Title

The Chemistry of Dependence: Cars, Chemical and Technological Change in the US, Germany and Japan

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Chemistry of Dependence:
The Changing Commitment of Car and Chemical Companies

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I. Introduction: Firms, Institutions and Dependency Relations

Several decades ago, a car could be put together with a few handtools. Today, its assembly requires not only the coordination of advanced machinery but also the input from a wide range of industries, among which the electronic and chemical industries have become two of the most crucial suppliers.1 While the electronics industry has been a substantial supplier for several decades, the chemical industry more recently has evolved from a supplier of aesthetic interior parts to a supplier that might substantially affect the pace and direction of automobile development. Chemical inputs, for example, allow the simplification of both cars and production processes and more frequent changes in the range of models supplied.2 The way in which the relationship between the chemical and the car industry can be shaped in the immediate future thus will become an increasingly critical factor of success in international competition.

This paper appraises the structural and technological changes taking place in the relationship between the car industry and chemicals in the United States, Japan and Germany. What shaped the relations of these two industries, and to what extent can we expect the particular ôchemistryö of this relationship to influence the success or failure of the car industry in the three countries? In an attempt to answer these questions, we will look at the nature of technological change in the car industry, the growing impact of chemicals and the possible consequences, in particular, for the relationship between car assemblers and chemical firms in the three countries. The extent to which a smooth integration of the chemical firms into the carmaking process can be achieved, we argue, depends on the type of underlying dependency pattern between supplier and customer industries.

The analytical approach that we have chosen departs from the notion that technological change and industrial restructuring processes are part and parcel of institutional arrangements that can vary from country to country.3 Instead, institutions originate in a particular setting in which, based upon their relative strength vis-à-vis each other, firms, governments and related societal actors agree upon ôworking arrangementsö that construct the existing institutional framework. As such, institutional arrangements are not static phenomena, as most authors stressing the cultural context of industrial and technological change are inclined to argue.4

This paper, therefore, suggests that the position of actors is best operationalized in terms of relative dependencies.5 Present institutional arrangements shaped by these bargaining processes, while bearing the mark of past dependency relations, thus shape the way in which industrial systems can adjust to technological change.

In a path-breaking study stressing the importance of technological change, Nelson and Winter in the early 1980s dubbed the setting of their technological trajectories the ôselection environment.ö6 Ten years later the concept of selection environment has been rephrased as the ônational system of innovation.ö7 In order to provide a systematic analysis for the institutional actors within such a national context, we propose an industry-level analysis. At the industry level, relative dependencies of (groups of) actors can be witnessed in much more detail, while industrial restructuring processes and technological change can be more easily documented. Moreover, any assessment of the real dynamism of innovation systems should also take into account the origins of the national institutions. More specifically, this requires that we look at the players that helped shape the rules, compliance procedures and operating practices of an industry (i.e., its institutions) in a much less macro-economic manner than most of the national innovation systems analysts have been inclined to do.8

To illustrate our argument for an industry-level of analysis, this paper operationalizes the ôchemistry of dependency relationsö between a number of actors: the car industry, its component suppliers in general and the chemical industry in particular, and governments. This provides a meso-level analysis of institutional arrangements. Consequently, different national institutional arrangements tend to mirror different interfirm relationships. These arrangements play a very important role in the innovation strategies that firms (can) pursue. Specifically, within a given institutional arrangement, a firm faces limits as to how much it can control its suppliers. Similarly, supplier firms face limits as to how involved they can get in the development of the final product beyond being just an uninvolved supplier. The extent to which chemical firms can actually contribute to the technological development of its customer industry, we argue, hinges therefore to a large degree upon the different national institutional arrangement in which the respective dependency relationship with the customer has emerged.

Likewise, within an institutional setting, governments can play a large role, either trying to overcome or to enforce the incentives and constraints imposed by the institutions. For example, by way of changing the regulatory environment, a government can encourage or make necessary close cooperation between customer and supplier industry. Or, the government, itself constrained by the institutions, may be faced with the inability to establish such cooperation without the consent of the strong actor, be it the supplier or the customer.

Substantial technological change has been underway in the automobile industry since the threat of slowed-down growth rates in the aftermath of the oil shocks of the 1970s began to undermine the future of the industry. Since most of the price increases of the oil shocks were transferred to the consumer, the response was reduced car sales. This led the car industry to direct development toward an increased fuel efficiency by increasing power supplied by a given amount of fuel, reducing vehicle weight and improving aerodynamics. Aside from fuel efficiency, issues such as durability and impact strength guided the penetration of plastics during the 1970s. The ability to shape plastics, unknown for steel, allowed for the integration of components during the design process, not only as separate parts tacked onto the car body, as had been the case during the previous decades. Moreover, the ability to mold several car parts into one had led to a simplification of the production process. As a result, assembly and tooling costs could be decreased, while automated production could be increased.9

Not until sometime in the 1980s, however, did this technological change accumulate to become so significant as to threaten the existing dependencies between carmakers and their suppliers. As new materials, such as plastics, not only become substitutes for metal inputs but affect the overall design and production process, technological developments in the car industry are coupled with those in the chemical industry. To the extent that the chemical industry is yet constrained to the back seat of technological advances in the car industry, it will push for the better seat by leaps and bounds. However, particular institutional settings make this more likely to happen in some countries than in others, adding to present restructuring problems and influencing the choice for particular technological trajectories, and (perhaps) hampering the learning interaction taking place. The latter could imply that the business leaders of today find it very difficult to sustain their lead due to a lack of flexibility of the institutions they themselves helped create.

To elaborate the above (institutional) arguments further, we have divided the remainder of this paper into two sections. Section II gives an account of the chemistry of dependency relationships between suppliers and car assemblers that have emerged in the United States, Japan and Germany, using examples of the largest carmakers respectively. Section III considers the nature of the technological changes taking place in the car industry. This section will take into account the implications of these changes for actors. We will look at the strategic material inputs of the car industry and the locus of their development. Based on this sketch of changing relationships, we will attempt to assess the current and prospective positions of chemical producers vis-à-vis their automobile customers in light of each country's institutional and dependency arrangements. A set of questions arise from our theoretical arguments: Which car complex tends to be in the best starting position when it comes to taking advantage of very necessary innovation in chemical-related materials? What role are the national governments likely to assume in shaping the future outlook of their national car-producing industry? What role can we consider to be the most promising in light of the structural and regulatory changes taking place?

II. The Car Industry and the Chemistry of Dependence in Japan, the United States and Germany

Institutions are the result of (past) bargaining relations.10 In particular, institutional arrangements in Japan, the United States and Germany developed in three distinct directions, hinging upon the relative dependency between assemblers and suppliers. This section will illustrate these developments as well as provide a general overview of the chemistry of dependence in the three countries. Finally, we will address the consequences of the resulting institutional arrangements for the different loci of innovation.

