particular component in today's technology, an old standard that requires three bolts may remain unquestioned. When engineering lead time is short, there may be even higher chances for old standards to remain unquestioned for generations of models.

Fourth, when each individual product manager is powerful, inter-project management may become difficult, as each managers behave so autonomously. When a sense of ownership of the product managers is too strong, they start to insist that their products be unique down to each components. In other cases, they may insist that their new products get novel technologies and equipment that were successfully introduced in the upper models in the past. Thus, the very existence of heavy-weight product managers competing for promotion may contribute to excessive complexity of the parts and the products.

Fifth, as Penrose (1959) points out, firms tend to adapt themselves to perceived environments as opposed to real ones. When auto makers increase product variety, they may be reacting to the perception that consumers need variety, rather than the real variety in actual demands. When engineers plan and develop variety of product design, there is no way they can calculate optimal level of product variety in advance. In such a situation, they tend to create more varieties for insurance -- a shot gun approach. When they manage to sell the variations in some ways or others, including heavy discounts, the planned variety becomes a self-fulfilling prophesy. There seems to be virtually no effective way to control this process of design multiplication. Thus, variety of product design tends to proliferate.

In a sense, the problem of excessive product variety, model changes and over-specification is closely related to the limit of "growth-oriented" model in general[15]. In the high-growth mode, firms tended to focus on competitiveness and customer satisfaction even at the sacrifice of interests and satisfaction of other stakeholders. The above design problems were

15 See, for example, Fujimoto (1993a), (1994c).

created as the auto makers over-adapted itself to customer needs that they perceived. As the makers move toward "balance-oriented" system in the post-bubble low-growth era, it is natural that they change their ways of product design as a part of this transformation. Customer satisfaction, as a philosophy, is still the most important theme for the manufacturing firms, but side effects that it creates have to be carefully controlled.

Product Simplification without Sacrificing Product Integrity: Now that "bubble economy" is over, Japanese product planners and engineers no longer can say that cost increase can be always justified by improvements in product functions and features. As customers have become more price-sensitive, it has become increasingly difficult for new products that has both high design quality and high price to penetrate in the post-bubble markets: single lens reflex cameras, men's suits, passenger cars, to name a few. Cost reduction is the necessity here. Cost planning becomes critical in product development projects.

While it is also difficult for the companies that already have efficient production system to further reduce costs dramatically by the shop floor Kaizen (improvements) efforts alone, product design simplification, low cost automation, and transfer of production facilities to low cost regions may be promising solutions. In the case of the Japanese auto makers of the 1990s, as discussed above, design simplification seems to be the most effective means for cost reduction. The "lean production" system (Womack et. al., 1990) now needs "lean product design".

What makes this challenge of design simplification more difficult to cope with is the fact that consumers expectations on total product quality, or product integrity, tend to be irreversible: once they experience a product of high product integrity and design quality, today's consumers tend to set their reference points based on these products. Thus, consumers' expectations on price tend to fluctuate as their budget constraints changes between booms and recessions, but their expectations on total product quality tend to stay at the high level even after the boom period is over. For example, many Japanese bought high-end Italian suits during the bubble era, and their tastes and sensibility to quality of suits and fabrics apparently changed in an irreversible manner. Now the boom is over, and consumers can no longer afford to buying luxury Italian suits or expensive designers brands. But they still keep a high-end suits in their closets, and which still set their standard on what good suits should be. Thus, the challenge to the major apparel companies may be to develop suits that matches high-end import brands in product integrity, while reducing their costs to half so that average post-bubble consumers can afford. Thus, lean design does not mean that the makers have to return to old designs. Simply creating "strip-down" model does not work in this situation.

In order to simplify product designs while meeting the expectations of today's customers on total product design and integrity, project leaders of new product development needs a sharp sense of priority that is backed by strong product concept. The capability of product manager as concept creator and translator would become even more important. When the cost constraints are not severe, the product manager (i.e., concept creator) can make a long laundry list of "good things to be achieved in the new product" and realize them one by one without violating the cost requirements. When the cost target is demanding, though, the product manager has to be selective in distinguishing what the product should pursue and what it should not. For example, the project leaders may have to make a list of "what this project does not do" explicitly and persuade the resisting engineers to follow it. Thus, a keen sense of priority in concept creation and powerful leadership in concept realization is needed on the side of project leaders.

