How Does Outsourcing Affect Performance Dynamics? Evidence from the Automobile Industry

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This paper examines the impact of vertical integration on the dynamics of performance in the context of automobile product development. Building on recent work in organizational economics and strategy, we examine a number of detailed case studies to evaluate the relationship between vertical integration and different performance margins. On the one hand, outsourcing facilitates access to cutting-edge technology and the use of high-powered performance contracts. On the other hand, vertical integration allows firms to adapt to unforeseen contingencies and customer feedback, maintain more balanced incentives over the product lifecycle, and develop firm-specific capabilities over time. Together, these effects highlight a crucial dynamic tradeoff: while outsourcing will be associated with higher levels of *initial* performance, vertical integration will be associated with a higher rate of performance improvement over the product lifecycle. We test these ideas with detailed data from the luxury segment of the global automobile industry. The data combine detailed performance measures over time with nuanced measures of the extent of vertical integration, as well as measures of the contracting and technology environment. We establish four key results. First, initial performance is declining in the level of vertical integration. Second, the level of performance improvement is significantly increasing in the level of vertical integration. Moreover, even after controlling for other factors impacting performance, the magnitude of these two effects are roughly identical – there is no relationship between vertical integration and "overall" performance. Finally, taking advantage of outsourcing during the early part of the product lifecycle and internal development during the latter years of the lifecycle depends on the institutional and strategic environment. For example, the long-term benefits to vertical integration are erased for those firms with a strong union presence. Overall, the empirical findings highlight that the vertical integration decision reflects a dynamic strategic tradeoff between short-term performance and the potential for improvement over time.

I. Introduction

Recent work in strategy and economics has made considerable theoretical and empirical progress in explaining the determinants of vertical integration and firm boundaries. From a theoretical perspective, transaction cost theory (building on Williamson), the property rights approach (Hart and Moore, 1990; Baker, Gibbons and Murphy, 2002) and the knowledge-based view of the firm (Kogut and Zander, 1992, 1996; Conner and Prahalad, 1996; Nickerson and Zenger, 2004) have each developed rapidly over the last several years. At least in part in response to this emerging theoretical maturity, recent attention has turned towards evaluating the empirical content of individual theories, and understanding the relationships among them.[1] Empirical research has focused attention on the tradeoffs that drive outsourcing choices, and identified the impact of shifts in the environment on make-versus-buy decisions (Whinston, 2001; Baker and Hubbard, 2004; Nickerson and Silverman, 2003).

While a large body of research focuses on the choice between vertical integration versus outsourcing, only a small body of research explores the performance *consequences* of vertical integration (Masten, et al, 1991; Masten and Saussier, 2002; Nickerson and Silverman, 2003; Boerner and Macher, 2005; Klein, 2004; Yvrande-Billon and Saussier, 2005). From the perspective of the strategy literature, understanding the performance implications of vertical integration is crucial. The determination of firm boundaries is often a long-lived strategic commitment, and a boundary choice made at one point in time will have performance and strategy consequences over time. For example, outsourcing a function sharply constrains a firm's ability to adapt to unforeseen contingencies or benefit from learning and experience associated with that function.

This paper proposes and implements a novel approach for evaluating the relationship between performance and vertical integration. Specifically, our analysis builds on the insight that a single vertical integration choice affects multiple performance *margins*. Theoretical work in economics, strategy, and organizations suggests that a key difference between vertical integration and outsourcing arises from the difference between what is achievable through specific formal contracts and what is achievable through

[1] For reviews of the empirical literature in transaction cost economics, see Boerner and Macher (2005), Klein (2004) and Masten and Saussier (2002). Whinston (2001) offers a synthesis of the relationship between property rights and transactions cost theories, and Argyres (1996) and Poppo and Zenger (1998) offer complementary syntheses of the relationship between transaction costs and the knowledge-based view.

maintaining activities within the boundaries of a single firm or organization. For example, Bajari and Tadelis (2001, BT hereafter) offer a simple formal model of procurement in which the benefit to outsourcing arises from the ability to write detailed formal contracts (and so offer high-powered incentives from an ex ante perspective), while the benefit to vertical integration results from the ability to renegotiate with workers in order to adapt to unforeseen contingencies. At the same time, the knowledge-based view (KBV) of governance choice emphasizes that, while outsourcing allows firms to rapidly access capabilities that are not currently maintained within the firm, vertical integration is a prerequisite for internal capability and knowledge development over time (Kogut and Zander, 1992, 1996; Conner and Prahalad, 1996, Nickerson and Zenger, 2004). Though distinct, both of these theoretical perspectives imply a crucial dynamic tradeoff faced by firms in the context of product development: while outsourcing facilitates high-powered incentive contracts and the ability to access cutting-edge suppliers, vertical integration enhances the ability to achieve a higher level of flexibility and learning. The principal objective of this paper is to provide qualitative and quantitative evidence of the performance implications of this dynamic tradeoff in the context of the global luxury automobile sector.