II. 1 The American Car System: Direct Control Efforts and Adversarial Institutional Arrangements

In the late 19th and early 20th centuries, all U.S. car makers started as assemblers rather than as manufacturers. Components easily were available from advanced suppliers in adjacent sectors that were technologically more sophisticated and mature, such as the producers of machinery, wagons and carriages, engines and bicycles. In many cases these suppliers entered into car assembly themselves, i.e., Dodge, Studebaker, Oldsmobile.

In the course of less than thirty years, the picture of an industry dominated by small (artisan) firms changed radically as a result of a few firms' strategies to gain control over the rest of the industry and establish particular supply relations. Henry Ford's early decision to strive for extreme levels of vertical integration was especially motivated by unfavorable dependency relationships with his suppliers.11 His strategy for achieving vertical integration was four-fold.

(1) Ford wanted to internalize the profits that important subcontractors -- much to his disdain -- had been able to realize. (2) Ford's dependency on outside suppliers had led to major supply disruptions. These disruptions were further induced by the poor state of the transportation infrastructure. Ford thus aimed to have suppliers locate close to his centralized and integrated factories, which, however, was difficult to achieve in view of the strong and independent suppliers of his time. (3) Ford wanted to eliminate minority stockholders like the Dodge Brothers who, as important suppliers, had challenged his control over the company at an earlier stage. (4) The large experiments with mass production pioneered by Taylor and Ford required special-purpose machinery that was not produced by the machine-tool companies; Ford's engineers had to develop these machines themselves.

The systemic character of the new Ford organization made vertical integration almost self-reinforcing.12 Rapid growth and productivity increases contributed to a level of vertical integration at Ford of almost 100% immediately preceding World War II.

General Motors and Chrysler adopted basically the same strategy, although, at least initially, GM pursued a lower level of vertical integration. In the terminology of Alfred Chandler, who closely monitored the formation of General Motors and ôSloanism,ö13 the increasing scale of production of American car manufacturers also enhanced the scope of activities, i.e., it fostered core firms' inclination to coordinate supplies through direct ownership.

The direct control strategy of the U.S. car makers, aiming at creating formal hierarchies of a large number of fully owned subsidiaries, however, limited the growth possibilities and the level of technological sophistication of other suppliers.14 Only a relatively small number of independent component suppliers could mature under these circumstances. The largest car component suppliers are almost all part of large diversified companies such as Allied Signal, TRW, DuPont, ITT, Rockwell, 3M and United Technologies.15 About 30 large firms account for more than fifty per cent of the non-captive car supplies, but the auto business of these firms accounts for only 10% to 30% of their sales. The remainder of the (limited) outsourcing of the U.S. car manufacturers has been undertaken with a large number of smaller subcontractors on a short-term, market-led basis. Consequently, the profit margins of assemblers and suppliers differ considerably in the United States, contributing to a generally adversarial assembler-supplier relationship.

While propinquity to car plants has therefore been only of secondary importance to these suppliers, many of the largest European and Japanese car suppliers have the bulk of their activities in the car business, and are often located near to the car assemblers.

The strategic orientation towards direct control of the car industry via vertical integration contributed to such adversarial relations with a large number of other societal actors as well. Due to the leading role of the car industry in the American industrial landscape, this mechanism shaped the institutional setting of American society far beyond the car industry itself. Disputes were often only settled by the Federal government. However, as a further illustration of the adversarial relations, this was often achieved with solutions inimical to the control strategy of the car manufacturers themselves.

First, the unwillingness of the car majors to allow labor to organize itself resulted in the creation of a strong sectoral labor union (United Auto Workers, UAW) outside the company boundaries, which ultimately became strong enough to enter into direct negotiations with management. Often, the trade unions could ally with government. General Motors, one of the leading actors behind Roosevelt's New Deal policies, had been one of the first companies to concede to the strength of organized labor. In 1941, after long and bitter fights, Ford was one of the last companies to allow direct representation of the UAW. One of the most important reasons the company allowed UAW representation was that Ford wanted government procurement, for which the Administration had obliged the company to open up to labor. Government procurement policies saved the company from bankruptcy in the early 1940s.

Second, the attempt of the car firms to control their dealer structure resulted in a U.S. Supreme Court prohibition on exclusive dealership in the late 1940s. This led to the rise of multi-franchise dealers and to an increasingly adversarial relationship between assemblers and dealers.16

More generally, the close link between industrial banks and the car industry during the Great Depression of the 1930s led to a number of Antitrust cases and restrictive laws such as the Glass-Steagall Act of 1933, which prohibited American banks from taking a large interest in industrial firms via stocks and bonds. This resulted in a strict distinction of banking identities between commercial and investment banks not followed by any of the other industrialized countries.

Most of these new institutional arrangements had to be mediated by the Federal government, which in turn contributed to its relative independence vis-a-vis the car majors. In the postwar period, thus, U.S. governments have adopted policy stances that do not take the interests of the car firms into consideration. The response of the federal government to public pressures in pollution and safety regulation is a good example. Since the mid-1960s, the U.S. government adopted a large number of mandatory standards, like the 1970s Clean Air Act, that ran directly opposite to the industry's interest (and consequently were fiercely contested and even outrightly hindered by the Big Three). Similarly, as discussed further in Section III.6.1, state standards, such as those of California, have critically shaped both timing and direction of technological developments in chemical-related industries.

Although most of the institutional arrangements settling disputes in the American car complex date back to the 1930s and 1940s, they are operating in almost unscathed condition in the 1990s. Car firms must comply with government-induced regulation and thus the relationship between the two is basically adversarial, as can be witnessed in the efforts of the Californian state government to press the development of electric cars (discussed in Section III).

II. 2 The Japanese Car System

The evolution of the Japanese car industry and its related institutions bears remarkable resemblance to the strategy of Ford and the ôFordistö institutional arrangements, in particular, if we look at the experience of Toyota in the immediate postwar period. However, in the case of the Japanese car industry, the institutional outcome of the bargaining processes is radically different.

In the postwar period Nissan and Toyota tried to copy the Fordist system of mass production, vertical integration and direct control. In 1949, however, facing acute financial difficulties and falling sales, Nissan and Toyota had to dismiss thousands of their workers. Nissan, for instance, fired almost 25% of its total workforce. Although this created serious labor shortages, both Nissan and Toyota kept the number of workers low by requiring more overtime, hiring temporary workers and subcontracting jobs to small firms with lower wages. ôThese measures proved so successful in maintaining earnings that the automakers continued them.ö17

The chemistry of supplier-assembler relations that emerged from this process after almost 30 years of uninterrupted experimentation and continuous institutional fine tuning has often been characterized as a pyramid. The assembler is situated at the apex of this pyramid and adds no more than 15% to 30% of the value of the final car. Directly below the assembler, there is a layer of first-tier suppliers that deliver their components directly to the end producer. The number of first-tier suppliers is limited and diminishing. Below this layer, the second-tier suppliers are situated: these subcontractors are not in direct contact with the end producer but deliver their products to a first-tier supplier that assembles the parts in integrated component systems. As a consequence of this hierarchy, Japanese assemblers often have a high degree of structural control over their subcontractors. Nishigushi calls the typical Japanese supply structure one of ôclustered control.ö18

