



NORTH-HOLLAND

Make–Buy Decisions in the Auto Industry: New Perspectives on the Role of the Supplier as an Innovator

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ABSTRACT

Combining recent theoretical results related to the ownership structure of the firm with the notion of modular design, this paper provides a new framework to analyze the decision of the automakers of whether to develop a new component in-house or to subcontract it to a supplier. Older frameworks associated with transaction costs or principal–agent theories have often been associated with contradictory empirical evidence on make–buy development decisions. Our perspective follows some recent insights proposed by the property rights theory of the firm, whereby a decision to pass the development of the innovation from the assemblers to the suppliers exists when the supplier product shifts from being complementary to being independent of the assembler product. The hypothesis we explore is that modularization of the automobile is a strong enabler of product independence, being the key driver of increasing supplier responsibility. Our analysis is based on detailed case studies of two important innovations that were introduced in the automotive over the past decades: the Antilock Brake System (ABS) and the airbag. The paper evaluates the role of the suppliers and the assemblers in the introduction and development of the innovation, and explains how we can understand this role in light of the proposed framework. © 2001 Elsevier Science Inc.

Introduction

This article is mainly concerned with the economic aspects of innovation. In particular, we wish to understand the economic incentives and constraints that determine the make–buy decision of the automotive assemblers. Several important changes have been happening in the automotive industry during the past decade. The most prominent one has been the rise of the supplier industry. From small players that manufactured individual parts, suppliers have grown to be partners of the assemblers, with design, testing, and manufacturing responsibilities, and an increasing global presence. An A. T. Kearney/University of Michigan study suggested that the transfer of direct task responsibilities began in 1985, and will continue through 2005, with as much as 80% of the value added of the car being bought from the suppliers rather than generated by the assembler.

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The question we wish to answer is why have we observed this trend towards increasing subcontracting in the industry, and what are its key enablers? Our hypothesis is that increasing competition at the level of the assemblers, and greater complexity of the car components, are driving this trend. Moreover, we sustain that modularization of the automobile is the key enabler for increasing supplier responsibility. These relationships between modularity, product complexity, and supplier responsibility have already been discussed in the general press and specialized journals (see, e.g., [1]). Nevertheless, these analyses have not yet proposed a theory that links causes and effects. Our perception is that recent advances in economic theory, which propose alternative ways of understanding and analyzing the nature of the firm, provide very good intuition to why this trend has been happening, why has it been dictated by competition and product complexity, and what is the role of modularity. The basis of our analysis is a detailed case study analysis of two important innovations that were introduced in the automotive in the past 2 decades: the Antilock Braking System (ABS) and the airbag. The paper makes a detailed exploration of the development of these systems, analyzing in particular the role of the suppliers and the assemblers in the introduction and development of these innovations.

This paper is organized as follows. First, we review the key perspectives associated to the make-versus-buy decision, and how they have evolved over time. Second, we present in more detail the recent perspectives on the property rights theory of the firm, and how they are relevant for understanding the buyer–supplier relationships in the automotive industry. In the third and fourth sections we apply the general perspective to the patterns of development of the ABS and the airbag innovations. We then conclude and propose directions for future research.

Perspectives on the Make–Buy Relationship

Assuming that introducing a new component in the car, say an airbag, generates some degree of monopolistic profits and accrued car sales, what we wish to know is who will be more likely to come up with the innovation—the assembler or one of its suppliers. The obvious way to address this question is to understand who has the bigger economic incentive to come up with the innovation and, therefore, will be more interested in investing in its development.

The literature on the economics of innovation has analyzed a set of problems that fit the question that we have just described. Models consider an environment where a large established firm enjoying monopolistic profits competes with a challenger for an innovation that will destroy current profits by establishing a new monopolistic setting ([2, 3] are the two core models; [4] presents a complete review of the literature). These models can be applied to the context of our paper if we consider the car assembler as the current large established firm, and the supplier as the smaller challenger. Conclusions derived of these models depend greatly on the assumptions about the degree of uncertainty associated to the potential stream of profits. If the degree of uncertainty is low, the established firm will invest, but if uncertainty is high, then the challenger will lead the investment.

The problem with these models is that they assume that the boundaries of the firms competing for the innovation are fixed *ex-ante*.¹ Therefore, they are of limited

¹ Henderson [5] presents another direction of critique to these models, emphasizing the importance to control for organizational capabilities and how they are affected by the characteristics of the innovation (in particular, whether its is radical or incremental) when considering strategies and associated outcomes. We will not explore these aspects in this paper, although we recognize they can provide an interesting extension to our analysis.

relevance for the context of the buyer–supplier relationship innovation decision we wish to analyze. Although acquisition of a large assembly firm by one of its suppliers may not be plausible, the converse is not true. Delphi or Visteon, the component arms of GM and Ford, respectively, have grown extensively during the last decade, partially through acquisitions. Lately, these firms have been considered to be spun off from their parent companies. The traditional models mentioned before can encompass neither of these important aspects. The problem is that, as Hart ([6], chapter 1) has pointed out, established theories of the firm fail to provide convincing explanations of where to draw the boundaries of the firm.

The problem of understanding economic relationships has been a new body of economic theory developed since the 1970s. The idea was to turn away from general equilibrium models and to focus on necessarily partial models that take in account more of the complexity associated to the interactions between privately informed agents. The literature has followed two complementary axes: a more descriptive approach, usually called transaction costs economics, and a more analytical vein within what became known as the principal–agent problem.

Agency theory, or the principal–agent problem, has been the core paradigm sustaining the analysis of the relationships between economic agents (see [7] or [8] for a full description of the theory). This theory analyzes decisions and outcomes of relationships between an uninformed principal that proposes a contract to an informed agent, which either accepts or rejects the proposal. In the basic example most widely used to explain the theory, the agent develops an activity on behalf of the principal, which endures some level of effort that (stochastically) influences the quality of a good or service produced. The principal cannot observe her effort, and will reward the agent based on the observed outcome—the quality. The agency theory provides a framework for understanding and designing contracting mechanisms that maximize the surplus of the agents.

A rich set of results has resulted from research in this field, in areas as diverse as managerial compensation or production organization (see survey by [9]). Models analyzing a buyer–supplier relationship have been developed (e.g., [10]), mainly with the objective of trying to find optimal incentive schemes that can approximate the first best solution of having a contract on effort, rather than on (noisy) outcomes. As on other results of the principal–agent, the core insight is the need to establish a tradeoff between risk sharing and rent extraction.