Evaluating the linkage between vertical integration choices and performance is subtle, since alternative contracting modes are endogenous to the economic, strategic, and organizational environment. Since the likelihood of being vertically integrated into a particular activity (e.g., the design and manufacture of a specific component or system for a product) will tend to be higher for those firms that have chosen to be vertically integrated, a simple comparison of the overall performance results between firms who have chosen vertically integration versus outsourcing are likely to be misleading (or ambiguous). For example, if the returns to vertical integration are quite significant for those firms that have adopted an integrated structure, and the returns to outsourcing are equally high for those firms who have adopted outsourcing, a cross-sectional performance comparison need not find any performance consequence to integration, even though each decision maker faced a clear performance tradeoff.

This challenge has motivated a small but growing literature on evaluating the performance implications of vertical integration. These studies focus on the costs of “transactional misalignment” – the performance loss associated with adopting (or inheriting) an organizational form which is "inappropriate" in a given economic or strategic environment.[2] As well, building on work such as Poppo and Zenger (1998), Macher (2006) provides evidence from the semiconductor industry that the conditions associated with high performance differ depending on whether a firm is vertically specialized or vertically integrated. This paper focuses on the *difference* between the static and dynamic performance implications of vertical integration. As the modern theory of the firm is premised on the idea that organizational choices have *both* costs and benefits, our analysis traces out the (static and dynamic) costs and benefits associated with vertical integration versus outsourcing.

To explore these ideas, we exploit the process of procurement and product development contracting which accompanies a "major" model change in the automobile industry. First, each "major" model change for an automobile model provides an opportunity to significantly alter product positioning, technologies, and contracting choices for that automobile model. Typically, there are approximately five years between major model changes, with a process that takes three to five years between initiation and automobile launch. Moreover, while broad positioning choices are made by a coordinated internal team, a given major model change involves hundreds of individual contracting and governance choices, impacting each of several distinct "systems" within an automobile, such as the brakes, engine, and body. Though historical factors shape contracting choices during each of major change, individual managers are able to choose a governance mode for the duration of the major model change.[3]

This setting allows us to explore how vertical integration is likely to impact performance over the product lifecycle. During the initial product development and sourcing stage, outsourcing will facilitate contracting on a global basis for cutting-edge technology, and the use of high-powered incentive contracting. In other words, the major model change provides an opportunity to take advantage of external innovations and to impose detailed performance contracts on an external supplier. Conversely, internal development limits the ability to take advantage of frontier technology, and internal wage contracts will offer only muted incentives to reach specific initial performance targets. However, the process of product development will eventually necessitate a period of ex-post adaptation, as a particular

[2] This approach was pioneered in Masten, et al (1991) and Masten (1993), and is discussed in Section II.
[3] Changes in governance mode during the product lifecycle is rare (see Figure 1 and Appendix A).

component or system is tested and evaluated over time in the market. While market and consumer feedback provides concrete guidance for potential improvements over the remainder of the major model, external suppliers may have very limited incentives to contribute to such improvements. Specifically, because the precise needs for ex-post adaptation cannot be anticipated (and the manufacturer cannot guarantee a precise volume of "work," since the extent of needs is also uncertain), such terms cannot be precisely articulated in the initial performance contract. Moreover, in many cases, the capabilities required for improvement rely on detailed model-specific knowledge (e.g., effective improvement may require coordinating with other units in the firm), or may rely on idiosyncratic knowledge about the precise technical characteristics of a given automobile. Consequently, relative to outsourcing, vertical integration allows firms to adapt to unforeseen contingencies more effectively and maintain effort over the product lifecycle for those systems that require improvement. Overall, while outsourcing allows a firm to achieve a high level of performance in the early stages of the product lifecycle, vertical integration will be associated with a dynamic benefit as the firm's performance increases over the product lifecycle.