The dependence of subcontractors can be illustrated by the fact that about 31% of all Japanese subcontractors still work exclusively with one manufacturer, and more than 50% supply no more than two core firms.[19] This number is even more revealing when we consider that a large number of observers have been keen on stressing that the structural control regime instituted by Japanese car assemblers over their supply structure disappeared several years ago.[20]

Indirect control is used as a complement to structural control. It can be exercised by the core firms over the suppliers in various ways: through minority shareholding, via the informal institutions of keiretsu, via quality control mechanism (often supported by regional technology centers),[21] multiple sourcing strategies, open cost accounting, supplier associations, and the like.[22] One relationship in this supply structure deserves further explanation. It has often been suggested by Western observers that the Japanese automobile supply system also involves single sourcing. This is only partly true; multiple sourcing still dominates the bargaining relationship with most first-tier suppliers, contributing to the car producersÆ structural control. The exception, however, is important: single sourcing takes place in strategic components, such as large complicated systems that require massive investments in tools, transaxles and electronic fuel injection systems, and engine computers, but to a lesser extent for simple parts or low-value-added materials.[23] Structural control of the supply structure is further aided by particular bargaining arrangements with company unions, company-loyal local governments (particularly clear in Toyota's hometurf, not accidentally renamed ôToyota Cityö) and closely related industrial banks, which provide relatively easy access to sources of inexpensive capital.

In general, the relationships constituting the institutional setting of the Japanese car industry have been heavily influenced by the core firms themselves. In particular, vertical keiretsu such as Toyota and Nissan (as opposed to firms belonging to horizontal keiretsu such as Mitsubishi Motors and Mazda) have been most effective in forging a stable, but nevertheless flexible, supply infrastructure. Because the core firms exercise structural control over such a large number of firms, the national governments have limited room to maneuver in the formulation and to implement effective policies. Consequently, after long consultations, the renowned ôvisionsö of MITI closely followed the interests in particular of Toyota and Nissan.

Suppliers of strategic inputs thus might be able to attain a certain degree of interdependence or even relative independence vis-a-vis the end producer. Often these suppliers are themselves large electronics firms or multinationals, which supply other clients as well. Consequently, some Japanese car firms have tried to limit their dependence on strategic suppliers outside their own group, for example, by concluding long-term and exclusive procurement relationships with major electronics firms. Toyota has struck long-term procurement deals with large suppliers such as Toshiba, Fujitsu and Matsushita Communication Industry, while Nissan has concluded similar deals with partner Hitachi. Honda has deals with NEC and Oki.24

In order to reduce their dependence on suppliers, including external supplies of core components, in particular in electronics, Honda, Nissan and Toyota have started to develop more in-house expertise. This might reduce their innovative capacity for large technological changes (see below). Mazda and Mitsubishi generally maintain close relationships with suppliers of strategic components in their own keiretsu. While within the keiretsu, single sourcing poses less of a control problem, the suppliers may have to divide their loyalty between different clients within the group to which they all have to be loyal. For a decade, this control problem has been experienced in electronics; it is a more recent phenomenon in chemical inputs. As chemical inputs emerge from low-value-added inputs to more strategic car parts, Japanese chemical firms may have to emerge from a dependent, multi-sourced situation to become a single-sourced supplier that can influence its customer's technological development. Alternatively, the car assemblers may have to dedicate more scarce resources to in-house development and production. Neither prospect may be tempting for the core companies. This shift underway in the Japanese chemical industry will be further discussed in Section III.

II. 3 The German Car System

The European car industry is dominated by the German car industry, making it the most relevant case for an analysis of the chemistry of the European car industry. By the mid-1980s, the value of German car production represented over 48% of the total output of European Union producers; the volume of German producers of car components represented 45% of total European output.[25]

A considerable part of Europe's technological capacity in the car industry is located in Germany, with particular strength lying with a small number of strong suppliers. Component industries in Germany account for twice as many patents as the assemblers, or over two thirds of all German auto patents.[26] Robert Bosch as a supplier of car components needs to be mentioned separately: Bosch accounts for one third of all patents in Germany, which is more than any of the German assemblers. In comparison, Nippondenso, Japan's largest auto supplier and not much smaller than Bosch in terms of overall sales (while being structurally controlled by Toyota), only accounts for 4% of all Japanese auto patents. This indicates that in Germany large component suppliers like Bosch are in an independent position. It also gives us a hint that the limited number of really influential suppliers in Germany are far more difficult to control (even if the car assemblers would desire so) than in the case of the Japanese car industry, with its large number of smaller suppliers (although accounting for a very large share of the patents and of R&D expenditures, see Section II.4).

Many German supply firms diversify into other industries and become even more independent. Aside from electronics, maybe the most extreme example is the German chemical industry, for which auto supplies represent only a small fraction of their market --

at most 30% -- despite the increased importance of chemicals for cars. This creates an ôexit optionö as it is dubbed by Hirschmann: a firm has the possibility to move out of the dependency relationship without fatal repercussions for its continuity.27 In a thorough study of the car supply sector in Germany, Dankbaar gives a number of interesting examples of car suppliers that have made use of this exit option when they found auto makers' demands unacceptable.28

Unlike in the U.S., the relative independent position of many actors in the German car industry has not resulted in anachronistic relations. In the end, assemblers and suppliers in Germany can perhaps best be considered as interdependent actors, not least because of the fact that after the complete annihilation of the industry in World War II all the German actors directed their efforts towards a rapid reconstruction of the industrial base. This process could largely make use of the old ôcorporatistö structures developed (for different goals) under Nazi rule. Michel Albert has called the German version of corporatism ôRhineland capitalismö, a form of capitalism fundamentally different from the prevailing Anglo-Saxon form. In ôRhineland capitalismö, the bargaining and dependency relationships in the car industry vis-a-vis regional governments have acted as role models for many other institutional arrangements in the Federal Republic of Germany. In particular, the role of industrial banks such as Deutsche Bank in acting links between the interests of suppliers and assemblers cannot be underestimated. Deutsche Bank has minority interests in both Daimler-Benz and Robert Bosch for instance. German industrial banks often have more substantial shareholdings in industrial firms than, for example, Japanese industrial banks. This increases their direct control over the industrial firms but at the same time makes them more vulnerable when problems arise with the assemblers.

The extent of this form of German ômeso-corporatismö can be illustrated by the fact that there is no separate organization of auto parts suppliers in Germany, evidence of the closely knit network of assemblers and suppliers.29 The German Automotive Association (Verein Deutscher Automobilhersteller, VDA), for example, organizes both assemblers and suppliers on a national scale in negotiations with the federal government and sectoral trade unions like the IG-Metal.

