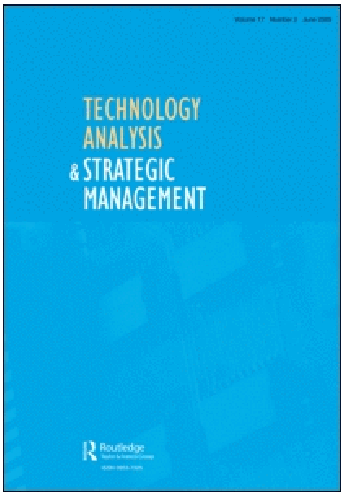

Technology Analysis & Strategic Management
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713447357

The "similarity" and "heterogeneity" theses in studying innovation: evidence from the end-of-life vehicle case

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The 'Similarity' and 'Heterogeneity' Theses in Studying Innovation: Evidence from the End-of-Life Vehicle Case

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ABSTRACT *The paper seeks to understand how eight companies in the European car industry responded to changing business conditions under the threat of regulation on the waste problem of end-of-life vehicles. It was observed that these companies pursued diverging innovation tracks in dealing with the regulatory pressure, although competing in the same markets and subject to similar regulatory pressure. The case is interesting to consider in the light of recent discussions of differences in styles of innovation. The question then is whether any sort of style of innovation may be distinguished in the diverging innovation tracks. The objective of the paper is to add to these discussions by considering the results of this case study in the light of 'similarity' and heterogeneity hypotheses that may be advanced around 'styles' of innovation.*

Introduction: Two Contrasting Theses

The innovation process is understood as a knowledge-based search for new products, processes, organizational routines and organizational structure. Technology development is an important means for companies to innovate, but innovation cannot be solely understood as technological innovation. Innovation is an important element for companies to increase their chances of long-term survival in a highly competitive business context. It may also be an important factor for companies to be able to respond to stakeholder pressure, for example, in relation to environmental issues. However, the very nature of innovation is still not fully understood, despite a vast body of literature. Since the first attempts to open up the 'black box' of innovation, it may be argued that at least two different streams of analysis have developed.

In one stream, the innovation process is seen as dependent on various contingencies such as market size, size of the firm and characteristics of the technology itself. While encompassing various bodies of literature, the central thesis emphasizes the 'similarity' of innovation processes among firms that operate under similar conditions. 'Globalization' is the strongest example of the similarity thesis. If the markets of an industry converge world-wide, if international trade fully liberalizes and if this industry is unrestricted by natural resource inputs, then it would be likely that a global style of doing business emerges. Examples of industries where the globalization thesis has been proposed include the agrochemical and pharmaceutical industries, the microelectronics and information-technology industries, as well as (parts of) international finance. The automotive industry

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0953-7325/98/040529-15

is another example for which the globalization thesis has been advanced. According to the International Motor Vehicle Program (IMVP), there is one best way of designing, assembling and selling motor vehicles, which is described by 'lean production'.[1] Others contest their findings, and argue that it is an empirical question in which several factors influence what style emerges.[2]

Weaker examples of the similarity thesis posit that distinctive 'styles' of innovation may be identified at different levels of analysis, for example within specific geographical, industrial or market contexts. National systems of innovation,[3] industry characteristics,[4] and strategic groups[5] are examples of theories that match the similarity thesis. For example, Patel and Pavitt[6] find that a firm's industry influences its rate and direction of technological accumulation. Patel and Pavitt[7] find that 'uneven and divergent patterns of technological accumulation persist in OECD countries'. Porter[8] argues that a firm's innovative capability and competitive success in international markets may be enhanced by characteristics of its home country. The common thread in these and other studies is that the rate and direction of a firm's innovation strategy is characterized by one (or a limited number) of variables, firms operating in a similar situation develop similar innovation strategies.

In the other stream, innovation processes are seen as socially constructed, following a unique historical path or trajectory in which not only technological or other problems, but also the visions, objectives and expectations of innovators and other social actors, play a role. Thus, the contrasting thesis stresses the 'heterogeneity', in terms of strategy, structure and performance, among firms that operate within the same contexts. Firms are unique because of several reasons. First, there is the possibility of 'strategic choice' in important contingencies such as (business) environment, technology and firm size.[9] Second, there is scarcity of the critical resources whose adoption and exploitation may bring the firm long-term competitive advantage.[10] Thirdly, most resources may be used to provide a variety of different services.[11] Finally, ordinary people, employees and managers may have different preferences, previous experiences and cognitive styles, which make them assess and solve differently strategic issues. Heterogeneity has been pointed out as a phenomenon that reflects the need for companies to distinguish themselves from their competitors in order to realize sustained competitive advantage and long-term survival.[12] Technological innovation at the resource level is seen as an important source of heterogeneity. Firms develop new activities as they renew their resource base. Rather than the static representations of resources by Penrose and the resource-based view theorists (among others Barney and Wernerfelt), a more 'dynamic' frame of knowledge and capability building is appropriate to understand and analyze technological innovation at the resource level.[13] If different 'styles' of innovation may be identified, then they would relate to patterns in the exploitation and exploration of the firm's resources.