Our empirical analysis proceeds in two phases. First, we report a series of short case studies illustrating the costs and benefits of outsourcing over the product lifecycle. Our qualitative findings suggest that external sourcing allows firms to access state-of-the-art technology but leaves them open to hold-up and low effort supply after the initial terms of the contract are satisfied, and that internal development is associated with inferior technology development and high costs for an initial model-year, but there are much greater opportunities for improvements over time.

We then turn to a more systematic empirical analysis. Our analysis exploits a detailed dataset covering luxury automobile models over a fifteen year period. For each model, we observe both the degree of vertical integration and the contracting environment for seven distinct automobile systems (e.g., the brake system, the seat system, etc.). We link these measures of system-specific vertical integration to system-specific performance measured at different points over the product lifecycle. Specifically, the analysis draws upon the annual system-specific automobile quality ratings reported in *Consumer Reports*. Since competitive advantage is closely tied to quality in the luxury automobile segment, these measures are a useful proxy for overall vehicle commercial success (relative to alternatives for that automobile model). Finally, for each model-system, we observe a set of system-specific vertical integration drivers.

For example, for each system, we observe whether the firm has existing in-house sunk investments in plant and equipment. Together, these data allow for a detailed examination of the relationship between vertical integration and performance over the product lifecycle, focusing on the benefits and costs of vertical integration for different performance margins.

Though we are cautious in our interpretation, the basic empirical patterns are striking. First, systems with a low level of vertical integration are associated with a much higher level of initial performance, but outsourced systems experience almost no ratings improvement during the latter years of the product lifecycle. In contrast, systems that are more vertically integrated have much lower initial scores, but a very rapid rate of improvement over the lifecycle. These basic patterns in the data are robust to the inclusion of alternative control structures in the performance equations, the use of system fixed effects, time fixed effects, and various company controls. The qualitative results are consistent using both OLS and an instrumental variables estimator, where the instruments for vertical integration are factors that are correlated with the vertical integration decision but are likely independent of system-specific quality levels. We are able to distinguish between different theoretical mechanisms by which the static versus dynamic tradeoff from vertical integration might arise. Consistent with BT, in environments where the potential for renegotiation and ex post adaptation are low (such as when union contracts are important), the dynamic performance benefits from vertical integration are eliminated. Consistent with the KBV, there is some evidence that both the short-term costs and the dynamic benefits to vertical integration are lower when firms have experience and capabilities in a particular area. Finally, the results suggest that there is no "overall" benefit to outsourcing or vertical integration within our sample. The benefits of outsourcing during the early stage of the lifecycle are equivalent to the incremental benefits received over the lifecycle associated with vertical integration.

II. The Performance Implications of Vertical Organization

While there is a voluminous literature on the drivers of vertical integration and contracting terms, a smaller literature focuses on the relationship between vertical integration and performance (Masten, et al, 1991; Masten, 1993; Silverman, et al, 1997; Nickerson and Silverman, 2003; Boerner and Macher, 2005; Yvrande-Billon and Saussier, 2005).[4] Though performance studies are central to evaluating the role of vertical integration for strategy, the study of performance must address a fundamental inference problem. Since vertical integration choices are chosen in response to firm's economic, strategic and organizational environment, differences among firms in their organizational choices likely reflect idiosyncratic differences in the benefits and costs of vertical integration (Masten and Saussier, 2002; Yvrande-Billon and Saussier, 2005). Estimating the overall impact of vertical integration by comparing the performance of firms that choose "make" rather than "buy" confounds the impact of vertical integration per se with differences in the (expected) returns to vertical integration among organizations that choose one organizational form over another.[5]

While cross-sectional comparisons of the relationship between vertical integration and performance may be misleading, individual decision-makers nonetheless face significant performance tradeoffs when considering vertical integration versus outsourcing. Individual organizational structures (vertical integration or outsourcing) will be associated with a particular profile of benefits and costs, and the decision to vertically integrate (or not) depends on a comparison of the *net* benefits and costs after accounting for multiple performance margins. In other words, while the decision to vertically integrate can be summarized in terms of net benefits, the performance implications of vertical integration will be realized along specific performance dimensions. As such, as emphasized in Poppo and Zenger (1998) and Macher (2006), the sources and conditions giving rise to high performance can differ significantly under vertical integration and outsourcing.