The problem is that, as with the innovation studies, simple agency theory does not distinguish between different ownership structures. The theory considers the relationship between GM with its parts subsidiary Delphi, to be no different from the one with its independent supplier Kelsey-Hayes. Yet, one would expect the two realities to be economically quite different. Therefore, it becomes difficult to use this paradigm to study the make–buy relationships to their full extent. It may provide interesting insights, but with the strong assumption of ex-ante fixed firm boundaries.

Contract completeness is the key for the similarity in the way the agency paradigm treats relationships between divisions of a same firm and arm’s-length supply. The theory considers a world where all states of nature can be observed and costless contracts covering contingencies established. Therefore, it is natural to find the two realities are one and the same. The problem is that real contracts do have a cost and do not cover all possible states of nature. Coase [11], and later Williamson [12, 13] or Klein, Crawford, and Alchian [14] were the first to explore the need to account for incompleteness in the contracting arrangements between firms when studying their decision making process.

According to the theory, two key aspects drive contract incompleteness. The first is that there are indeed costs of enacting a contract specifying the conditions for a transaction between economic agents. It's a complex endeavor, mobilizing managers and lawyers.² Second, agents have limited ability to identify and plan for all possible states of the nature. As a result, there will be outcomes of a certain endeavor between firms that have not been considered in the contract.³ How these unforeseen events affect each of the contracting firms will be key for the economic outcomes of the relationship. Incompleteness also opens the possibility for recontracting. In the original principal-agent paradigm there is nothing for which to recontract, because all possible outcomes have been accounted for from the beginning. In the new paradigm, if a new unforeseen situation arises, parties will want to renegotiate, and the bargaining power of each of the firms in this event plays a determinant role in the economic result.

The original literature of transaction costs was not formal, but provided a general rationale to think about whether to subcontract a certain activity, say the manufacturing of a part, or keep it in-house. Assuming that the manufacturing step can be performed as efficiently in-house as by an outside supplier, the decision would be determined by which of the solutions has lower contracting costs for the firm. If the firm is doing the manufacturing, transaction costs are associated to monitor increasing complex activities. If the activity is done through arm's-length contracting, then transaction costs are associated to the enforcement of the contract, given that the firm with lower switching costs can try to hold up the other to extract additional rents from the relation.

Theory sustains that the make-buy decision should be governed by specificity of the assets needed to engage in development and production of the relevant good. Uniqueness of the assets involved in the relation or uncertainty on the outcomes increases the likelihood of opportunistic behavior from the supplier, increasing the transaction costs of using market to secure production. As asset specificity decreases, switching becomes easier, and opportunistic behavior is less likely to happen. As a result, market price relationships become better to assure efficiency because they avoid transaction costs of in-house bureaucratic control.

Both the principal-agent and the transaction costs frameworks have been key references guiding empirical analysis of the behavior of the firms in what concerns make-buy decisions, particularly with examples drawing in the automotive industry. Monteverde and Teece [15] established one of the landmark empirical evaluations supporting the transaction costs theory. They evaluated the role of asset specificity in GM and Ford make-buy decisions for their car components, finding evidence supporting the transaction costs paradigm. They found the engineering development effort of any given component (proxy for asset specificity) to be positively correlated to the likelihood of vertical integration of production for that component. They also found evidence that assemblers will vertically integrate when high switching costs lock the assembler upon a supplier.

In 1984, Walker and Weber [16] analyzed data for 60 component make-buy decision of U.S. automakers. They found that cost differences in production overshadow transaction on what regards decisions between in-house production and subcontracting. Never-

² For example, it would have a prohibitive cost for an assembler and a supplier to write a contract that would specify all the contingencies associated to potential new government regulations that could force changes in the supply conditions.

³ For example, an agreement may not specify what happens in the event of a flood that prevents a supplier to deliver to an assembler in due time.

theless, variables associated to asset specificity were also having a small influence in the make-buy decision, and were according to Williamson's perspective. In a more recent study Walker [17] concludes that transaction costs economics hold to a certain extent, but corporate decentralization and relational (long-term) contracting diminish the importance of high-asset specialization as a necessary condition for low transaction costs in-house and high transaction costs in the market.

Liker et al. [18] analyzed 143 Japanese Suppliers and 189 U.S. suppliers to understand whether agency theory or transaction cost economics could help explain the differences in the contracting behavior of the two countries. Their overall idea is that Japanese trust-based buyer-supplier relationships would generate an incentive scheme that, according to the predictions of agency theory, lead to higher levels of subcontracting, when compared to the United States. Nevertheless, the study finds no difference in supplier involvement at design level between Japan and United States. Product complexity (transaction costs asset specificity argument) and tier status (reputation effects—see below), not country, were the best predictors in terms of supplier involvement in design. A subsequent study of 122 Japanese Firms by Wasti [19] concludes that, contrary to opportunistic behavior assertions of agency theory, the level of supplier involvement in design work is negatively associated with the availability of alternate suppliers for the design of the component at hand. Moreover, the longer a supplier has been supplying its customer, the less control the customer retains over design specifications. Explanation seems to be confidence relationships built between OEMs (assemblers) and suppliers in Japan.

The results discussed above seem to cast doubts about the empirical validity of the transaction costs and agency views of the firm, at least in what concerns the specific issue of whether to subcontract the development of a component or to maintain it in-house. The problem is that the perspectives described above, the transaction costs or agency theory of the firm, are not set up to address the decision on where to set the boundary of the firm. Therefore, they would work under certain conditions, but not in others. Conflicting empirical evidence seems to support this assertion.

The Property Rights Theory of the Firm and the Buy-Supply Decision

Several authors [20–22] asserted that existing perspectives of the firm were not suitable to explain the potential integration decision between firms. In particular, they sustain that (a) existing agency theory does not provide a reasonable explanation for the differences in incentives between an integrated and a multidivisional firm (such as the relationship between GM and Delphi); (b) transaction costs are a first cut to a much larger ownership problem. Ownership is, therefore, at the root of the theory.

The core assumption underlying what came to be known as the property rights theory of the firm is the inability of the firms to write ex-ante complete contracts about future transactions that depend on unforeseeable future states of the world. Under this approach, the firm is a collection of assets over which it has control. There are specific rights (specified in a contract) and residual rights (unable to be specified) over the assets of a firm. Possession of residual control rights defines ownership. According to this perspective, integration in itself does not change the cost of writing a contract. What it does change is who has control over those provisions not included in the contract (the residual rights).