The paper seeks to understand how eight companies in the European automotive industry responded to regulatory pressure. In the late 1980s, public authorities at the national and EU levels questioned the environmental consequences of the amounts of waste that remain after the processing of end-of-life vehicles. During the 1990–1995 period, car manufacturers developed 'recycling strategies', i.e. coherent sets of actions to solve the problem of automotive waste by increasing the recycling rate of end-of-life vehicles.

If the similarity thesis holds, then commonalities within the empirical set of innovative response strategies can be related to the presence of contingency variables. However, if the heterogeneity thesis holds, and if Penrose's view of the firm as a unique bundle of related, productive resources is correct,[14] then the firm may only solve the issue by changing its activities or products, or developing new activities or products, such that the environmental consequences are reduced to acceptable levels. This would require the firm to pursue innovation at the resource level, and to change its activities by integrating such innovations in their organizational routines. Most likely, this would result in a differentiation of responses.

The End-of-Life Vehicle Recycling Issue

The environmental issue considered is the need for car manufacturers to reduce the amount of waste from processing of end-of-life vehicles. Cars are among the best-recycled consumer products; about 75% of the vehicle weight (essentially metals) are recovered for recycling. However, 25% remains as waste. Today's end-of-life vehicles were designed about 15 years ago. Since, the relative share of metals in their material composition has decreased, hence the amount of end-of-life vehicle waste is expected to increase. Plastic materials have increasingly substituted for metals, and numerous new parts that compose of composite materials have been added to the vehicle in order to offer novel functions to the customer.

In the mid-1980s, public authorities in various European countries became concerned about the increasing amount of end-of-life vehicle waste and started to develop policy initiatives aimed at stimulating car manufacturers to reduce this waste stream through source reduction and increased levels of recycling. For example, the German Environmental Ministry issued a draft regulation in August 1990, in which the Ministry proposed that car manufacturers take back free of charge end-of-life vehicles from the last owner; that they establish a dense nation-wide network of collection sites for end-of-life vehicles; that they re-use parts and materials when economically and technically viable; that they disassemble end-of-life vehicles in order to realize precisely-defined recycling targets; and that they include waste minimization objectives and the environmentally compatible treatment of end-of-life vehicles as objectives in the development and production of new models. Car manufacturers were allowed to charge a 'third party' on their behalf with the responsibility to take back and recycle end-of-life vehicles. Other national authorities in the European Union (EU) as well as the European Commission followed the German lead, but extensive negotiations between the automotive industry and the various regulators influenced the choice of a mode of regulation as well as its contents.[15]

Car manufacturers responded to the threat of regulation by setting up recycling schemes, some of them in cooperation with shredder, car dismantling or material recycling firms. Politically, they joined forces in national and international lobbies in order to prevent the authorities from implementing their policy objectives through direct regulation. While accepting the need for solving the end-of-life vehicle waste issue, the automotive industry argued it needed full discretion in developing the most effective and efficient solutions. Technologically, car manufacturers explored three different search trajectories: (1) selective disassembly and recycling of parts and materials, (2) improved treatment and separation of shredder waste, and (3) metallurgical recycling. Different response strategies are thus observed, different search trajectories were adopted and different modes of co-operation were established. With hindsight, three distinctive stages can be discerned in the automotive industries efforts to develop recycling strategies (Table 1).

Although end-of-life vehicle waste became an issue only in the late 1980s, the automotive industry had already concluded from various studies conducted in the 1970s–1980s period that changing material composition of vehicles since the mid-1960s