Indeed, the particular sources of benefits and costs from vertical integration are at the heart of leading theoretical approaches to vertical integration, such as economic approaches grounded in contracting and transaction costs or the KBV. Consider, for example, the role of contracting costs. In

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[4] Reviews of the literature on the determinants and performance consequences of vertical integration include Shelanski and Klein (1995), Masten and Saussier (2002), Boerner and Macher (2005), Klein (2004), and Yvrande-Billon and Saussier, (2005). Our approach is also complementary to studies examining contractual incompleteness and contract design (Joskow, 1988; Crocker and Masten, 1991; Crocker and Reynolds, 1993; Saussier, 2000).

[5] The most well-developed approach to overcoming this bias is to focus on the impact of transactional "misalignment," documenting the performance consequences of choosing an organizational form that is inconsistent with observable aspects of the economic and strategic environment (Masten, et al, 1991; Masten, 1993; Silverman, et al, 1997; Mayer, 2000; Leiblein, et al, 2002; Menard and Saussier, 2002; Bigelow, 2003; Nickerson and Silverman, 2003; Yvrande-Billon and Menard, 2003; Sampson, 2004; and Mayer and Nickerson, 2005). Our approach is complementary to the approach of Forbes and Lederman (2005) in their study of the airline industry.

nearly all approaches throughout the economics literature, firm boundaries matter because it is impossible (or too costly) to specify all potential contingencies contractually.[6] While market-based relationships are governed by the details of (costly) contract design, vertical integration allows an organization to maintain control through authority relationships with its employees. Ultimately, firms face a tradeoff between high-powered performance incentives in order to guarantee performance over the (limited) contingencies covered by formal contracts, versus the benefits that come from being able to renegotiate with internal workers (who have less high-powered incentives) and so adapt to unforeseen or unspecified contingencies (Williamson, 1985; Bajari and Tadelis, 2001). As highlighted by BT in the context of procurement contracting, these fundamental differences between outsourcing and vertical integration manifest themselves in terms of performance dynamics: outsourced projects are likely to be associated with a high level of initial performance (in order to satisfy the terms of the original contract), while internal projects (or cost-plus projects) are likely to be associated with increasing relative performance over time (since these organizational forms allow for renegotiation and adaptation). In other words, a single vertical integration decision impacts both a short-term and long-term performance margin, and the choice between vertical integration and outsourcing depends on the relative importance of these two distinct dimensions.

The KBV offers an alternate theoretical perspective on the impact of firm boundaries (Wernerfelt, 1984; Kogut and Zander, 1992, 1996; Conner and Prahalad, 1996, Nickerson and Zenger, 2004). At its heart, the KBV suggests that both the accessibility and accumulation of knowledge are shaped by firm boundaries, as firm boundaries serve to demarcate the nature and extent of relationships, including the extent of trust, reputation and sense of organizational identity (Kogut and Zander, 1996; Nickerson and Zenger, 2004). While most work in the KBV focuses on the impact of firm boundaries in solving a single type of problem (e.g., a decomposable problem can be solved across firm boundaries), individual vertical integration decisions often govern multiple problem-solving episodes. For example, in the context of procurement contracts, initial problem-solving requirements will often benefit from the ability to access external knowledge sources and will involve modular problem-solving tasks. From a dynamic perspective, however, project-specific learning is likely to be higher under a vertically integrated

[6] Building on Dye (1985), a recent theoretical literature focuses on the implications of contracting costs on contract design (see, among others, Anderlini and Felli, 1999; and Battigalli and Maggi, 2004).

structure. Internal employees have higher incentives for project-specific learning, and also are more likely to make that knowledge available for others to use throughout the organization. Moreover, as a project evolves and problem-solving becomes more interdependent, internal problem-solving efforts may facilitate coordination and the management of complexity. Thus, similar to the discussion of contracting costs, the KBV posits a dynamic tradeoff: while outsourcing allows firms to rapidly access knowledge that the firm lacks from an *ex ante* perspective, vertical integration is a prerequisite for the development of internal capabilities and learning over time.

These insights motivate our hypotheses. Specifically, consider the setting of product development contracting in which vertical integration choices involves significant contractual incompleteness and the potential for learning over time. Both economic theory and organizational theory highlight the potential for a dynamic tradeoff between vertical integration and performance:[7]

Hypothesis 1: Initial performance is lower for higher levels of vertical integration.