To explain the relevance and mechanics of the theory, we place it in the context of the automotive industry supply decision, the locus of our problem.⁴ We will imagine that both the assembler A-cars and the supplier S-parts are aware of a market opportunity for the introduction of a new antilock braking system (ABS) in the car, and they contract for its development. We assume that the contract will specify the allocation of property rights on the innovation, a sharing rule for the verifiable amount of investment from each part, as well as for any verifiable revenues. As a general setup we also consider that both investments of A-cars and S-parts are important for the success of the ABS, with the probability of success increasing with the effort of both firms.

The problem is that development of a complex system like the ABS has potential pitfalls, some of them where the parties will not be able to anticipate. For example, they may not predict changes in government safety regulations, which may affect the approval of the system by regulatory authorities. Therefore, it is not possible to write a complete contract that specifies all the characteristics of the ABS innovation up front, and considers all potential pitfalls in the development process. Neither is it feasible to write a contract based on effort, where the number of engineering hours, qualifications of the engineers, types of equipment, prototyping policy, etc., used in the development of the ABS would be specified. In short, we are in an incomplete contract framework, as described before. As a result of the incompleteness, we assume there are opportunities for renegotiation of the contracts after the investment phase and before the actual supply relationship starts (from where the revenues will come). As we will further detail, this possibility will make the ownership of the residual rights critical to determine the outcomes of the contractual relationship.

What we wish to understand is who will push (invest) more for the development of the innovation. For this purpose, we will consider scenarios determined by (a) the degree of market development for the innovation, and (b) the ownership structure. The ownership structures to be considered are S-parts and A-cars as separate firms, or owned together by A-cars.⁵ The market possibilities are whether or not the companies perceive the existence of an outside option for the investment, i.e., if the owner of the residual rights of the innovation can make a profitable use of it outside the contractual agreement (if this breaks up at the renegotiation phase). The combination of these two dimensions generates four different possible scenarios.⁶

The two initial scenarios analyze the implication of having or not an outside market for the ABS when we consider firms as separate entities. The key aspect to understand the contract structure in this scenario is to acknowledge that this outside market is only a real possibility for S-parts and not for A-cars. In fact, the assembler does not have any interest in pursuing the development of the innovation with another car manufacturer, because this would prevent him from differentiating its products.

⁴ This is a loose interpretation of the formal models discussed in the theory, in particular those presented by Hart [6] and Salanié [7], chapter 7, and Halonen and Williams [23].

⁵ We consider that the situation where the supplier owns the assembler is not reasonable in the context of the auto industry.

⁶ It is important for the analysis to consider that any potential integration between firms does not change their ability to observe relevant variables. Any audits that A-cars can do to S-parts if they are integrated are also feasible when they are separate companies. Integration in itself does not change the cost of writing a contract, what it does change is who has control over the provisions not included in the contract. This is reasonable assumption for the auto industry, where the standard contract gives assemblers the right to perform detailed audits on their suppliers.

If there is a potential market, S-parts expected rents will be larger. Moreover, if firms are separate, contract incompleteness makes it impossible for A-cars to prevent S-parts to use the knowledge acquired in their joint investment to implement a similar product in another car manufacturers. Therefore, S-parts faces greater incentives than a-cars to invest in the innovation. As a result, the equilibrium strategy for this scenario is to have most of the investment in the development of the ABS done by S-parts, who will also own the residual ownership rights over the innovation. A-cars will mainly do complementary investments needed to incorporate the ABS in the car, but not much more than that. Will S-parts try to hold-up A-cars to try to extract surplus from the accrued vehicle sales? Eventually, but the existence of a market also suggests alternative suppliers for which A-cars could change, thus reducing the risk of such a behavior.

What does integration changes in firm's incentives? Once A-cars owns S-parts, its obvious strategy is to prevent her to access the outside market and thus providing other automakers with the same product. Knowing this, S-parts will invest only according to the return it may reach by selling to A-cars. Therefore, there will be underinvestment from S-parts, particularly if we compare it with the possibility to sell outside. This underinvestment might have consequences such as potential delay of the introduction of the ABS or inferior quality.⁷ As one would expect, the situation would not change if ownership of the ABS would be passed to A-cars, because the incentive structure would still be the same.

When can the above situation be different? Suppose the perception now is that there is no outside market for the ABS and that the firms are separate. Then, parties are aware that once the investment is completed, both A-cars and S-parts may try to behave opportunistically, holding up the other to try to extract more rents out of the relationship. The outcome will reflect the bargaining power of the two parties. Given that there is no outside application for the innovation, it is reasonable to consider that A-cars has much greater bargaining power⁸ than S-parts, and will hold her up. As a rational agent, she should be willing to accept renegotiations until her profits are driven to zero. The problem is that S-parts is aware that her expected rents may become diluted by the unbalance of power before she decides to invest. Therefore, her reaction will be to underinvest in the development of the innovation in the first place, hurting the overall endeavor. Ownership of the residual rights will depend on how important the investment is of each party. If the investment of the supplier is not so important (e.g., the know-how in the technology is so incipient that S-parts is not much ahead of A-cars), then A-cars may pursue the venture himself. In this situation, incentives will be adequately aligned, because the investor will capture the expected market. If the investment of the supplier is necessary then, as explained below, vertical integration may be the only way to avoid underinvestment.

Again, we ask what would change if the firms integrate. Although some opportunistic behavior between divisions of a same firm will still exist, the hold-up threat is not credible because the management of S-parts could easily be fired in such an event. Because this threat is dismissed, rents dilution is not so critical. Therefore, there will be less problems of underinvest in the development of the innovation, rendering better

⁷ Firms are aware of this conflict of interests. For several years, GM has tried to portray Delphi as a global parts player, staining it is independent of the car maker's activity. Yet, GM is still the major customer of Delphi. Recently, to assure full independence, GM announced the spin-off Delphi.

⁸ The assumption here is that in case of no agreement, the lost business for the supplier is much more important than for the assembler.

	Companies Integrated	Companies Separate
Market Exists	<p>④</p> <p>Underinvestment from Supplier because of reduced market incentives</p>	<p>①</p> <p>Adequate investment from Supplier and Assembler</p> <p>Supplier owns residual rights</p>
Market Absent	<p>③</p> <p>Adequate investment from Supplier and Assembler</p>	<p>②</p> <p>Underinvestment from Supplier because of hold-up problem</p> <p>Ownership depends on relevance of supplier investment</p>

Fig. 1. Market scenarios, ownership structure, and investment patterns.

results for both parties. It is important to note here that the possibility that A-cars dismisses S-parts and invests in the innovation only by herself is ruled out by the assumption that both investments are important for the innovation outcome.⁹ Otherwise, we would be back on the previous scenario.