Table 1. Four stages in developing recycling strategies

	Time period	Most important actors	Leading actors
Stage 0	1970s–1980s	Problem definition and identification of potential solutions	Car manufacturers, individually and via industry organizations
	late 1980s	Research on plastics recyclability	Car manufacturers and plastics producers
Stage 1	1990–1991	Start of dismantling pilots and collective political lobby	Car manufacturers alone, or with car dismantling and shredder companies
Stage 2	1991–1992	Build-up of recycling networks via bilateral agreements with car dismantling companies	BMW, Ford, Opel
Stage 3	1991–1995	Build-up of recycling networks via framework agreements with shredder companies who act as 'third parties'	Volkswagen B Preussag Mercedes-Benz B Preussag, Renault B Compagnie française des ferailles (CFF), Peugeot B CFF, FIAT B Falck

might compromise end-of-life vehicle recycling practices in the long run and that vehicle disassembly and subsequent materials recycling might contribute to solving the potential end-of-life vehicle waste problem. Additional studies were commissioned to propose and evaluate potential solutions, including chemical recycling of plastics, vehicle disassembly and material recycling, and incineration of shredder waste. In the late 1980s, car manufacturers in Germany and France joined plastic producers in large-scale R & D projects on plastics recyclability. For car manufacturers, these R & D projects were related to the issue of automotive waste. Knowledge of the recyclability of specific materials (physical and chemical properties, costs and benefits) is essential given the problem definition and potential solutions. For plastic producers they were parts of larger R & D programmes on plastic recycling, since the issue of plastic waste threatened their business in other markets as well, notably in packaging.

It was not until the German Environmental Ministry made public its policy objectives that the automotive waste issue became a problem to be solved. A two-fold industry response marked the beginning of the first stage. (1) The automotive industry started a lobby through its industry organizations in order to prevent government regulation. The most important among these were the End-of-Life Vehicle Recycling Project of the German car industry (PRAVDA) and the lobby at the European level by the European Association of Car Manufacturers (ACEA). In consultation with other industry organizations, the industry developed alternative policy plans. (2) Individual car manufacturers started so-called 'vehicle dismantling pilots' in 1990–1991. These pilots served multiple objectives:

- assessing the cost and potential benefits of vehicle disassembly;
- developing cost-efficient disassembly routines;
- developing and testing concepts for larger scale end-of-life vehicle recycling;
- developing knowledge of design for disassembly and design for recycling;
- increasing the efficiency of current vehicle designs and assembly procedures;
- continuing research into material recyclability; and,
- creating markets for recovered automotive materials.

To a certain extent there was coordination of dismantling activities at the industry level through PRAVDA and ACEA. Although car manufacturers reported largely similar objectives for their respective dismantling pilots, the greater share of the activities were firm-specific. Several car manufacturers cooperated with companies outside the automobile industry, e.g. Volkswagen and Peugeot–Citroen with shredder companies and Mercedes-Benz with a steel-works. BMW, FIAT, Ford Europe, Opel and Renault did not cooperate with other companies in their dismantling pilots. One of the most important conclusions drawn from this first stage was that if vehicle disassembly and large-scale recycling of automotive parts and materials were to provide a solution for the automotive waste problem, this would only be viable in a network of decentralized end-of-life vehicle recycling centres. In addition, car manufacturers developed model-specific disassembly manuals and design guidelines on how to improve vehicle recyclability, as well as dedicated tools and equipment for draining the end-of-life vehicle and for the removal of specific parts and components. The first stage was characterized by the acquisition of relevant knowledge and the development of organizational capabilities.

During the second and third stages, car manufacturers started to implement their recycling strategies, building on the results from the previous stage. However, they did so in two groups following two different models. BMW, Ford Europe and Opel are in the first group. FIAT, Mercedes-Benz, Peugeot–Citroën, Renault and Volkswagen are in the second group. For strategic reasons, BMW also joined the second group at a later stage.

Car manufacturers in the first group started to implement end-of-life vehicle recycling in the 1991–1992 period. They did so by engaging in bilateral agreements with selected car dismantlers. Initially, these cooperations worked on a small scale and ran parallel to the dismantling pilots. They served to test under full market conditions the end-of-life vehicle recycling concepts as developed in the dismantling pilots. Results were apparently positive, since by 1995, BMW, Ford Europe and Opel had associated with several dozens of car dismantlers as 'recycling partners' in Germany (and in the case of BMW also in other countries) to implement the option of selective disassembly and recycling of parts and materials. The car dismantling partners take care of collecting the end-of-life vehicle and of administrative procedures for deregistration, and they remove hazardous substances from the vehicle. They are not being paid for these activities by the car manufacturer, the argument being that car dismantlers can increase their local market shares because the manufacturers' commercial network is obliged to deliver end-of-life vehicle at their sites. Consequently, disassembly activities for material recycling remain limited. For example, BMW requires its recycling partners to disassemble a limited number of plastic parts and to deliver these without cost and in separate batches to its plastic parts factory. Still, these cooperations are important for another reason. The car manufacturer actively assists the car dismantler in modernising its procedures by providing expert advice, insists on respecting environmental regulations, and introduces new tools and equipment.