Hypothesis 2: Performance improvement is higher for higher levels of vertical integration.

Our discussion also highlights the mechanisms underlying these hypotheses. The dynamic performance implications of vertical integration decisions should be realized when, compared to external contracting, internal development facilitates (a) renegotiation and the potential for adaptation to unforeseen circumstances and (b) learning and complex problem-solving, motivating the following hypotheses:

Hypothesis 3a: The impact of vertical integration on initial performance will be muted for firms with a higher level of ex ante experience and/or knowledge.

Hypothesis 3b: The impact of vertical integration on performance improvement will be muted in environments where renegotiation, adaptation, and learning are more difficult.

III. Case Studies from Automobile Product Development

In this section, we begin to examine the hypotheses suggested by both the contracting and KBV views in the context of automobile product development. We highlight differences in capabilities and knowledge, and in performance incentives to illustrate the implications of the impact of vertical

[7] If the size of one of these two performance margins was significantly larger than the other, there would be a net positive return to a particular contracting model. However, when we observe significant variation in contracting practices (as in the automobile industry), there is no expectation of a systematic relationship between vertical integration and a measure of overall performance over the course of a full product development contracting cycle.

integration of different performance margins. Our qualitative analysis focuses on four polar cases to illustrate the potential benefits and costs resulting from internal development versus outsourcing (Figure 1 and Appendix A present an overview of the contracting process in automobile product development).

At the heart of our analysis is the product lifecycle for automobile models. While automobiles receive incremental upgrades annually, an automobile model undergoes a "major" model change approximately every five years. A "major" model change provides an opportunity to significantly alter product positioning, technologies, and contracting choices. Of course, even for major model changes, a manufacturer is constrained by the history of the vehicle, sunk investments, etc. However, the process underlying a major model change is substantial, and there is typically a 3-5 year period between initiation of the product development process for a major change and the launch of a new automobile model.

During the earliest stages of automobile product development, the manufacturer has latitude to access any supplier and set detailed requirements, most of which relate to a large number of foreseeable contingencies. Whereas external suppliers are offered high-powered performance requirements contracts, internal suppliers are provided more muted incentives, often yielding a higher level of "coordination" with other components and/or systems (Novak and Stern, 2006). The realization of initial performance (associated with the introductory model year) motivates incremental innovation and improvement over the life of the major. However, while internal teams are provided a constant level of incentives, are learning during the project, and can be directed through authority relationships, external suppliers have few incentives for further effort, internal teams. Of course, total profits depend on the success of the vehicle across the entire product lifecycle. As such, firms face a dynamic tradeoff: while outsourcing may yield a higher level of "initial" performance, vertical integration will facilitate performance improvement over the product lifecycle.

The "Early" Years in the Lifecycle. Two benefits arise from outsourcing during the early years of the product lifecycle: the ability to access frontier global technology and the ability to write and enforce detailed procurement contracts with high-powered incentives. First, when one chooses an external procurement mode, one is able to access the "best" in global technology and capabilities through a competitive bidding process. In contrast to the *ex ante* capability levels of internal teams, each bidder is themselves a specialist, vying with each other to achieve "best in class" and are able to take advantage of their learning from multiple projects within a given system. This type of access to frontier technology is particularly important in quality-sensitive segments such as the luxury segment, which is the focus of our empirical work. Second, there may be significant incentive effects associated with outsourcing that would favor the short-term performance margin. Consistent with BT, one benefit of outsourcing is the ability to (endogenously) induce contractibility on a set of observable performance measures. These detailed contract provisions induce high-powered incentives for meeting specific performance requirements relating to the achievement of technical specifications and cost objectives before the initial date of product launch. In contrast, internal development teams are governed by wage contracts and authority relationships, and there are only modest performance penalties in place for a given failure. While subjective incentive schemes and promotion may provide incentives, it is unlikely (and, not even optimal, given the learning and coordination that firms would like to encourage) to employ internal development teams with the same high-powered incentive schemes as one would an external supplier.