Simple or "lean" product also needs "concept-based" value engineering. The Japanese auto makers have been active in introducing and executing value engineering, but this usually meant changing designs and materials given the functions and other product properties, and given the engineering and testing standards of the company. The engineers, planners and product managers may have to go one step ahead and examine whether functions and specifications themselves are necessary in the light of product concept and customer expectations. Specialist value engineers alone cannot do this kind of jobs. What is needed is a tight communication and knowledge sharing between product managers, planners and engineers.

In fact, a recent survey indicates that a majority of cost reduction at Toyota and other Japanese auto makers in 1993 fiscal year was contributed to by design simplification, as opposed to reduction of overhead, reduction of capital investment, or Kaizen activities. In the mid 1990s, the design simplification will continue to be a main source of cost reduction for the Japanese auto makers struggling to regain their cost competitiveness.

5.2 Stages of Capability Building in Product Development

The transition from fat design to "lean product" can be seen historically as a result of the collapse of the "bubble economy", or a consequence of the post-bubble recession. At the same time, it may be regarded as a stage of evolutionary process for firms' capability building. Although we should avoid deterministic linear model, there seems to be many cases where manufacturing firms in fabrication-assembly industries (i.e., machinery and system industries) go thorough the following paths:

(1) Pursuit of better functions and technologies at the individual component level. Building organizational capabilities around element technologies: Element-focused strategy for product development (lansiti, 1993). Functional organization best fits this stage.

(2) The element-driven strategy faces the limit. The firms find that they cannot differentiate their products by superiority in component technologies alone (Clark, 1990). The companies with superior component technology alone tend to fail in the market at this stage.

(3) The companies start to focus on product integrity (Clark and Fujimoto, 1990) as a key differentiater at the system (i.e. total product) level. System-focused strategy for individual product development is chosen (lansiti, 1993). Tight project teams and "heavy-weight" project managers are better structures for this stage (Clark and Fujimoto, 1991).

(4) The companies pursuing customer satisfaction through total product quality face a problem of over-quality and increasing cost as a side effects of their efforts toward higher product integrity and product variety. The companies with superior project management at individual product level tend to fail in the market at this stage. Heavy weigh product manager system and strong cross-functional team, designed for higher product integrity, often create a problem of lack of cross-project coordination.

(5) The companies start to make efforts toward "lean product design" by cutting product cost dramatically mostly by simplifying designs while maintaining the level of product integrity and customer satisfaction. Shifting focus from individual products to the company-wide product line may be a key for this stage, as the problem of "fat design" tends to happen in the lower end products. Reorganization for multiple project management often becomes the issue. A strong multi-product planners who have a clear sense of product positioning, or individual product managers who have a clear sense of priority and orientation to Isimple design often become key people.

Of course, there may be reverse sequence, skipping stages, further shift to other foci of capability building, or renewal of the above cycle. Again, it is dangerous to apply a deterministic stage model to the real world, but this kind of model may help researchers understand the dynamics of capability building. In fact, the above framework seems to apply reasonably well to the cases of SLR cameras, men's suits, automobiles, and so on. The above model implies that "focus of competition" shifts over time, and focus of capability building also shifts accordingly.

Also, it is important to note that capability building on the manufacturer side and capability building on the customer side interact each other and evolve side by side. For example, the shift from element (component) focus to system (product integrity) focus is likely to be accompanied by improvement of customers' capability to discern subtle product differences at the total product level in the context of their problem solving in the consumption space. Knowledge hierarchy of the manufacturer and that of the customers interact each other (Clark, 1985).