The equity in bargaining positions has also resulted in a more even distribution of profits. For most of the 1980s, a profit hierarchy as found in the U.S. and all other parts of Europe, did not exist in Germany between assemblers and first- tier suppliers.30

A complimentary explanation for the phenomenon of profit convergence in Germany is the strength of the metal trade union to bargain for national or sectoral deals covering the whole supply structure. The institutional arrangement, in Japan, of company oriented unions in the core firms and no unions in the lower tiered supplier firms, has contributed to large differences in profit margins. An important result of this particular institutional setting has been that the Federal government can often act as a broker between the various interest parties, not least because German trade unions as well as industrial banks hold such a strong bargaining position vis-a-vis industry.

II.4 Conclusion: The Chemistry of Dependence and its Consequences for the Locus of Innovation

Table 1 summarizes the chemistry of dependence as it has developed in the three countries with the most important car sectors. Although the above elaboration was made with special emphasis on the car industry, the institutional picture holds for many industries in these countries.

Table 1: The Chemistry of Dependence in Three Countries

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Source: Boston Consulting Group, 1990, p. 338.

The institutional setting is accompanied by and facilitates a particular distribution of R&D expenditures in the car industry. Because even the largest manufacturers have difficulty keeping up with technological progress in all relevant areas (due to the high R&D costs involved in developing each single technology), the ôlocusö of R&D expenditures and of innovation becomes an increasingly strategic consideration. More than ever, the technological capabilities of the whole car complex (including core firms as well as first-tier suppliers determine the competitiveness of the industry. In R&D projects, the combined efforts of an assembler and its suppliers make up an increasing proportion of R&D.31

Table 2 compares the relative expenditures on R&D in six national car systems, making a distinction between assemblers and a sample of first-tier component manufacturers. The table shows that component manufacturers in Germany and the UK have the highest R&D intensity in the world, higher even than the car assemblers in these national car systems. On average, the European car complexes spend more on R&D than their Japanese competitors (4.0% against 3.5%), partly due to the practice of ôdouble-biddingö. The U.S. car complexes spend less than their European and Japanese contenders -- around three per cent on average.

Table 2: R&D as a Percentage of Sales at Assemblers and Component Manufacturers in Six National Systems, 1988

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Source: Boston Consulting Group, 1990, p. 338.

Outside Germany and the UK, one can witness a hierarchy of R&D expenditures between assemblers and suppliers. In countries such as France and Italy, moreover, a higher percentage of component manufacturers are owned by domestic or, in the case of France, even by foreign assemblers. Such ownership structures reduce these captive suppliers' incentive to spend a high amount on R&D as long as the mother company does so. In Japan, with the exception of the chemical industry, the R&D gap between assemblers and suppliers is the smallest, indicating that innovation is spread over the value chain.

Clark and Fujimoto (1991:140ff) examined this innovation process, looking at the source of design. They concluded that over 70% of the components supplied in Japan have been developed on the basis of ôblack boxö engineering in which the supplier is solely responsible for the developmental work: the parts delivered by the supplier are consequently treated as black boxes by the assembler. Yet the large majority of this is ôdelegated developmentö. This implies that the assembler still has significant control over the components delivered. Only 8% of Japanese deliveries contained supplier proprietary design, which means that Japanese component manufacturers usually do not own the rights of the very components they supply. In other words, ôblack boxö engineering Japanese style requires institutions of structural control.

In Europe, the percentage of ôblack boxö outsourcing is considerably lower (46%), but the share of supplier proprietary design is relatively higher, reflecting European suppliers' more independent position. In the United States, 81% of all R&D at core companies is done in-house, and 19% is outsourced --of which only one-sixth is on the basis of supplier proprietary design. The high level of vertical integration in the United States car complexes therefore implies a tremendous concentration of R&D expenditures at the Big Three and a relatively weak bargaining position for many suppliers.

The above drawn picture of the chemistry of dependence, complemented by the subsequent location of R&D in the supply chain, has fundamentally contributed to the past competitive success of many Japanese ôleanö producers, has facilitated the structural problems of American competitiveness and helps underscore the generally mixed picture that has developed of German (industrial) competitiveness. But will these relative positions be sustained?

An answer to this question requires an assessment of recent technological and
regulatory changes in the car industry. In particular, the role of chemical inputs seems to become vital. To the extent that chemical firms themselves are bound to play an increasingly crucial role in their respective national institutional structures, the nature of their integration into the carmaking process promises to pose some substantial adjustment problems for car manufacturers trying to maintain their technological and organizational independence, if not dominance.

Depending on the existing dependency patterns within the institutional arrangements, the outcomes may vary significantly in each of the three countries. In the next section, in an attempt to answer these questions, we will look more closely at the nature of technological change in the car industry, as well as the effects of development on chemicals upon the car industry.

III. Factors of Change: The Growing Importance of Chemicals and Related Control Problems

The influence of technology on the car industry has always been substantial. In the 1980s this influence increased further, witnessed by the still growing overall level of R&D spending in the car industry.32 However, more than ever, technological change has become a social and political process in which the relative positions of actors are affected, while much of the dynamism is influenced by bargaining relations.

The increasingly political nature of technological change is due to the fact that product and process innovation are increasingly becoming intertwined. Instead of a broadening of the restructuring race (many new products and many new actors), a deepening of the restructuring race can be expected (new, efficiently produced products, selection of actors).

Despite the inclination of some governments to strive for radical product innovations, until the year 2000 product innovations in the car industry are expected to be mostly incremental. Nevertheless, these innovations will have widespread implications for the chemistry of dependence in the car industry:33

(1) Engines will probably become somewhat smaller; the use of other fuels (such as alcohol and hydrogen) could slightly increase; and more weight-saving plastic composites and ceramic reinforcement will be used in car engines.
(2) The use of Continuously Variable Transmission techniques is expected to increase.
(3) The body design of cars will not change dramatically in the near future, although new materials will make smoother and more compact shapes possible.
(4) The chassis of cars will become more sophisticated (for example, with anti-lock braking) with the increased use of new materials.
(5) The car interior will also become more sophisticated -- but many traditional materials may still be used due to accommodate consumer tastes. In electrical generation and distribution systems. The most radical changes are likely to emerge. The costs of electronics as a percentage of production costs is expected to grow to 20% or to 25% by the turn of the century.
(6) Mini vans and big four-wheel drive vehicles were a major product innovation of the 1980s. It seems unlikely that the electrical car will be able to be comparably successful in the coming decade unless governments considerably step-up environmental regulation.

Progress in the car industry will increasingly be tied to progress in the chemical industry as the above goals are pursued. This next section will illustrate the growing impact of chemicals on the car industry. It sketches out the present chemistry between car and chemical firms, and assess the difficulties created by the continuation of anachronistic institutions governing these relationships.

III.1 The Growing Impact of Chemicals on the Car Industry

A threatening stagnation of the world market followed by the oil shocks of the 1970s caused the automobile industry to overcome declining sales by relying on fuel-efficient technologies. Since then, the range of chemical inputs has expanded significantly. Progress in composite and polyethylene-based technologies has allowed aesthetic parts to be incorporated into automobiles, and chemical products to substitute for structural components. The outcome for the car industry of these developments will depend on (a) appropriate progress in the chemical industry, and (b) the effective integration into car production. What will amount to a series of incremental changes in the car industry through increased penetration of plastic inputs represents a significant shift in the relation of chemical producers to their car customers.