The key conclusion of the behavior described above can be summarized in Figure 1. If there is an outside market, firms should be separate, and the ownership should be allocated to the firm that is making the most important investment decision, the supplier. If no outside market exists, then integration is the best solution, given both investments are critical. If they are not critical, the assembler can dismiss the supplier and invest himself in the venture. These insights fit the general conclusion of the theory ([6] chapter 2) that complementary goods should be owned together, while if they are independent they should be owned separately. Moreover, it also fits the asset specificity history of the traditional transaction costs theory, but with more careful qualification of the hypothesis and outcomes, and a story that relies more on incentives and ownership than on transaction costs.

THE ROLE OF MODULARITY

For many years, the relationship between assemblers and suppliers has been straightforward. Because each car was designed from scratch and seen by the automaker as a unique product, all investments in solutions and technologies for new models were undertaken by the automaker. Given this market setting, it is easy to conclude from the above discussion that no role existed for the supplier at the development level. At the manufacturing stage, particularly for simpler parts where there was a well-developed market, subcontracting would naturally occur.

Recent developments of many products' architecture suggest a shift of the theoretical underpinning of supplier-customer relationships concerning industrial goods. Guided

⁹The idea is that there may be unique competencies in S-parts that A-cars cannot easily replicate.

by the example of computer development, many physical products are showing an architectural change. As an example, take the sufficiently complex product car. In the past, it has been designed, manufactured, and assembled as a highly interconnected system of thousands of parts. Recent developments show that the path taken to reduce this complexity is to divide the complex system into modules with a lower level of complexity between them. These modules can be designed, manufactured, and assembled independently, saving time and coordinating resources, but still work as an integrated whole, assuring the desired functionality (see [1] for a discussion on complexity and modularity).

But there is another, so far often overlooked, phenomenon attached to the modularization of the automobile. Because the basic concept of a car is very similar across the different vehicle manufacturers, i.e., all have an engine to propel the vehicle, all need mechanisms to decelerate the vehicle, all have four wheelers to stay on the road, all have similar seating devices etc., it is not surprising that most of the vehicle manufacturer arrive at similar solutions where to set the modules' boundaries. In addition, many modules are more or less invisible for the end customer. Economies of scale both in engineering and manufacturing allow applying similar modules to different cars, first across models of one platform, then across platforms, and—to some extent—across different cars of different vehicle manufacturer.¹⁰ This second dimension of modularity is what we will call technology interchangeability, and is at the core of our argument.

Modularity, through integration of functions and technology interchangeability, becomes the can opener for the supplier to escape the holdup problem described in the previous section. At a first level, it balances the bargaining power of the assembler and the supplier, enabling their deintegration even in the absence of an outside market. In fact, integrating functions in modules that will work together is a complex task that is often possible only if both assembler and supplier commit important resources to the development. Therefore, the incentives for opportunistic behavior after investment takes place are strongly tamed. Holdup from one of the sides is no longer credible because the negative impacts in its own operations would probably surpass the benefits by squeezing profits of the other side.

At a second level, when interchangeability becomes possible, suppliers are no longer deemed to sell their product to only one customer. In contrast, they can sell it to many customers, and the bargaining power shifts to the supplier. What the modularization creates, is, in effect, a new market for the suppliers' products. It enables the supplier to apply similar solutions to different assemblers, and amortize his investment across several clients. In this case, he has the greatest incentive to come up with new solutions and products for the automobile.

Figure 2 describes the two dynamics. If we go back to the scenarios discussed in the previous section, at a first level, modularization enables deintegration between assembler and suppliers, and a transition from scenario 3 to scenario 2. Further on, at a second level, as markets are established, modularization drives a shift towards scenario 1. How technology development and a slow shift of the product architecture towards a higher level of modularity allows the emergence of these markets will be described with help of the ABS and airbag systems as examples.

¹⁰ Another driving force can be seen in the recent consolidation process in the automotive industry. Nevertheless, the effect that the modularization has to the supplier industry as argued here, must be accompanied by a shift to modular product architectures.

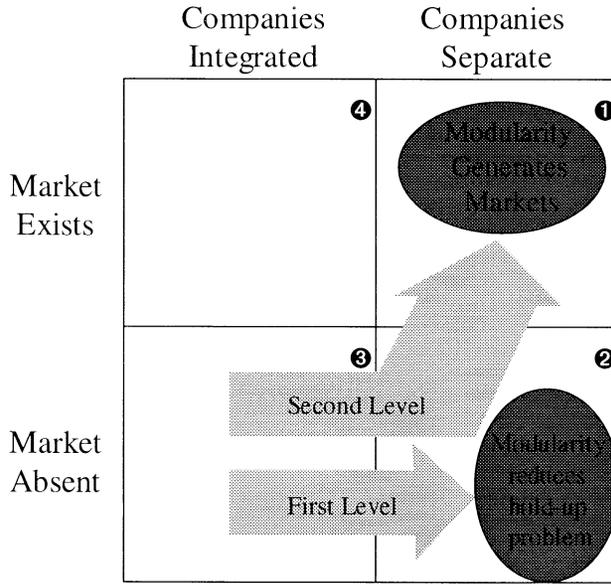


Fig. 2. Ownership trends enabled by modularization.

Case Study 1: The Antilock Braking System

THE DEVELOPMENT OF THE ABS

During heavy braking on wet or icy roads, it is very easy for the driver to inadvertently lock the wheels. When this happens the car starts slipping on the road, and stopping the vehicle takes much more time and effort. Experienced drivers avoid these situations by rapidly pumping the brake pedal, repeatedly taking the wheels to the point of locking and then allowing them to roll again. This technique, called cadence braking, requires a high level of skill and concentration under panic conditions, far from the ability of an ordinary driver. Nevertheless, the idea to make cadence braking automatic has existed for several decades, and eventually led to the development of the antilock braking systems (ABS). The first system able to prevent wheels from being locked under conditions of excessive braking was the 1952 Dunlop Maxaret. This system, which was totally mechanical, was applied to an aircraft rather than a car, but represents the first commercial application of the invention.