In the third stage, a number of shredder companies and metal refinery firms entered the scene. They saw business opportunities in end-of-life vehicle recycling. Such companies had developed their own end-of-life vehicle recycling concepts and proposed to act as 'third parties' to take commercial responsibility for organising end-of-life vehicle recycling. They started to implement the technological option of improved treatment of shredder waste. For example, the largest French shredder company, Compagnie française des ferailles (CFF), concluded framework agreements with both Renault and Peugeot–Citroën for organizing end-of-life vehicle recycling at an industrial scale, using its process for valorizing shredder waste in cement ovens. Since 1992, CFF has opened a number of end-of-life vehicle recycling sites in France. At these sites, CFF associates with local car dismantlers (via their industry organization) for taking care of vehicle drainage. In principle, disassembly of parts for materials recycling could take place at

		Stage 1: Developing knowledge and capabilities	
		Dismantling pilot without a partner	*Dismantling pilot with a partner*
Stages 2–3: Implementation of recycling strategy	*Selective disassembly through a dedicated network*	BMW, Ford Europe, Opel	—
	Improved treatment of shredder waste through a 'third party'	FIAT, Renault	Mercedes-Benz, Peugeot–Citroën, Volkswagen

Figure 1. 'Styles' in developing and implementing a recycling strategy by European car manufacturers.

CFF's sites, but lack of outlets for recovered materials is the reason why this happens on a very small scale. In November 1992, FIAT concluded a framework agreement with Falck (a large Italian shredder company), several material recycling firms, and the Italian association of car dismantlers. Since 1994, the German companies Preussag, Thyssen-Sonnenberg and Klöckner have proposed comparable framework agreements to the German car manufacturers to which Volkswagen and Mercedes-Benz responded. Mercedes Benz, the only company having explored the option of metallurgical recycling, has not (yet) succeeded in commercializing this concept. BMW also signed such a contract as a strategic move to prevent monopoly power, rather than abandoning the previous build-up of a dedicated network of car dismantlers.

Figure 1 summarises the differences among European car manufacturers in the mode of cooperation during the knowledge and capabilities building stage (stage 1) and choice of technology in the implementation of recycling strategies (stages 2 and 3). The discussion of the implementation of recycling solutions indicates that European car manufacturers are not eager to take a major control over vehicle dismantling and recycling technologies. Rather, FIAT, Peugeot–Citroën, Renault and Volkswagen have engaged shredder companies to act as a 'third party' in developing large-scale end-of-life vehicle recycling activities. Mercedes-Benz has done likewise, as the company was unable to license its metallurgical recycling technology for upscaling and commercialization. BMW, Ford Europe and Opel have developed dedicated networks of car dismantling firms over whose dismantling activities they have close control. It provides them with the opportunity of buying recovered material cheaply.

Discussion I: The End-of-Life Vehicle Case and Similarity Hypotheses

How may such differences be accounted for? In this section, I forward several hypotheses that match the similarity thesis. Table 2 provides the background data for several of the hypotheses. I make extensive use of Whiston (1995).[16] Whiston is one of the very few researchers who advanced hypotheses of why car manufacturers develop diverging recycling strategies, without, however, testing them explicitly. His hypotheses come close to the various similarity hypotheses of innovation.

First, industry characteristics are considered. In Pavitt's taxonomy, the automotive industry is a 'production intensive' industry, dominated by economies of scale and a strong tendency to cost reduction.[17] From this perspective it may well be understood why car manufacturers have used the automotive waste issue to improve their vehicle designs through the exploration of design for dismantling—or 'design for recyclability'. To the

Table 2. Summarizing the similarity argumentation

	Production volume (1)	Market share Europe (2)	Level of vertical integration (3)	Market strategy	Country of origin
Volkswagen	d	c	c	All segments	Germany
Opel	c	c	b	All segments	Germany
Ford Europe	b	b	b	All segments	Germany/UK
Renault	c	b	a	All segments	France
Peugeot–Citroën	c	c	a	All segments	France
FIAT	b	c	c	All segments	Italy
Mercedes-Benz	a	a	c	Top segment	Germany
BMW	a	a	N/A	Top segment	Germany

Notes: (1) a = <600 000; b = <1 500 000; c = 1 600 000–2 000 000; d = >2 000 000 data for production in Europe for 1995 provided by CCFA; (2) a = <6%; b = 6–12%; c = >12% (data for 1990 provided by CCFA); (3) a = 20–25%, b = 30–35%, c = 45–50%, expressed in percentage of value added (data for the mid-1980s, Chanaron, Ref. 19).

extent that reconsidering vehicle design through a new lens results in cost reduction, design innovations have been adopted. This perspective also sheds light on the reluctance of car manufacturers to engage in take-back and recycling activities, as they have traditionally not been in this business and expected small or negative returns of these activities. Take-back and recycling activities would increase the complexity of the business, which is at odds with current trends of outsourcing major parts of the production process, including the design and supply of parts and components. However, the intra-industry diversity in developing recycling strategies is too subtle to be captured within Pavitt's taxonomy.