Advances in the chemical industry will prove crucial in helping the car industry meet the technological challenges of the future. Already, plastic products have improved their performance range to include recyclability and reparability. As a result, their applications in cars have increased significantly. The chemical producers are able to impact what a car can do and what it can or should look like. As a result, plastic parts perform more than one function, and plastic parts shape whole parts of a car, not just single panels.

We can identify three phases of plastic inputs into cars.

First, in the early 1970s, they were used for structurally insignificant but stylistic interior parts. These plastics included conventional polymers such as styrene, polyolefins, PVC or polyurethanes. The second phase, starting during the late 1970s, included plastics based on more advanced polymers with sophisticated electrical, mechanical and thermal properties -- so-called engineering plastics or composites. These products were applied to car exteriors, including bumpers, some body panels such as the hood or tail-gate, side fascias, air filters and intake manifolds.34

The current area of application -- the third phase -- is to the chassis, which represents a strategic part in the car; design and planning. We are observing the continued penetration of plastics into the body panels but, more importantly, into structural components such as the floor, drive shaft or leaf spring. Currently, the most important ones include polyamides, thermoplastic polyesters, polyacetals, polycarbonates and polyphenylene.

With regard to technological innovation, the chemical industry therefore faces some significant challenges, resulting from a combination of environmental regulation (discussed below), competition among chemical-related materials, such as engineering plastics or composites and competition from other substitutes for steel, such as aluminum, and the demand these challenges impose on technological development within the chemical industry itself. The challenges that the chemical industry must overcome in order to become a more crucial supplier include the following:

(1) Plastic parts lack strength and stiffness, which so far has been compensated for by thickness. This shortcoming has obstructed the mass production of such parts as light-weight plastic engines.35
(2) Plastics are still less able to absorb heavy impact as their elasticity modules is far below that of steel.
(3) For plastics to be used for major body parts, they will

need to be more paintable so that they are completely repairable.36

Innovations in plastic technology for cars reveal a path of incremental improvements, starting with the substitution of plastic for metal and moving to the supply of entire car parts. Significant, if not radical, innovations in the chemical industry may allow a radical breakthrough in this customer industry: a steel car may be replaced with a plastic one.

III.2 The Chemistry of Dependence in Chemical-Car Relations

The chemistry of dependence between the chemical and car industries resembles the relationships analyzed in Section II. In both Germany and the United States, we find that chemical firms have a low dependence on sales to the car industry. To a certain degree, this low dependency is a result of the long-standing tradition that both industries have in their respective nations, enabling them to develop their own technological expertise with which to enter the relationship with each other. In Japan, the chemical industry has developed as a lower-tier supplier to the car industry in a structurally controlled, and therefore highly dependent, position.

DuPontÆs involvement in GM presents an interesting case of the dependency relationship between cars and chemicals. In the early days of GM, DuPont was an influential player, supplying much of GM capital and thereby putting GM in a dependent position. Put simply, GM could be viewed as a capital investment of DuPont. As early as 1917, DuPont owned shares of GM, which grew to about 37% by 1922 and leveled out around 26% until the early 1960s. In 1962, the Department of Justice required the total divestment of GM shares under the anti-trust laws. The divestment was completed by 1965.

Aside from a long-standing tradition of both industries, the low dependency in the U.S. is also the result of cars being a significantly smaller market than the Pentagon for many plastic products. In fact, many products supplied today to car firms are spillovers from products developed for the military markets. Composite materials is the most prevalent example.37 As such the car market for large U.S. chemical firms such as DuPont and Dow, has ranged between 15% and 20% for the relevant products over the last decade.38 This percentage might change for two reasons. First, with the decreased military market, commercial markets can be expected to drive technological development and absorb a larger portion of production. Moreover, considering the increased role of chemical inputs into cars and the recent boom in car sales, the car market may soon become more significant for U.S. chemical firms.

In Germany, a similar picture emerged. The three large chemical firms, BASF, Hoechst and Bayer, all have supplied between 15% and 30% of relevant products to the car industry over the last decade. Since the military has not been a significant force behind technological development in the industry, cars absorb a slightly higher percentage of chemical products than they do in the United States, making the relative position of German chemicals vis-a-vis the German car industry approach one of interdependence.

The chemical industry in Japan is characterized by a high degree of fragmentation (within Mitsubishi alone, there are five chemical firms competing for the same markets), by a fragile financial base, and by an undistinguished scientific knowledge base.39 Long deprived of governmental assistance to build up a strong scientific knowledge base and long stuck among the lowliest of keiretsu members, the chemical firms have failed to even come close to what their U.S. or European pendants have achieved -- technological and financial independence from their customers, which would put them in a strong position vis-a-vis their car customers. As such, the Japanese chemical firms have emerged as suppliers that are highly dependent on their customers for technological development, financial assistance for the acquisition of equipment and for markets.

As plastics increasingly are used in automobile technology, the car firms have taken it upon themselves to develop the required chemical technology. All of the five big car companies have their own chemical R&D labs out of which they specify the plastic products to be produced by the chemical firms. As a result, the chemical firms act as ômixersö of chemicals, not as developers of technologies, in contrast to their Western counterparts. Not much technological skill is involved in stirring together chemicals according to a carmakerÆs specifications. Fierce competition among the chemical makers for the contracts has led to multi-sourcing by the car firms, leading to very high dependency upon car sales.

There is not much difference between vertical and horizontal keiretsu, with chemical producers depending for up to 75% of their sales upon the car markets.40 In contrast to both Germany and the United States, this dependency can be attributed to the late start that the chemical industry received with regard to governmental assistance or even to intra-keiretsu assistance for financing and technological development. In the postwar period, steel firms in Japan have enjoyed much more independence from the car business than have chemical firms. Since the 1950s, the Japanese steel industry has been surrounded by favorable government treatment in targeting and restructuring practices, thereby helping it to differentiate production, enter as well into the production of finished products and retain a higher degree of independence vis-a-vis upstream core assemblers in a large number of industries.41 Policies to assist the steel firms financially, to aid in the access to foreign technology and technological know-how and to allow the formation of cartels made steel firms internationally competitive by the 1960s in crucial steel technologies.42 Much of the strength of steel producers vis-a-vis the government and its customers needs to be attributed to their competitive position in the prewar international economy-- a position that the Japanese chemical industry lacked entirely and is only now struggling to establish.

III.3 The Locus of Development for Chemical Inputs

Turning to the three important inputs mentioned in section III.1, the locus of their development mirrors the overall dependence of cars and chemicals firms in all three nations. Table 3 shows where the strategic parts were developed.