The potential relevance of ABS systems to the safety of the roads was discovered during the 1960s and early 1970s. A number of studies demonstrated that 10% of all the accidents with heavy vehicles and 8% of accidents with cars were due to slipping [24], and that a large fraction of these accidents could be avoided if systems to prevent wheel lock were used. As a result, initial tests to install ABS systems in trucks started in the early 1970s. Nevertheless, the initial solutions proved to have poor reliability and a prohibitively high price. Therefore, it was only in 1984 that Bosch and ITT-Teves introduced the first commercial car ABS system, already based in microprocessor technologies.

Because of their high cost, the early systems were extras installed only on luxury automobiles such as the Ford Lincon Continental (in the United States) or the Ford Scorpio (in Europe). Worldwide, less than 1% of the cars produced in 1984 were equipped with ABS. The success of Bosch and ITT-Teves rushed other competitors

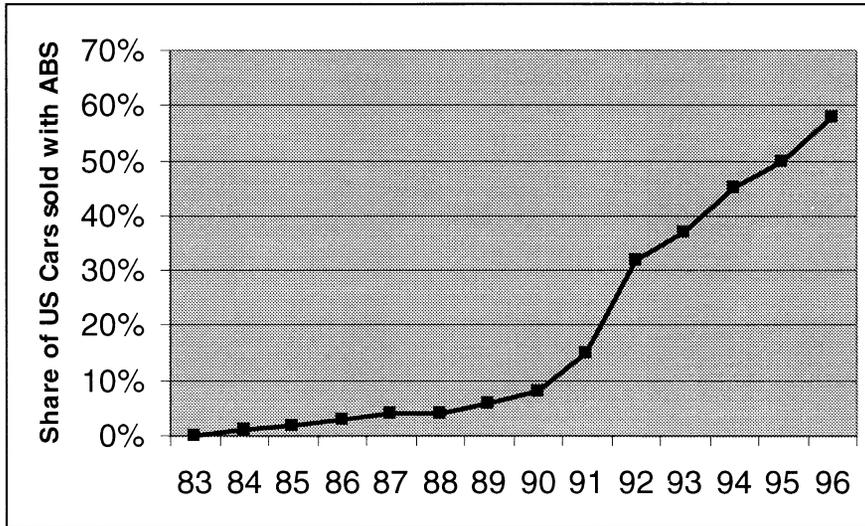


Fig. 3. Installations of ABS in new cars sold in the United States (source: [25]).

to the market and, over the following years, a number of other ABS products became available. Lucas signed contracts to supply Ford in 1986. In Japan, Nippondenso and Sumitomo started production in 1986 and 1987. In the next years, many others were to follow. As Figure 3 illustrates, ABS was a clear market success, with demand for ABS growing rapidly. By 2003, it is expected that 95% of the cars will be equipped with an ABS.

TECHNOLOGICAL INVESTMENT IN THE ABS SYSTEM AND THE BUY-MAKE DECISION

The question we are interested in answering is why did we have Bosch and ITT-Teves and other suppliers, rather than GM or VW, as the innovators of the ABS? In light of the discussion of the previous sections, we will argue that the modular characteristic of the innovation is the major driver for having the property rights in the suppliers, and not in the assemblers. We will explore this assertion in the following paragraphs.

The existence of suppliers responsible for the development and manufacturing of braking systems is almost as old as the existence of the automotive itself. In fact, the normalization of the wheel base happened very early in the history of the auto, which prompted the development of braking systems that could easily be interchanged between autos. In this sense, we can say that the brake has always been a module in the auto. As a result, there have been greater incentives for the suppliers to be responsible for the product, because they could split the investment across different assembler clients. In fact, several firms with know-how about the product have been established for many years, including Dunlop, the original ABS innovator, D.B.A., Bendix, or Automotive Products plc.

When initial ABS systems were conceived, they were mostly mechanical devices automating the manual cadence braking that drivers would try by themselves. In these systems, the speed of the wheel was monitored through belts connecting the shafts to an actuator that would mechanically release pressure on the calipers once the belt would stop rolling. For the purpose of our study, the important aspect of the initial ABS is

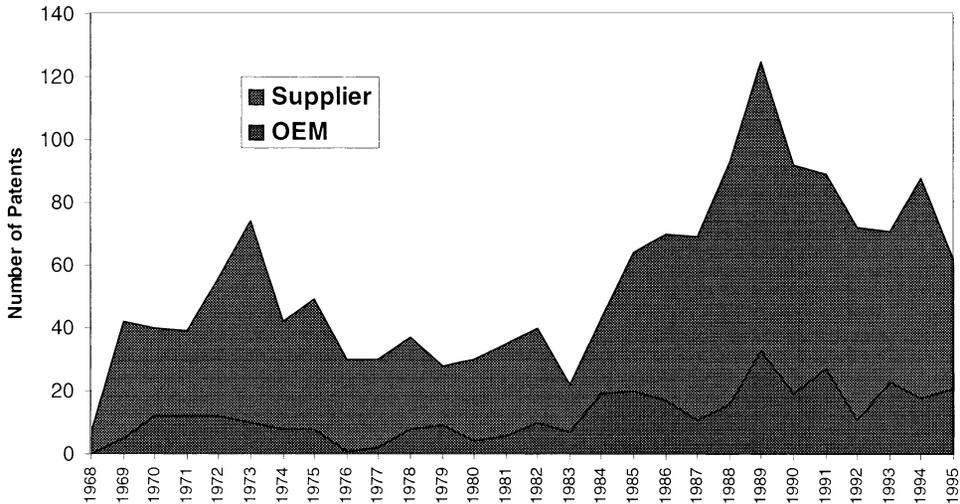


Fig. 4. Patents count assemblers and suppliers; $n = 2041$ (source: [26]).

that it kept the modular characteristic of the braking system. The solution just described is clearly independent from the vehicle where it is applied. Therefore, if we consider the incentive structure associated to the development of the innovation, and frame it in the scenarios described in the previous sections, we clearly understand that the suppliers are facing much larger economic incentives than the assemblers to promote the development of such an innovation. If the supplier succeeds, his potential market includes all the automakers (OEMs). If the assembler succeeds, then his potential market is likely to be only their cars, as he probably would not be willing to pass the innovation to another automaker.

Our perception is that, since the 1970s, suppliers were aware of the market opportunity for the introduction of the ABS, provided that they were able to meet the necessary reliability and safety concerns of the automaker. Therefore, it is not surprising to find Bosch and ITT-Teves leading the introduction of the ABS system. Nevertheless, this only means that these companies were successful in putting the ABS into the market. To support our view, we have to show that suppliers in general were leading the development effort, trying to assure the possession of the ownership rights, particularly in contrast to the assemblers.