Characteristics of the intra-industry structure may be advanced as hypotheses matching the similarity thesis. Differences in company size and levels of vertical integration would clearly be variables to consider. The size argument, when measured in units of production volume, can be qualified straightaway. Volkswagen is the leading mass producer in Europe, followed by Opel, Peugeot–Citroën and Renault. BMW and Mercedes-Benz are relatively small-scale specialty producers. Yet, as may be observed from Figure 1, there is no match between size and recycling strategies.

Regarding levels of vertical integration, Whiston advances that competitive gain could be created in the supply of material. Since some car manufacturers retain high levels of control and linkage over material and parts supply, the degree of vertical integration within a particular auto company is an important factor to be considered.[18] This hypothesis is problematic, because it is not sufficiently specified. With respect to vertical integration *per se* it is obvious that there are large differences between individual car manufacturers. By the mid-1980s, Fiat, Mercedes-Benz and Volkswagen had high levels of vertical integration, whereas those for Renault and Peugeot were considerably lower. Opel and Ford of Europe were in between these extremes.[19] However, aggregate levels of vertical integration are not constant over time for individual car manufacturers. Currently, there is a trend to decreasing levels of vertical integration. Because it is changing, it would be hard to use this factor as the independent variable in a study. Moreover, vertical integration is a composite variable. Levels of vertical integration can be decomposed with respect to specific parts and components; design and production of some parts and components is fully integrated, whereas other parts are essentially bought in, including parts design and technical engineering. They may also vary among the various production plants of individual car manufacturers, because of cost differences. Thus, it would not be vertical integration in itself that is a significant variable for diverging recycling strategies, but rather the car manufacturers' motivations for choosing specific levels of vertical integration, most significantly, in vehicle design and engineering. In this case, however, the vertical integration hypothesis reverts to a heterogeneity hypothesis.

Regarding the strategic group hypothesis, Whiston speculates about "the importance and influence of the car manufacturer's market-segment or niche, its market share, and its particular product image or characteristics on developing a specific recycling strategy: "It may well prove to be that the unit-cost of disposal of a single vehicle is fairly insensitive to the *absolute* price of the vehicle. In which case, in relative terms, manufacturers of more expensive luxury vehicles will obtain some comparative advantage. Alternatively, from a large mass-production standpoint, new design principles geared to improved recycling and disassembly procedures may also possess, in terms of economy of scale, some comparative advantage" (emphasis in the original).[20] This hypothesis would require detailed economic analysis, which, according to Whiston, is not feasible for the time being, given the "too early" stage of development [of vehicle take back and recycling] to carry out or even attempt such an analysis".[21] However, this hypothesis may also be qualified. According to this hypothesis, BMW and Mercedes-Benz would be expected to develop closely similar recycling strategies, but this is shown not to be the case. Moreover, the implicit (but incorrect) assumption in this hypothesis is that the car manufacturer itself will be undertaking dismantling and recycling activities. At the level of the car dismantler or end-of-life vehicle recycling plant, the combination of specialization into specific models or marks and economies of scale may well lead to a comparative advantage. However, the focus of dismantling and recycling (e.g. disassembly of reusable parts from total-loss vehicles vs dismantling for material recycling from worn-out vehicles) seems to be a prime choice for specialization for car dismantlers and end-of-life vehicle recycling plants. The semi-automated disassembly lines, as developed by, e.g. Volkswagen, are dedicated to material recovery from worn-out vehicles and flexible for the dismantling of end-of-life vehicles of different makes.

Next, the hypothesis may be advanced that car manufacturers' recycling strategies depend upon the characteristics of national regulatory pressure, and that they are embedded in national industry structures. Indeed, the French and German authorities chose different approaches in initiating end-of-life vehicle recycling policies. The Germans aimed for direct regulation, whereas the French preferred a voluntary agreement.[22] The Italian and English authorities agreed closely similar agreements to the French, whereas the Dutch adopted an approach of their own.[23] This might lead to the conclusion that national regulatory styles were important variables in determining car manufacturers' recycling strategies. However, the German Environmental Ministry was unable to keep to its own, preferred mode of regulation. In February 1996, the German Ministry agreed to the same voluntary agreement as had been devised in France, because of fierce industry opposition to direct regulation. Car manufacturers did not simply comply with regulation, but they tried to influence and shape the regulatory context to their interests, while simultaneously conserving a considerable space for developing such solutions to best serve their interests by collective and organizational learning, and to allow for competitive gain to be pursued. The analysis of the French and German cases (the two countries that host more than one independently-operating car manufacturer) reveals that under the same political circumstances car manufacturers developed diverging recycling strategies. Nevertheless, it should be acknowledged that the 'third party' contracts with recycling and metal refining companies have a very national orientation.