Table 3: Locus of Development of Chemical Inputs into Automobiles

	Dashboard	Bumper	Floor
German car system:			
VW	supplier	supplier	supplier/in-house
MB	supplier	supplier/i-h	supplier/in-house
BMW	supplier	supplier/i-h	supplier/in-house
U.S. car system:			
GM	supplier	supplier	supplier/in-house
Ford	supplier	supplier/i-h	supplier/in-house
Japanese car system:			
Toyota	supplier	in-house	in-house
Honda	in-house	in-house	in-house
Nissan	in-house	in-house	in-house
Mazda	in-house	in-house	in-house
Honda	in-house	in-house	in-house

Source: Plastics Age, various issues; Japan Chemical Week, various issues. Interviews with German, Japanese and U.S. car firms.

First, Table 3 exemplifies the extreme strategic importance attached to the production of floors. All car assemblers still define their platform strategy (and the related floor producing capabilities) as a core capability and prime weapon in international competition, and therefore have sustained their own in-house capability.

Second, while there is no significant discrepancy among and between German and U.S. firms, the difference is clear in the Japanese case. Here, all relevant development to date remain located with the carmaker, equally in vertical and horizontal keiretsu. This illustrates the innovative weakness of the Japanese chemicals suppliers, due to the fact that the institutional arrangements of structural control had put these actors in lower- tiered -- and thus dependent -- positions. Only Toyota has been able to outsource to suppliers the production and development of a relatively low-tech input like the dashboard. None of the other Japanese car producers have been able to do so, while the European and American producers without exception have been able to profit from the ôblack boxö engineering of their more innovative suppliers.

In chemical inputs, therefore, the general picture presented by Clark and Fujimoto attributing important competitive advantages to the possibility of Japanese car manufacturers outsourcing substantial parts of their development to suppliers needs considerable readjustment. The picture as drawn in terms of the chemistry of dependence in the three countries; however, it neatly applies to the car-chemical relationships.

When it comes to production of the plastic parts, there is so far no in-house capability in any of the three countries. Both in Germany and the U.S., plastics are supplied by relatively independent original equipment manufacturers (as discussed earlier). This includes GM and Ford, which still source out many other car parts to affiliated suppliers. In Japan, the production of these parts is sourced out to affiliated suppliers, except in the case of Honda, which has no formal supplier group and instead has the parts supplied by independent manufacturers.

As plastic parts become an increasingly strategic element of the automobile, their loci of development and of production become crucial control issues for automobile producers. How much can be outsourced without losing control over the technology that goes into those strategic plastic car parts? In the end, this is a question of balancing cost issues (which in the past dominated the issue of outsourcing) with control issues (which arise the moment the outsourced part assumes a strategic role in the final product).43

Aside from the technological issues, the car and chemical industry face a number of challenges with regard to the operationalization of integrating more chemicals into the carmaking process. These issues have the potential to significantly alter the existing dependency relationship between car and chemical firms.

Because improvements in the plastic technology for cars in the U.S. and Germany come primarily from the chemical industry, the car assemblers are challenged to develop the technical skills that are required to effectively exploit those new technologies. As of yet, most automobile engineers and designers in those countries are trained in metal-mechanical skills, and still have to acquire the skills necessary to include plastic components in their plans and to develop the appropriate CAD programs.

In Japan, on the other hand, the required technology continues to be developed within the car assemblers themselves, which, at least for the time being, means that the skills required for effective exploitation are available to the carmakers. In the long run, however, this in-house development can represent a considerable obstacle to the further penetration of plastics technology, as carmakers may encounter limits to the amount of expertise they can acquire through in-house development. The issue is how much expertise can be developed in-house that might not be better left to a strong, highly technologically advanced chemical industry.

In sum, whereas the German car complex already developed the appropriate consultative institutions, the American car assemblers have considerably more difficulties in combining their inclination for direct control with the new reality of increased chemical know-how. The old institutional setting of direct control creates additional and considerable adjustment problems for the American car assemblers. Likewise, the old institutional setting of structural control in Japan creates considerable adjustment problems as well. The next two subsections consider these problems as ôcontrol dilemmasö i.e., the problem of continuing anachronistic institutional relations.

III.4 Dilemmas of Direct Control in the United States

In a domestic environment still dominated by adversarial supply relations (a legacy of the past?) and penetrated by Japanese transplants that are emulating their national supply chemistry abroad, there are many barriers for U.S. carmakers to change their supply relations in a direction that would decrease their control but perhaps increase their degree of innovation. In such an environment, direct control often represents a more logical strategy to overcoming antagonism in the short term, but may prove self-defeating in a longer term. We can refer to this as one of many control dilemmas the U.S. car industry is faced with in its relations towards suppliers.

The most fundamental control dilemma for U.S. car companies is how to enhance the role of non-captive suppliers, such as the large chemical firms, in view of (1) the relatively limited base of independent and innovative suppliers in the U.S. national car system, (2) the necessity to prevent dependence on strategic, non-captive suppliers that are not under control, and (3) the fact that these suppliers are often diversified conglomerates that will not allow themselves to become encapsulated in a network of structural control comparable to the Japanese networks. For these reasons, the Big Three may see no alternative but to sustain high levels of vertical integration.

As Richard Lamming notes, no American car maker seems to have the intention to ôlose control over any part of the vehicle technology.ö44 This is an illustration of the continued inability of American institutions to provide an open bargaining environment in which actors can share technological know-how and interact on the basis of longer term relations. In reaction, the big car producers are unlikely to divest from the development and production of key components and materials. Neither have the car producers been willing to give up their privilege to switch from one supplier to another (a privilege frequently used, creating sustained mistrust). Ford, for instance, uses a so-called Sinferior technology escape clauseö that allows it to switch suppliers before the end of the contract if another firm comes up with a technologically superior product.45 The much heralded Ignacio Lopez, procurement director with GM before his highly-publicized transfer to Volkswagen, used many of these techniques to squeeze short-term profits out of suppliers, contributing to long-term distrust already so much ingrained in the American chemistry. Recent research of Susan Helper reveals mixed progress in this respect: with General Motors' strategy of extreme cost cutting leading to lower commitment from the suppliers (the ôLopez effectö), and some -- albeit limited -- success with other American car manufacturers.46 Only the Japanese transplants have created a really different relationship with their suppliers. However, other than calling this a trust or ôvoiceö relationship, as Helper is inclined to argue, we would prefer to dub this type of relationship one of structural control.