As a means for evaluating investment levels in the technology and allocation of ownership rights, we will use patent count. Because patent count is an output indicator, it does not accurately reflect all the resources devoted to the development of an innovation. Nevertheless, whenever specific investment data is not available, it is accepted in the literature as an adequate indicator to assess inventive activity. Moreover, because patent protection fits the ABS innovation, it is also the appropriate measure of ownership rights, the focus of our analysis.

Figure 4 shows patent activity throughout time from 1968 to 1995.¹¹ As anticipated, the suppliers did most of the investment in the development of the ABS, which would indicate that they possess the ownership rights over the innovation. The assemblers did

¹¹ We took out the spurious patents, i.e., companies that had less than two patents over the whole period evaluated.

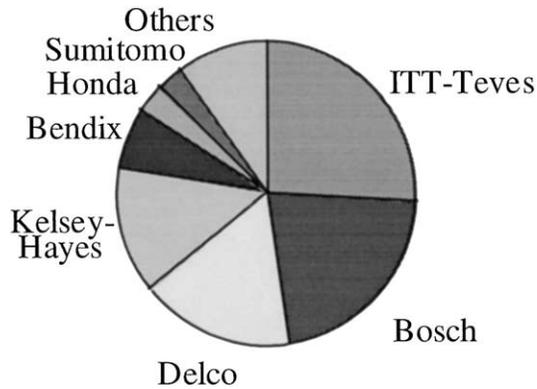


Fig. 5. 1994 World ABS installation market shares (sources: [25, 27]).

mainly complementary investments needed to incorporate the ABS in the car. The next step to confirm our initial story is to assess whether these suppliers had the correct vision in terms of expected financial returns. Figure 5, which presents the market shares of sales of ABS in 1994, seems to confirm our perception. As we can see, assemblers are only represented directly by Honda, and indirectly by Delco, a components firm owned by GM. Once again, evidence appears to confirm that suppliers dominated the market.

Nevertheless, because of its singularity, we should carefully look at Delco. This situation where a market exists, but the development is being assured within a vertically integrated structure corresponds to scenario 4 of our early discussion, as illustrated in Figures 1 and 2. As we pointed out then, the problem with this scenario is that there may be underinvestment because the potential market is not fully considered when the investment decision is made. The fact is that GM as the world's largest automaker may mitigate this underinvestment. If Delco considers ABS installation in GM as a captive market if successful in its development, then this may indeed be a stronger incentive than expected profits from independent suppliers fighting to get contracts.¹² Once again, the theory seems to fit what has been happening in the auto world.

Summarizing the findings of the case study, we conclude that this case study would fit the first scenario described earlier in this paper (see Figure 1). The existence of an outside market generated large incentives for independent suppliers, which led the development of the ABS from the early beginning, both in terms of ownership of the intellectual property, and market dominance. Moreover, we explained why the modular characteristics of both conventional and ABS braking systems played a crucial role in giving a clear up-front perception of the potential ABS market, and enabled development and testing somehow independent of the assembler.

Case Study 2: The Airbag

THE DEVELOPMENT OF THE AIRBAG

Over the last 4 decades several solutions for protecting automobiles' occupants from colliding with the dashboard, the steering wheel or the glass in case of an accident were developed. One basic idea was to keep the passenger connected with the seat—this

¹² The fact that there are other supply companies in the market will also prevent Delco from shirking.

created the seat belt. Two disadvantages of this system spurred the search for alternatives. First, a seat belt requires some initial action of the driver,¹³ and, second, they provide only limited protection against neck and head injuries caused by the whip-like motion of these parts when the rest of the body is stopped at high deceleration rates.

The idea to avoid these problems was to put a cushion-like device between the solid parts of the car and the driver. When an accident occurred, the cushion would be inflated automatically. The basic concept for an airbag as an inflatable restraint system dates back almost half a century, with the first patents for airbags being granted in the 1950s, both in the United States and in Germany. However, it took until the late 1960s before a suitable propellant was found. Driven by research related to the space exploration of the 1960s, engineers developed quasi a reverse rocket mechanism. By burning sodium acid, they could create enough gas to fill an airbag in a few milliseconds.

The market introduction of airbags in the United States was accompanied by a decade-long legal battle between the big three U.S. OEMs and governmental institutions. Triggered by Ralph Nader's book "Unsafe at any Speed," the administration began to consider automobile safety as a public issue that can be demanded and enforced by governmental agencies. The more the administration pressed for mandatory introduction of airbags in new cars, the more the car companies fought against it, fearing reliability cases in courts later on. Despite these court battles, however, during the late 1960s and early 1970s, the big three all were developing airbag systems.¹⁴ GM sold the first airbags from 1974–1976, although without major economic success. Following this experience, no American carmaker introduced airbags until the late 1980s. Mercedes-Benz began to offer airbags in 1985 in America, but without having a major impact on the public perception due to its small market share. In 1987, the situation began to change. Chrysler's management started to see airbags as a marketable safety feature. It started to have its vehicles equipped with airbags. Ford and GM followed quickly. In less than a decade, airbags entered the entire automobile population of new cars in North America (see Figure 6).

For the purpose of this paper, we wish to contrast the situation during the 1970s and early 1980s, when most of the development was undertaken by the automakers, with suppliers responsible only for manufacturing parts, with the situation in the 1990s, where large suppliers offer entire airbag systems to various automakers. We will argue that, despite some contribution from the changes in the policy of the automakers towards increasing outsourcing, modularization of the product's architecture was the major factor that enabled increasing supplier responsibility.

TECHNOLOGICAL INVESTMENT IN THE AIRBAG SYSTEM AND THE BUY-MAKE DECISION

An occupational restraint system like an airbag has to fulfill four basic functions. First, it has to be able to detect the event of an accident through some kind of device. Second, it needs a mechanism that uses the signal of the detection device and decides what kind of action to trigger. Third, a device to trigger the physical action of inflation is required, and, fourth, a mechanism to inflate the bag itself must be in place.

¹³ Automatic seat belts, which were introduced during the late 1970s early 1980s, tried to get around this problem. They were, however, the outcome of the OEMs' attempt to provide alternatives to the governmental airbag requirements. Their economic success was rather questionable.