Although the German, French and Italian schemes are oriented toward the same technical goals, i.e. improved treatment of shredder waste, there are subtle national differences in the composition and operation of the various consortia.

Finally, little can be said regarding the 'globalization' and 'triad' hypotheses. The data used were collected in Europe only. The car manufacturers studied are all European companies shown by the facts that their design and development work their production and sales are to a very large extent realized in Europe. In this respect also Opel and Ford should be considered as European companies, operating quite independently from their American parent companies. It was appropriate to limit the case to Europe, as both the North American and Japanese companies lag behind the Europeans.[24] They watched what was happening in Europe and learned from these experiences.

It would appear from the above that neither of the discussed similarity hypotheses is fully capable of capturing the diversity of car manufacturers' recycling strategies. Therefore, I wish to turn to the alternative heterogeneity thesis in order to develop another explanation, one that is based on resource differentiation between the car manufacturing companies.

Discussion II: The End-of-Life Vehicle Case and the Heterogeneity Thesis

Regarding the heterogeneity thesis, Whiston argues that "car manufacturers may differentiate themselves in order to gain competitive advantage in end-of-life vehicle recycling: those companies who at present are undertaking extensive product development, research, [and] new design, in compliance with any forthcoming disposal-legislation ... *are preferentially priming themselves for new market opportunities*" (emphasis in the original).[25] Indeed, all European car manufacturers have developed some sort of recycling strategy, including those car manufacturers (and Japanese importers) not studied in this case. He continues to say that "such a statement clearly depends ... upon the extent to which any such knowledge gained is tacit or of a transferable-knowledge form".[26] Two factors indicate that it is fairly difficult for a car manufacturer to gain a competitive lead in design for recycling. First, innovatory gain in the automotive industry usually lasts for a limited period of time due to a rapid and wide diffusion of knowledge and techniques across car manufacturers. Second, within the context of PRAVDA and ACEA, car manufacturers exchanged information and discussed a range of potential solutions, including design for recycling, thus reinforcing transfer of the relevant knowledge among them. As a consequence, Whiston suggests that "*ultimately* there will be little 'competitive-edge' to be gained", and that currently "it would appear that there is *not* a single pace setter; one manufacturer who is out in front" (emphasis in the original).[27]

Whiston thus rejects this hypothesis, a hypothesis that points towards the heterogeneity thesis. But he may well have been too quick in dismissing this hypothesis. The horizontal collaborative ventures in developing end-of-life vehicle recycling were primarily aimed at standardizing and optimizing dismantling procedures and at advancing knowledge in material recycling. Furthering design-for-recycling knowledge depended on dismantling pilots, but these pilots also provided highly valuable feedback on specific vehicle designs resulting in cost advantages. Thus, car manufacturers did try to develop 'innovatory gain' in compliance with any forthcoming regulation. The question then is why and how car manufacturers developed diverging recycling strategies in a situation of uncertain potential of innovatory gain.

The argumentation is that companies, in order to solve environmental problems, need to change their activities or to develop new activities, i.e. to innovate. Innovation theory holds that three factors stimulate companies to innovate: the growth rate and size

Table 3. Complementarity, technological opportunity and appropriability determine the mode of coordinating the preferred option

	Complementarity	Technological opportunity	Appropriability of profit opportunities	Resulting mode of coordination
(a)	High	High	High	No cooperation—hierarchical control
(b)	High	High	Low	Close co-operation
(c)	High	Low	High	Prepare business plan
(d)	High	Low	Low	Specialized subcontracting
(e)	Low	High	High	No cooperation—diversification
(f)	Low	High	Low	Distant cooperation
(g)	Low	Low	High	Standard subcontracting
(h)	Low	Low	Low	No co-operation—'keep the dog out'

of market demand, technological opportunity and appropriability conditions.[28] These factors have been used in empirical studies of environmental innovation.[29] Given the regulatory pressure on car manufacturers to find a solution to the end-of-life vehicle waste issue, market factors are not considered to be relevant in this specific case. However, if various innovative options were viable for solving environmental problems, it would be expected that firms would prefer to choose that option where technological opportunity is highest and where appropriability conditions are most favourable.