The suppliers' fear that the carmakers might appropriate their design and research efforts without sufficient remuneration to develop next generations of technologies is nurtured by these efforts. Strong and independent suppliers get a powerful impetus to offer these car firms only second-hand technology, take their best technology to other car makers or even stop developing components for core firms altogether.47 The fear of being drawn into an unfavorable dependency relationship with carmakers can even lead to a withdrawal from direct supplier relations with particular innovative suppliers, in the same manner that some of the most innovative suppliers started to withdraw from contracts with the Pentagon in the 1980s. General Electric's plastics division, for instance, retreated voluntarily to a second-tier status and started to supply resins to specialized component manufacturers rather than be directly dependent on the car assemblers. On the other hand, in the strategic area of design engineering, the auto makers remain eager to maintain direct contacts with GE.48

III.5 Dilemmas of Structural Control in Japan

Since the mid-1980s, a new development is underway in the dependency relation of cars and chemicals in Japan. With the role of chemicals becoming increasingly strategic for cars, automobile firms are reaching the limit of how much of the appropriate technology can be produced in-house. To prevent falling behind the ongoing integration of chemical technology and its firms in the production process in the U.S. and Europe, it were car firms that joined MITI's efforts to get more heavily involved in establishing a firm scientific knowledge base in chemicals.49 While dashboards and even car bumpers required limited basic knowledge, the development of car floors and other strategic inputs cannot be achieved by shortcutting technological development and importing the necessary technologies. Products such as car floors require a more fundamental understanding of the underlying chemical processes.50

In response to the car firms demands, the chemical industry in the early 1990s became one of the hi-tech industry that the Japanese government declared crucial for international competitiveness. Joint R&D projects, in which both car and chemical firms are involved and which are orchestrated by MITI, followed. With the acknowledged necessity to establish a strong chemical supplier industry, the chemical firms, though still financially strapped and lagging behind in much of the relevant technology, have gained a better position vis-a-vis their customers.

Despite the better-than dismal prospects for the Japanese chemical industry, the above-described strategies in pursuit of international competitiveness impose a series of dilemmas upon the national bargaining institutions. First, the dependence upon other industries and the government to determine the direction, timing and extent of basic research in chemicals poses a particular problem for the chemical firms since most chemical-processing industries take up to 25 years from development to production. Even if there is now a concerted effort to support the chemical industry, the delay gives non-Japanese chemical firms a considerable lead, and it will be very difficult (and very costly) to catch-up.

Second, as chemical inputs become strategic to the car body, Japanese car firms abroad may soon be faced with supply problems, as, so far, no second-tier suppliers have joined the car industry abroad. This will make it difficult to establish a structural control relationship abroad. It also could pose problems for the assemblers when they have to find comparable local suppliers, not many of which can be expected to enter a relationship of dependence as did their Japanese counterparts in Japan.

Finally, the joint efforts of customer industries and MITI to start supporting the chemical industry influence the national bargaining institutions in the car industry in yet another direction. In the 1980s and 1990s, MITI's institutional role has not been without problems. MITI has become the enforcer of the quota, agreed upon with the European Union and the United States as ôvoluntaryö export restraints. A firm like Honda particularly has suffered from the quota allocation of MITI (it is often last in these allocations, due to a lack of domestic bargaining power). The shift in MITIÆs role made its position more disputed and stimulated some of the car assemblers to evade MITI's influence.

Therefore, the dependence of carmakers on the government for assistance in promoting one of their supplier industries, such as chemicals, can be expected to reinforce the bargaining position of MITI (as well as of the chemical firms) towards the car assemblers, and in turn might weaken the influence of the car assemblers on the formulation of government policies, in particular in the strategically vital area of trade policy.

III.6 The Impact of Control Dilemmas on the Adaptability of the Car Industry to Changes in the Regulatory ôEnvironmentö

We can take the above arguments one step further and look at the impact of anachronistic institutional practices on the wider topic of environmental regulation.

The regulatory issues that are linked to the environment are:

(1) Pollution: Over the past years, higher sales' volumes have easily outpaced lower emission rates. The car still constitutes the single largest danger to the environment.

(2) Depletion and the increased cost of non-replaceable resources, in particular oil and some materials: More fuel efficient and smaller cars have been developed, but in the future, overall sales' volumes may also be affected.

(3) Traffic congestion: Governments tend to become less willing to promote car use and to invest in big expansion programs for highways and infrastructure. (Budget shortages also contribute to this trend.) Even the UK government -- which in the second half of the 1980s had embarked on a large highway expansion program while squeezing investments in public transportation -- appears to abandon its policy. At the same time, the car industry's bargaining power is still considerable.

In many countries, past underinvestments in public transportation make an unattractive alternative to car transportation.

In the 1980s, growing consumer awareness and increased traffic casualties led many governments to sharpen car safety regulations and to compel car owners to have their cars checked at fixed intervals by a garage or a dealer. These inspections not only increase the costs of car maintenance; they encourage consumers to buy a new car after a shorter period of time and to buy higher quality cars with less defects.

In Japan, exceptionally strict inspection rules have helped car manufacturers to speed up their product cycles and introduce new models every three or four years. Some European car systems, such as Germany, the UK and Sweden, also maintain strict car inspection regulations and therefore shape technological development in the car industry.51 In markets with strict inspection rules, Japanese and luxury car producers hold a relatively strong position.

Likewise, environmental regulations influence competition among individual car makers. The U.S. -- particularly the government of the state of California -- has decreed strict rules on emission norms and on the use of less polluting, alternative types of fuel. Many Western governments have stated objectives to include recycling costs in consumer prices, forcing assemblers to look downstream for other material inputs. The German government has already drafted legislation to oblige car makers to collect and recycle used cars (fervently opposed by the Japanese car manufacturers that have no production sites in Germany).

Most of the governmental regulations have thus been met with stepped-up R&D efforts and the development of more fuel efficient engines, integrated catalysts, and lighter, recyclable materials.52 These challenges, as indicated above, resulted not only in increased competition among carmakers in the attempt to effectively integrate the new materials and their suppliers in to the production chain, leading car assemblers to embark on several joint projects to develop alternatives for environmentally friendlier inputs. The regulations also led to the stepped-up competition among suppliers to outcompete each other for materials suitable to meet regulatory demands. The research into new inputs is increasingly characterized by competition among suppliers for the substitution of steel and cast iron.

While the share of chemicals is expected to increase continuously, aluminum too has become a viable alternative. Aluminum usage by the car industry is expected to more than double, from 2.4m tons in 1990 to 5.7 tons in 2006, according to the Commodity Research Unit.53 However, the ôgreeningö of the production process itself has received less attention. Volvo seems to be one of the few firms engaged in this field. Based on its cooperation with ICI, for example, Volvo is planning to use water-based paints in a completely new production site.

The defensive reaction of U.S. carmakers to the California ôelectric carö regulation is revealing exception to the generally competition- and innovation-spurring response to environmental regulation. This law, adopted by the California Air Resource Board in 1990, requires that by 1998 2% of all cars sold by the major automakers emit no pollution. Building the car was not the problem. All major U.S. carmakers have achieved that much; and so have their European and Japanese competitors.54 The problem, instead, will be to sell the electric cars: ôWhile Chrysler executives called their mini-van ôstate-of-the-artö for electric vehicles, they declared that the art was miserable.ö55 Carmakers expect that neither the car's performance nor its range nor its cost will meet customers' expectations.

One of the reasons that the electric car regulation has led to such pessimistic response by U.S. carmakers and to the production of a car that is neither efficient nor cost-effective, (again) lies in the continued adversarial relationship between carmakers and their suppliers. Development of chemical inputs for cars, as mentioned earlier, is not done jointly with suppliers, parts are bought from independent manufacturers. Such disjointed development in the absence of government involvement to coordinate cooperation among the two industries might have proven suboptimal to meeting the demands imposed by regulation in a satisfactory manner.