¹⁴ The history of the car airbag in the United States indeed shows several noneconomic factors explaining the delay of its overall market appearance for almost 20 years. Graham describes in detail how NHTSA and the big three battled in court rooms for years about which safety technology to install in the vehicles (see [28]).

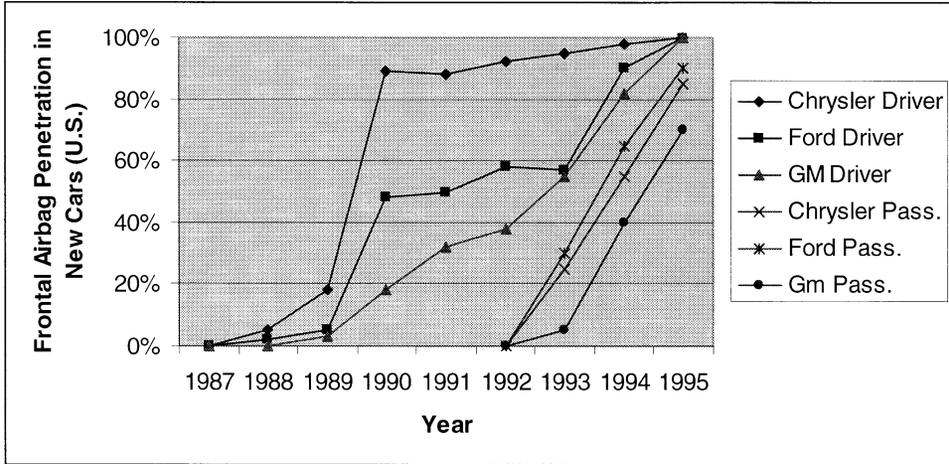


Fig. 6. Frontal airbag installation of new light vehicles sold in the United States (source: [26]).

The first versions of airbags in the late 1960s had several sensors in the front of the car to detect an accident.¹⁵ The signal was then transmitted to a diagnosis unit via cables. The trigger was an electrical circuit that ignited the propellant, sodium-acid, which would expand rapidly to inflate the bag. Two important features prevented the airbag concept from being a module at this time. First, the physical location of its several parts made it impossible to preassemble its components. This made independent testing of the whole system almost impossible too. Second, when the decision unit got the accident detection signal it did not know what was happening to the part of the car between the sensor and the occupants' compartment. The different designs of the crumple zones, and the different geometrical dimensions of engine compartments, chassis, frames, and hoods across various models and makes made it unlikely to use one airbag system in an identical way in two different cars.

Because of the characteristics described above, every airbag system was mostly dedicated to its specific application environment. In other words, there was no integration of functions, or set boundaries for the system, and very limited interchangeability between car models or brands. The key implication for the purpose of our argument is that there were no "external" markets for the airbag systems developed then. Moreover, because the technology was in its early stages, suppliers did not have specific assets that required them to be involved in the development. As a result, we would expect to find assemblers leading the airbag development effort, with little involvement from suppliers. This situation corresponds to scenario 2 described earlier.

Today's airbag systems look different. The advancement in electronics and microprocessors made it possible to change the product architecture of the system "airbag." Sensors are today far more accurate and reliable than 30 years ago. This allowed shifting their position from the car's front into the passengers' compartment. It further allowed the reduction of the number of sensors required for a flawless operation. In addition, the advancement in microprocessors improved the capabilities of the decision unit. The variability among airbag systems for different cars could be placed into the software, rather than in the system's hardware.

¹⁵ The idea of having the sensors in front of the car was to detect the accident as early as possible.

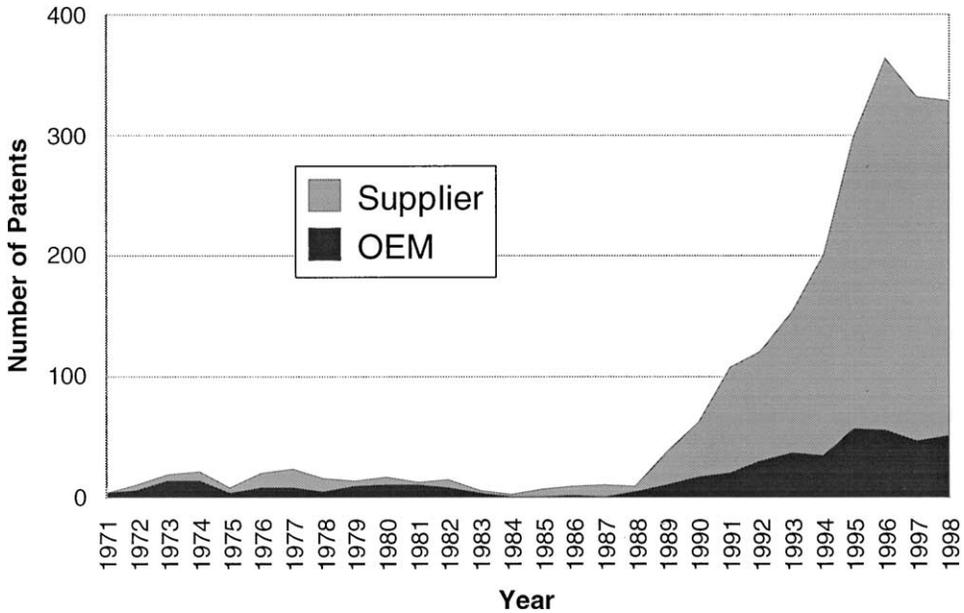


Fig. 7. U.S. patents regarding airbags granted to OEMs (assemblers) and suppliers from 1971 to 1998 ($n = 2,233$)¹⁹ (source: [26] U.S. Patent and Trademark Office; Community of Science, Inc.).

These technological changes allowed the gradual transformation of the airbag into a module of the car. Nowadays, it is possible to place all physical parts for the driver's airbag into the steering wheel. The colocation of its parts was the final aspect needed to assure that the airbag achieved a module status within the car's product architecture. This, in turn, opened up an entirely new market for the suppliers. Now, they have the incentive to invest in design resources and manufacturing facilities to develop airbag systems, because they can be easily interchanged between different car models and various assemblers.

Going back to the dynamics illustrated in Figure 2, the arrows show what we should expect the trend towards modularity to be associated with, increasing participation from independent suppliers in airbag development, which will eventually acquire most of the innovation's ownership rights. To test our assertion, we will follow the same methodology used for the ABS case: patent count will be used to measure the magnitude of investment in the development of the airbag as well as the allocation of property rights.