In addition to innovation theory, theory about the internal growth of the firm is relevant too. The Penrosian perspective suggests that firms would prefer to develop new activities by expanding the range of productive services that may be derived from the resources that they already control, rather than developing activities for which they do not yet have the resources.[30] If firms do acquire new resources for new activities, they would prefer those which are complementary to the existing stock of resources and activities, i.e. which enhance their value-adding.[31] If various ways of changing activities are viable, the firm would prefer the most complementary.

Moreover, it may not only be argued that firms prefer to choose those options that are highly complementary and that have high technological opportunity and favourable appropriability conditions, but also that firms prefer to undertake such options themselves, rather than engage in some form of co-operative arrangement or market transaction with other companies. Indeed, several authors have proposed that choices about the mode of control over activities may be derived from such factors as complementarity and appropriability.[32] If it is assumed that each option may be scored on a dichotomous scale of 'high' vs 'low', and if the factors are independent, then a $2 \times 2 \times 2$ matrix may be constructed that describes which mode of coordination would be preferred (Table 3).

In situation (*a*), the option is highly complementary to the firm's core activities; the firm sees opportunities for innovation in relation to its resources; and it believes it can appropriate the profits from implementing this option. In such a situation, the firm should not hesitate to develop this option and to integrate the required resources and activities within the firm's hierarchy, because in doing so the firm enhances its competitive power. Therefore, the firm is likely to pursue a strategy of direct control over the implementation of this option and the required resources are developed in-house. The extensive programmes for increasing energy and materials efficiency, such as 3M's 'pollution-prevention-pays' programme would be an example.

If an option is adequately described by situation (*b*), the firm does not see profit opportunities or cannot readily appropriate any profits from implementing the option, despite high complementarity and high technological opportunity. Close control over developing and implementing the option is required, but the firm is unwilling to fully integrate these activities since they raise costs without much prospect of positive revenues. A strategy of 'close cooperation' would be more apt in this situation. However, the combination of high complementarity and low appropriability creates a risk of moral hazard; the firm may be 'held up' by its contract partner.[33]

When complementarity is high, and when the firm thinks that the opportunity for innovation is low but that it will have no difficulties in appropriating profits from implementing the option, such as in situation (*c*), the firm has to choose between prevailing technological opportunity or appropriability in its assessment. This situation may occur when there is a 'reverse salient',[34] or a 'technological imbalance'.[35] If the firm chooses to explore the few technological options in an attempt to reinforce its core capabilities, it faces uncertain and costly investments in R & D, which are likely to be integrated within the firm's hierarchy. However, if the perceived lack of technological options is considered more important than the appropriability of profits, the firm is likely to forego profit opportunities. The decision between these two options depends on a detailed analysis of costs and benefits. Thus, the firm should develop a business plan for investing in technology development.

In situation (*d*) the option is still highly complementary, but the firm does not believe that there are opportunities for low-cost innovation in developing the option nor to appropriate any profits from implementing this option. Because of high complementarity, close control over problem-solving activities is desirable, but the firm might be reluctant to invest in developing the required capabilities since it sees few chances for successful innovation. A likely strategy in this situation would be to contract another company to develop the required highly specialized technology ('specialized subcontracting'). Such a solution increases the firm's cost level, but the firm may not be able to escape these investments because of the high complementarity. As is the case in situation (*b*), there is a risk of moral hazard. Therefore, before implementing such an option, the firm is likely to try minimizing cost by using its power and influence. Generally speaking, end-of-pipe pollution-abatement technologies fall into this category.

Another situation is (*e*). Any option here is characterized with low levels of complementary to the firm's core activities. However, the firm sees options for technology development that promise to create appropriable rents. The firm can choose to develop the capabilities that are required for undertaking the problem-solving activities, or not. If it does, it diversifies in relatively unrelated activities and the firm is likely to try to transform these activities in such a way as to make them part of the firm's core activities ('diversification').

However, in a situation of low complementarity, it is likely that the firm lacks the required capabilities for developing solutions by diversification. Therefore, diversification is a risky strategy, all the more so when appropriability of profit opportunities is uncertain or low, as in situation (*f*). It is more likely that the firm thinks that other companies can implement the option more efficiently, because the required resources and activities constitute their core. Then, the firm might engage in cooperative agreements with these companies in order to develop dedicated solutions, but because of low complementarity there is less need to exert close control over the cooperative agreement. Such a strategy could be called 'distant cooperation'.