The "Late" Years in the Lifecycle. A very different set of capability and incentive effects characterize the later years of the lifecycle. While access to global technology was important in the initial development stage, performance improvement after product launch requires detailed model-specific knowledge. Consistent with the KBV, an external supplier may be "best in class" from a global perspective, but internal teams will have idiosyncratic capabilities and knowledge, facilitating performance improvement over the lifecycle. Incentive contracting also tilts towards vertical integration. While outsourcing involves detailed contracts, the enforceable terms of the contract (in terms of technology specification and quality) are largely satisfied by the time that the initial major model is introduced. While prospects for future contracts and general reputation does provide important incentives for continuing effort, the lack of a direct authority relationship or reliance on subjective incentive schemes mutes formal incentives for ongoing quality improvements. This effect is reinforced by the organization of supplier activities: while a post-contract change may require ten engineers who worked on the original project, supplier employees are allocated to new projects shortly after the project satisfies specified formal requirements. The inability to access personnel is reinforced by the provisions surrounding renegotiation and ex post adaptation: to maintain secrecy and avoid expropriation, contracts limit the extent to which employees can be pulled from other projects to return to an earlier one (e.g., provisions restricting the freedom of suppliers to use shared physical facilities). In contrast, the more balanced incentives and authority relationships that characterize internal development allow these teams to be able to provide significant effort in response to the need for ex-post adaptation (Bajari and Tadelis, 2001). Incentives can be provided internally to undertake activities which are formally "non-contractible" (e.g., through promotion incentives), and the firm can use its authority relationship to adjust the level of effort and the composition of personnel to respond to contingencies and the specifics of consumer feedback.

Taken together, these patterns highlight that the benefits of vertical integration (and its costs) will be related to specific times and circumstances over the product lifecycle. To deepen our understanding of these dynamic patterns, we review a series of short qualitative case studies, which highlight how the impact of vertical integration and outsourcing manifest themselves over the product lifecycle.[8]

The Volvo 850. The 850 model was Volvo's first US front-wheel drive vehicle. In order to balance weight in a front-wheel drive vehicle, the engine is aligned east to west, rather than north to south, as in rear-wheel drive vehicles. Such an east-west or "transverse axis" engine design required an extremely narrow, "short" gearbox for the automatic transmission. With no experience producing automatic transmissions at the time of this episode (the late 1980s and early 1990s), Volvo lacked the internal expertise to produce such a complex and unusual design in time to meet its product launch deadlines. Instead, Volvo contracted the gearbox design to an outside supplier, Aisin Seiki. As part of the contract, Aisin Seiki maintained resident staff at Volvo to meet daily with body and engine designers as changes were being made. Not only was initial product performance successful, but, over time, Volvo was able to take over key functions (e.g., software development and maintenance) through learning. Volvo's outcome with Aisin Seiki is an example of using outsourcing to access the best in global technology. Any given company will only have a limited number of sources of internal expertise that will allow a luxury automaker to differentiate in terms of design and technology. Of course, commitment to an outside supplier will lock the manufacturer in to a given technology and vendor, raising the potential for hold-up. However, if there are few unforeseen contingencies in initial product development, as in the Volvo-Aisin Seiki example, the manufacturer can realize a technological "leap" along with the opportunity for learning going forward through outsourcing.

[8] Each of these short case studies is based on interviews and fieldwork conducted by one of the authors.

The 1992 Cadillac Seville ABS Brake System. In contrast, internal development may lead to poor initial performance, and the need for costly revisions. Until the early 1990s, the dominant antilock brake system (ABS) design was mechanically-based, that is, the designs were based on motors. By 1990 Cadillac had invested $100 million in mechanically-based ABS technology. As a result of that investment, Cadillac's internal brake division, AC Delco, was heavily focused on the specifics of the mechanically-based technology. However, in 1989, Bosch, a leading global supplier, introduced a dramatically redesigned electronically-based system. Based on solenoids, a completely different approach to ABS, Bosch offered better performance at half the price of the mechanically-based systems. Cadillac was already in development of the 1992 Seville, and attempted to respond to the Bosch innovation by implementing a "hybrid" solution that combined Bosch and AC Delco parts. The hybrid system had significantly higher cost and worse performance than the Bosch alternative. The Cadillac outcome demonstrates risks in internal development, as firms rely on a narrower range of in-house capabilities when sourcing internally. As internal suppliers are not as close to global technology developments, they are at a greater risk of being leapfrogged in terms of initial product development, and are constrained by internal capability limitations.