The U.S. patent data concerning airbags tell two different stories (see Figure 7). The first one reflects the political arguments between governmental agencies and the car manufacturers until the late 1980s. Total patenting activity concerning airbags is rather low in this period, which may lead us to conclude that "political" considerations eventually slowed down the development effort of the early years. Triggered by the first commercial introduction of an airbag in the late 1980s, and a growing concern by cars' final customers of safety issues, companies began investing heavily in research and development for this technology. The overall hockey-stick shape of the figure, therefore, was caused by the overall behavior of the assemblers and their market.

The second story in this data is the one relevant for the purpose of our paper, and it becomes clearer when looking at the relative distribution of patent activity between assemblers and suppliers over the entire time period. Throughout the 1970s and early

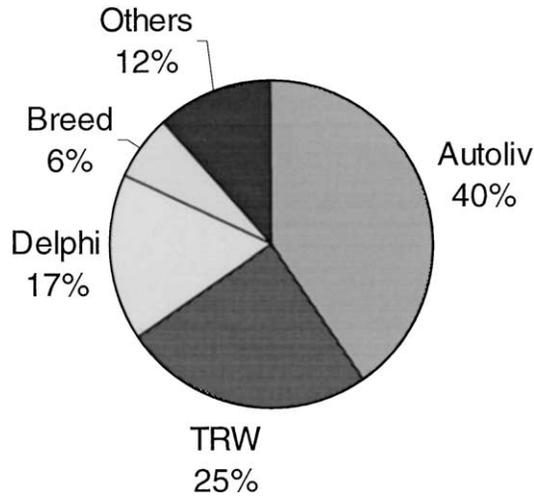


Fig. 8. 1998 Worldwide market share of airbag manufacturer, total ~\$6 bn (source: company data; 10k).

1980s, the assemblers conducted a big chunk of the innovation and engineering work. All three American car companies were involved in developing airbag systems, and even more the European ones (Mercedes-Benz especially, did almost all airbag development work in-house). At that time only two major suppliers are known of having been involved in developing airbags: Eaton, Yale & Town, and Allied Chemical. Both dropped out of this business after having failed to convince the assemblers of the reliability of the technology.

Nevertheless, over time, suppliers started to invest more heavily than the assemblers did.¹⁶ This shift in development activity coincides with the change in product architecture explained above. The gradual development of electronics and computer technology allowed for a further modularization of the product car, and one of the modules emerged was the airbag. Once it became clear that essentially the entire new vehicle population was a potential market for an airbag system with comparatively little variance across models and makes, suppliers began to invest more heavily than assemblers did.¹⁷ The recent overwhelming supplier dominance on patent count would lead us to conclude that they are now the ones with the residual ownership rights of the airbag and not the assemblers that originally innovated.

In fact, as a look at today's market shares demonstrates, a number of strong suppliers have been able to establish themselves as the airbag suppliers. This group encompasses companies such as Breed, Autoliv, Takata, or TRW. The market for complete airbags is clearly dominated by suppliers (see Figure 8). Out of a worldwide airbag market of estimated \$6 bn they supply more than 75%.¹⁸ Interestingly enough, similar to what was described for the ABS case, the components arm of GM, Delphi, has also a strong presence in the market, showing a consistent behavior.

¹⁶ As explained in the section of the ABS case study, we are using patent activity as a proxy for investment in development activity.

¹⁷ Again, the willingness of the OEM to equip their cars with airbags in the late 1980s explains why the market for airbags appeared in the first place at this time. What it does not explain is why we see a shift of research activity over time from OEMs to the supplier. This is the main concern of this paper.

¹⁸ The 12% others include, besides OEM production, other worldwide suppliers like Takata and smaller, regional suppliers like TEMIC or Petri in Europe. Delphi is considered here as part of GM.

The story of the airbag development is more complex than the one of the ABS, but is also more rich.¹⁹ As we described, initial airbag systems were so integrated in the overall vehicle that they were considered as part of the product car itself. Therefore, as we anticipated, independent suppliers played a limited role, and would certainly not be granted any residual rights over the innovation. Nevertheless, as the airbag evolved and became a module, independent suppliers stepped in and gradually took charge of the development. This trend described earlier and shown in Figure 2 is a clear example of our suggestion that modularization drives increasing suppliers responsibility and spurs the unbundling of the supply-chain structure.

Conclusions

This paper combines recent theoretical results related to the ownership structure of the firm with the notion of modular design to provide a new framework to analyze the decision of the automakers of whether to develop a new component in-house or to subcontract it to a supplier. Our initial perception was that if there is an outside market, assembler, and supplier should be separate, and the ownership should be allocated to the firm that is making the most important investment decision, usually the supplier. If no outside market exists, then integration is the best solution if both investments are critical. If not, the assembler can dismiss the supplier and invest himself in the venture. We then tested our proposition with two detailed case studies. Both fit the original perspectives.

For the ABS, we sustained that the modular characteristic that the braking system has always had, something that was kept when the ABS started to come along, helped in establishing an up-front perception of a potential cross-OEM market for an ABS. As a result, and according to the model, independent suppliers should be facing the larger incentives to invest in the development of the ABS, and should be leading, both in terms of ownership of the intellectual property, and market dominance. This is precisely what our case study revealed.

Airbag systems tell a different story. When they were first developed, their integration with the rest of the vehicle was so deep that they were considered as part of the product car itself. Therefore, as we had anticipated, independent suppliers played only a limited role in the initial development phase. As the airbag evolved and became a module, independent suppliers gradually took charge of the development and seized ownership of the innovation. This trend, illustrated in Figure 2, is at the core of our suggestion that modularization tames the holdup threat and generates new markets, driving an increase in supplier responsibility promoting the supply-chain unbundling.

Overall, our model and the two case studies presented demonstrate the importance of understanding market incentives and ownership structure to find who in a buy-supply development contract will push more for the innovation and how the residual rights should be allocated. Moreover, the insights found fit the general conclusion of the theory proposed by Hart and others according to which complementary goods should be owned together, while independent should be owned separately. In addition, it also fits the asset specificity history of the traditional transaction costs theory, but with more careful qualification of the hypothesis and outcomes, and a story that relies more on incentives and ownership than on transaction costs.

Despite the positive results, two case studies are a limited sample upon which to ground our theory. Therefore, it would be important to extend the model to other applications, and towards a statistical level analysis, to have a more robust evaluation of the proposed framework.

¹⁹ We counted only companies or individuals that were granted at least three airbag related patents over the 28-year period.

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