Similarly, the nature of the dependency relation in Japan between cars and chemical firms might also have contributed to a less-than-perfect outcome. Here it could be argued that the lack of expertise within the chemical industry and the limits reached by the in-house research of the car firms might have prevented the car industry from producing a functional electric car.

In Germany, finally, meeting governmental regulation related to the use of new materials seems to be a more amicable, possibly more successful, process. Much as was the case with other suppliers, chemical firms have closely cooperated with car firms, for example, in the production of recyclable cars. Both VW and BMW have come up with such a car. There is a striking reason for this apparently more harmonious relationship with regard to meeting governmental regulation: from the beginning chemical firms and car firms were involved in the drafting of relevant regulation.[56] The coalition of chemical and car firms and government designed a regulation system that requests car firms to take back cars when they are to be wrecked or recycled. This regulation has been especially effective for (a) those car firms that have full recyclability and (b) those car firms that have remanufacturing and wrecking capacities. Not surprisingly, the Japanese car manufacturers were not content with the regulation: they would have to invest enormous additional sums in recycling capacity or bargain with German wreckers. The Japanese car firms consequently reproached the German car complex (including the car firms and the government) to have create non-tariff barriers.[57]

In sum, the penetration of chemicals into the car industry has necessitated that carmakers cooperate with the chemical firms in R&D (which is now being done in Japan) and even in the design of regulation. Where these two arrangements are possible (so far apparently only in Germany), better results can be achieved than in countries where, given the national institutional arrangement, such cooperation is not as easily achieved (as is the case in the U.S. and Japan though for different reasons).

IV Conclusion: The Chemistry of International Competition in Cars

This paper has assessed the institutional arrangements as created in the car industries of the United States, Japan and Germany. It has been argued that the ôchemistry of dependenceö -- constituting the distinct institutional setting in these three countries -- has had a major impact on the past strategies of the car industry. This analysis included the question of how effectively the locus of innovation had been arranged in the three car systems. We have also considered whether this chemistry will have an impact on the future strategies of the national car industries. The latter question was elaborated in two related areas: the changing relationship with chemical companies and the challenge posed by regulatory reform in the three countries.

The continuous efforts of the American car complexes to sustain control over their strategic inputs sustains a relatively adversarial chemistry between assemblers and chemical firms. This implies that the car firms tend to underutilize the knowledge base of the chemical firms, while the chemical firms tend to keep relations with the car firms at arms' length, severely hampering the exchange of information between the two actors. This inaction will become a problem for the American car industry if technological progress moves rapidly and change originates in other countries.

The chemistry of the American car complexes does not accelerate the learning curve for the use of new materials and chemical inputs. If this proves to be a major concern, the government (at the federal or state level) will be the only actor capable of breaking the spell. However, due to the adversarial relations between the players and the lack of a coherent industrial policy in the United States, this seems unlikely, or possible only at a very slow pace.

The (structurally) dependent chemistry of the Japanese chemical industry vis-a-vis the car firms has been instrumental for the development of strong and innovative car assemblers. It is not clear whether this will continue. The lack of technological sophistication on the part of the Japanese chemical firms might prove to be a major obstacle for them when pitted against the innovative strength of the Japanese car complexes. Due to their relatively low status in the supply hierarchy, Japanese chemical firms have also been very slow in following their major customers to other Triad markets, i.e., to Europe and Northern America. Even with the support of the Japanese government, it might take considerable time for the chemical industry to make the required innovations. The same is true concerning the needed changes in the design of the Japanese supply structure: it is not likely that the core producers will find it easy to outsource strategic supplies to lower-tiered firms (which enables them to gain a degree of new independence).

Finally, the analysis gives ample evidence that the German car system seems to have the most appropriate institutional setting, i.e., it has an appropriate chemistry of dependency relations, which takes optimal advantage of technological and regulatory changes underway. To many car industry observers this might come as a surprise, because the German car industry is often portrayed as inflexible, not very innovative and unproductive (see Section II.4), certainly if compared to the Japanese industry. Both the chemical producers and the car assemblers in Germany are strong and independent enough to make the necessary investments in relevant materials technologies themselves. The role of the German government can remain one of a broker between the two actors, balancing between stimuli and regulation (the carrot and the stick). As a consequence, in many innovative projects we see a large number of German actors collaborating, either in creating a common regulatory setting -- for example, towards recycling strategies -- in developing pragmatic solutions to the quest for new (electric) car models and in developing new supply relations as regards the strategically important input of chemicals in general and plastics in specific. This is bound to create sufficient ôcritical massö to make the German car complex (including assemblers, suppliers, trade unions, financiers and governments) a forceful and sufficiently innovative competitor. This will be even more true if the chemistry of international competition continues to go beyond mere market interaction, which we expect.

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46 Susan Helper, Three Steps Forward, Two Steps Back in Automotive Supplier Relations, 1994 manuscript, forthcoming in technovation.

47 For examples of this mechanism in the case of General Motors, see Business Week, October 19, 1992.

48 Information gathered in an interview with Dan Lura, Industrial Technology Institute, January 1991.

49 For example, witness the cooperation among car firms, MITI and chemical-related firms in such ongoing projects as the Research and Development Program on Basic Technologies for Future Industries (JISEDAI Program) which was enacted by MITI in the early 1990s. MITI, Research and Development Program on Basic Technologies for Future Industries (JISEDAI Program) (Tokyo: MITI, various issues).

50 Amendola, p. 493.

51 Boston Consulting Group, ôThe EC Automotive Components Sector,ö p. 79.

52 The New Materials Society, p. 6.24.

53 Financial Times, February 18, 1993.

54 In fact, the Japanese firms have been engaged in large-scale electric car development projects since 1971. See, Masami Tanaka, ôJapanese-style evaluation systems for R&D projects: The MITI experience,ö Research Policy, Vol. 18 (1989), p. 363.

55 New York Times, p. C1 and C2. May 6, 1994.

56 Keck, ôThe German System of National Institutions.ö

57 For observations on the European car industry environmental strategy, see, for instance, Peter Groenewegen, ôDiverging Environmental Strategies of International Car Producersö, (Conference, Sustainable Mobility, University of

Amsterdam, 1993); and Frances Cairncross, ôHow Europe's Companies Reposition to Recycleö, (Harvard Business Review, March-April, 1992).

We have to keep in mind that two big American car majors (Ford and Opel/GM) are also represented in the German national system of innovation, thus giving them the option to profit from the particular ôchemistryö of the German institutional setting. For the sake of argument we have left them out of the analysis, until now. In the past, the American firms have been not very capable in transferring the knowledge acquired in Europe to other parts of their business, for example, in the United States. This is understandable, since the technological trajectories chosen in the German institutional context tend to be different from those emanating from the US chemistry, thus contributing to transfer problems.

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