The Toyota Lexus LS400. On the other hand, internal development can offer the potential for significant improvements over time. During the late 1980s, Toyota created Lexus as a new brand and division in order to position Toyota to enter the luxury auto segment. Toyota had no experience in producing such high-end vehicles, with their related increase in quality requirements. Indeed, the initial design was extremely expensive for Toyota to produce, particularly given that Toyota was concerned about maintaining a reasonable quality level and realizing a high quality rating. To achieve these objectives, Toyota's design relied on the use of a large number of separate parts for reinforcement, and there were very few outside suppliers who could have completed the job for Toyota at a lower cost. To facilitate learning and stability, Toyota maintained a single project manager over the first two Lexus product development projects; over time, Toyota realized significant reductions in cost alongside continuing quality improvements in terms of design and part simplicity. Ultimately, the Lexus achieved the #1 position in quality ratings. The Lexus project manager stated, "Even when we did the two piece body outer, we thought about doing a one piece. We started to plan for this during the first program."

Employees were rewarded for their ability to contribute to this goal. The Lexus case reflects a benefit of internal development -- project management can manage beyond the "life" of an individual project and invest in objectives and criteria that are difficult to write down and enforce in contracts. Toyota used its high personnel stability along with internal promotion incentives to design a plan for gradually building the skills needed to deliver high quality products. In this way, internal development reinforces the potential to exploit authority relationships, subjective incentive compensation, and the ability of an organization to accumulate knowledge and learning over time.

The Saab 9000. Finally, significant quality problems can remain unresolved with outsourcing because external suppliers lack incentives to improve product design after meeting the initial contract terms. SAAB, for example, went through two near bankruptcies and merger attempts in the 1980s/1990s. The original 9000 was planned as a sister vehicle to the Fiat Lancia, but finally ended up as part of the General Motors Opel Vectra platform. SAAB had initially contracted with Hella for brakes prior to the merger with GM, but adapting the 9000 to the Vectra platform after the merger necessitated a great deal of changes to the brake design. The resulting brake performance was fraught with problems that required costly changes. According to a VP at Saab, "Savings can disappear overnight due to changes." The original contract with Hella did not account for the merger, and it was very costly to enforce those changes, as Hella had already met the terms specified by the original agreement. The SAAB story exemplifies an issue with outsourcing: external suppliers face too few incentives to go beyond the terms of the contract, and, after initial effort to satisfy the terms of the contract, have few incentives to invest in the specific problems and challenges that arise in the context of an individual manufacturer.

Figure 2 summarizes our qualitative findings, complementing our earlier discussion. While these cases do not provide systematic industry-level evidence, they suggest the impact of vertical integration on realized performance in the automobile industry, motivating our more systematic empirical analysis.

IV. Data and Methods

Sample and Methods. This study combines a proprietary and original dataset based of contracting choices and the contracting environment in the global auto industry with system-specific ratings drawn from *Consumer Reports (CR* hereafter*).* The data on contracting choices, product architecture, and the contracting environment was constructed from a multi-year study of the global automobile industry. The dataset consists of observations from the luxury performance car segment (defined by *CR* as vehicles priced above $30,000 in 1995) and the companies included in the sample are drawn from Europe, the U.S. and Japan, accounting for roughly 90% of revenues in the global luxury performance market (Appendix B describes the sample and interview process in detail). We combine this contracting choice data for a given "major" model change with system-specific performance ratings published by *CR.* These performance ratings are used to construct the dependent variables throughout the analysis. The *CR* rating varies from 1-5, with 5 as the "highest rating") for each system for each model-year. For each of the 19 "major" model changes that we examine, we gather data for the first four years after the introduction of that "major" change. We measure short-term performance in terms of the ratings supplied for the first two model-years of the major, and long-term performance in terms of the ratings supplied for the third and fourth model-years of the major. When performance measures were available from both of the two years, we took an average; when only one year is available (within the relevant two-year span), we take that as the performance measure for that period.

Note that, for each model-year, there are potentially multiple years of performance data, since the performance ratings for a given model-year will be updated even after the year of initial introduction. In our main analysis, we examine the model-year performance rating associated with the *first* rating provided for that vehicle model-year. Our results are robust to alternative formulations of the year-by-year performance measures. The final dataset consists of 112 observations of system-specific contracting choice, the contracting environment, and performance. Table 1 provides all variable names, definitions and summary statistics.