If an option were characterized with low complementarity and low technological opportunity, yet high appropriability, as in situation (*g*), this would resemble the need to buy in standard technology. Because of low complementarity and low technological options, the firm is unlikely to develop such technology itself. However, if other companies have developed it, it is profitable for the firm to adopt it, because of the high appropriability of profits associated with using the technology. In this situation, the firm is likely to follow a strategy of 'standard subcontracting'. The purchasing of standard pollution abatement technology would be an example of an option with such characteristics.

Situation (*h*) is the last possible characterization of an option. In this situation, the option is not complementary and the firm does not see low-cost technological opportunities or appropriable profit opportunities. In such a highly constrained situation, implementing the option might be a threat to the firm's capabilities, if reallocation of scarce resources to problem solving implies a weakening of existing capabilities. Moreover, the firm is only interested in cooperation with other firms if it can develop low-cost solutions for the firm. Therefore, denying the problem, or trying to influence the political process in order to redefine the problem or potential solutions, are more likely strategies than engaging in developing and implementing the resources and activities for this option. This strategy is one of 'keeping the dog out'.

In order to explain the divergence in recycling strategies of European car manufacturers, I proceeded as follows in testing the relationships between complementarity, technological opportunity and appropriability. I thoroughly analyzed the three options that emerged from the problem definition (selective disassembly of parts and materials, improved processing of shredder waste and metallurgical recycling) on the dimensions of complementarity, technological opportunity and appropriability. Table 4 summarizes the results of this analysis. Next I hypothesized for each option that the corresponding organizational arrangement would be chosen for implementation, assuming first that my analysis of the options was correct and, secondly, that car manufacturers proceeded in the same way. Finally, I compared which were the options of choice and which organizational arrangements were adopted in developing and implementing these options. It appeared from this comparison that :he hypothesized relationships are confirmed by the empirical data (collected through extensive interviewing and document analysis). Thus, BMW, Ford Europe and Opel, pursuing the option of selective disassembly of parts and materials for recycling, adopted a strategy of close co-operation through a dedicated network of car dismantlers when it came to the implementation of this option, because profits from such activities would be low and hard to appropriate. The other car manufacturers implemented their preferred option of improving the processing of shredder waste through a strategy of distant cooperation by concluding framework agreements with shredder and metal refining firms as a 'third party'. They did so because the level of complementarity and appropriability of profits was considered to be low', despite a significant technological opportunity in improving the efficiency of the shredding process. Moreover, to the extent that car manufacturers identified cost-efficient solutions to improve their vehicle designs and assembly procedures during the first stage of dismantling pilots, they kept those solutions under their own close control.

Conclusion

Based on the similarity and heterogeneity hypotheses, different explanations for the variety of innovative responses in the case study are examined. The paper argues that neither national, industry-specific, nor market-specific styles of innovation provide satisfactory explanations for the observed variety of innovation processes in response to stakeholder pressure. The paper aims at making three theoretical points:

Table 4. Assessment of the end-of-life vehicle recycling options along the complementarity, technological opportunity and appropriability dimensions

	Complementarity	Technological opportunity	Appropriability
Selective disassembly and recycling of parts and materials	High	High	Low
Improved processing of shredder waste	Low	High	Low
Metallurgical recycling	Low	High	Low

(1) Depending on the level of detail in the analysis, different styles of innovation might in some cases be distinguished. I propose, however, that sources of variety stem from managerial discretion in directing and co-ordinating the innovation process. It is proposed that the choice of a specific solution and mode of coordination by individual firms depend on the relation between the resources needed for this solution and the core competencies of this firm. The relation is described in terms of complementarity of resources and activities, perceived technological opportunity, and appropriability conditions.

(2) To the extent that innovation is about the acquisition, development or recombination of resources (including tacit, intangible resources such as knowledge, capabilities and experience) in order the undertake new activities, I propose that 'complementarity' is another innovation stimulating factor in addition to growth and size of the market, technological opportunity and appropriability.

(3) If firms may choose among a variety of organizational arrangements in developing and marketing innovations, including internal integration, various modes of inter-firm cooperation and outsourcing, I propose that firms' perception's of technological opportunities to innovate are an additional factor to complementarity and appropriability in the mode of governance choice.

Acknowledgements

An earlier version of this paper was presented at the fourth ASEAT International conference held in Manchester, 2–4 September 1997. I would like to thank Ken Green, University of Manchester School of Management and Jacqueline Senker, University of Sussex Science and Policy Research Unit, for their stimulating remarks and suggestions. The end-of-life vehicle case study was financially supported by the EC DGXII Monitor/SAST and HuCaMo programmes.

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