The above hypothetical framework also implies that capability building may not be a smooth and balanced process, but an unbalanced process of overshooting and re-balancing. A firm may focus on one dimension (or level) of product development capability, accumulate organizational capability along one dimension, do it too much, face problems in other dimensions or levels, and try to regain balance by shifting attentions to other dimensions. It may even be the case that better companies may have pursued this "off-balance" strategy, rather than balanced strategy at given time, which created strong competitive capability over time as an unintended result.

In this context, we may regard the current issue of design simplification among the Japanese firms as the move from the stage (4) to stage (5) in the above framework. In other words, the problem of fat design should be analyzed in the context of long-term evolutionary process of the firms' capability building.

6 Conclusions and Future Prospects

This chapter examined the dynamic aspects of product development capabilities in the Japanese auto makers. The main messages may be summarized as follows:

(1) The pattern of product development performance (i.e., lead time, productivity, and product integrity) of the 1980s was partly region-specific and partly firm-specific. The Japanese makers in general tended to outperform the others in some criteria, but there were inter-firm differences among the Japanese in other areas. Only a few Japanese makers achieved high performance in all three criteria.

(2) The pattern of critical product development capabilities of the 1980s (e.g., suppliers' design capability, manufacturing capability in product development, capabilities in simultaneous engineering, wide-range skills

of engineers, strength of product managers, etc.) was also partly region-specific and partly firm-specific, reflecting that of product development performance. The pattern consistence of the capabilities as a system contributed to overall success of some of the Japanese volume producers in the 1980s.

(3) The product development capabilities of the effective Japanese firms of the 1980s evolved gradually as a combination of factors of system emergence, including rational calculations, entrepreneurial visions, historical imperatives, knowledge transfers, and pure chances. Although the system was ex-post rational from international competition's point of view, the advantages of the emerging systems were in many cases, not recognized by the firms when hey were first tried. Historical imperatives and unintended technology transfers played an important role in this capability building process. At the same time, firm-specific abilities of converting unintended trials to carefully designed systems was also important. Thus, the dynamic process of capability building itself was both region-specific and firm-specific at the same time.

(4) Whereas the product development capabilities of the effective Japanese firms were gradually built as a result of an evolutionary process, the U.S. and European firms, facing the competitive challenges from the Japanese, started to change their systems to catch up with the Japanese best practice in product development. Unlike the Japanese case, the product development capabilities were recognized explicitly as a rational system, and introduced to the Western firms mostly in a top-down approach. Some modifications were made by them through this rationalization process. Partly as a result of this knowledge transfer, product development performance of the U.S. makers in lead time and productivity improved rapidly, and the average performance differences narrowed in many criteria.

(5) The Japanese auto makers, on the other hand, faced a problem of "fat design," in terms of product varieties, model change frequency, model-specific parts, over-specifications, and over-quality. This phenomenon may be explained by "overusing" of product development capabilities by the Japanese firms, or a side effect of the firms' capability building processes. In other words, the problem in the 1990s may have been created not because the Japanese firms deviated from their success

pattern in the 1980s, but because they pushed the very capabilities to an extreme.

(6) Some of the Japanese makers and projects are already making efforts to solve this overshooting problem by simplifying designs of the new products and cutting costs without sacrificing product integrity. This indicates that the dynamic process of capability building may not be a smooth and balanced one, but a zigzag path of overshooting and re-balancing between different aspects of the capabilities and performance. The pace of capability building will be uneven over time.

As the regional differences in product development performance at individual project level narrows in the early 1990s, the patterns of competition in the world auto industry will change as well. First, the impact of product development capabilities in individual firms, regardless of their geographical origins, will increase their relative importance. Seeing the industrial competition as battles between national teems will thus become somewhat obsolete. Second, multi-level management of product development will become more important, to the extent that the firms' capabilities at other levels than individual product development projects (e.g., management of company-wide product mix, component technology development, etc.) become a key to the success in the market.

Despite such changes, some of the fundamental theme in the competition of this industry may remain unchanged. The competition based on product development performance, capability and capability building would continue, where mutual organizational learning between the competing firms is the key. Intense international competition will continue, and so will the evolution of their product development capabilities. On the academic side, further empirical studies will be needed in the future for better understanding and analysis on this dynamic process of the competition through new product development.

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