System-specific performance measures. The dependent variables throughout the analysis are a series of performance measures drawn from *CR.* For each system *i* on model *j* in year *t* after a major model change, $\text{PERFORMANCE RATING}_{ijt}$ is the first *CR* quality rating for that system, ranging from 1-5, with 5 as the "highest rating."). The mean of PERFORMANCE RATING is 3.54, with a standard deviation of just under 1. Overall, while relatively few vehicles receive a rating of 1, there is significant variation in the performance ratings, across systems, automobiles, and time. We use PERFORMANCE RATING_{ijt} to calculate each of our measures of performance over the product lifecycle.

First, SHORT-TERM PERFORMANCE is the average of PERFORMANCE $RATING_{ij0}$ and PERFORMANCE $RATING_{ij1}$, as available. When only one *CR* rating is available, only one is used. In other words, SHORT TERM PERFORMANCE is a measure of the performance measure during the first two years of the product lifecycle (inclusive of the introduction year). Similarly, LONG-TERM PERFORMANCE is the average of PERFORMANCE $RATING_{ij2}$ and PERFORMANCE $RATING_{ij3}$ as available. When only one *CR* rating is available, only one is used. We use these two measures to construct a measure of PERFORMANCE CHANGE, which is set equal to the difference between the LONG TERM PERFORMANCE and SHORT TERM PERFORMANCE variables. There is a significant difference in the mean levels of SHORT TERM PERFORMANCE and LONG TERM PERFORMANCE (mean = 3.43 versus 3.70). In other words, across the sample, there is a modest upward trend in vehicle ratings over the product lifecycle. Finally, OVERALL PERFORMANCE is the average of the LONG TERM PERFORMANCE and SHORT TERM PERFORMANCE variables, and provides a measure of the overall performance of the vehicle over the duration of the major change.[9]

Contracting Variables. The contracting measure throughout the analysis is VERTICAL INTEGRATION, the percentage of the system produced in-house, with 1 indicating in-house production of all components within that system.[10] For each component, system, vehicle model, and time period, we have collected data on the make / buy decision outcome. The vertical integration measure at the system level is calculated as the average across the individual components for that system, and each component is weighted equally. Parts supplied to firms by wholly-owned subsidiaries, such as the Delphi division of General Motors, are treated as in-house. Parts produced by partially owned suppliers, such as Nippondenso (Toyota), were treated as outside suppliers.

VERTICAL INTEGRATION exhibits substantial variation across the sample, ranging from 0 (fully outsourced) to 1 (in-house production), with a mean of .51 and a standard deviation of .32. Moreover, it should be emphasized that much of the variation in VERTICAL INTEGRATION is "model-specific." For example, in an OLS regression of VERTICAL INTEGRATION on individual model-year

[9] For any given major-model, OVERALL PERFORMANCE is not simply the average of PERFORMANCE RATING. Since we require only one observation in the first two years after the major model introduction, and one observation within the third and fourth year, an average confounds differences in the number of ratings with the timing of those ratings. The qualitative results do not change if we employ an average over all available years.
[10] Masten et al (1989) use a similar measure at the component level.

dummies, $R^2 = 0.58$, most of the individual model-year effects are individually significant, and the overall F-test statistic is highly significant at 8.74. In other words, vertical integration is "clustered" according to model-year. As discussed in the next section, we will exploit this correlation in VERTICAL INTEGRATION across systems within a given model to construct instrumental variables for VERTICAL INTEGRATION in the context of a performance regression.

Contracting and Performance Drivers. Our analysis also includes a set of system-specific contracting and performance drivers. These measures are included to control for model-specific performance drivers that may be correlated with VERTICAL INTEGRATION. As described in Table 1, these measures include PLATFORM, SUNK COST, COMPLEXITY, DESIGN GOAL, SKILL SHORTAGE, UNION, system level fixed effects and a time trend. Appendix C discusses these measures, and their relationship to VERTICAL INTEGRATION and different performance margins.

The Empirical Framework. Our empirical objective is to exploit this small but nuanced dataset to examine short-term and long-term performance for each of seven individual systems within an automobile model. To focus on the core empirical patterns, we adopt a simple linear specification,[11]

$$SHORT\ TERM\ \ PERFORMANCE_{ijt} = \beta_0^{STP} + \beta_{VI}^{STP} VERTICAL\ INTEGRATION_{ijt} + \beta_X^{STP} X_{ijt} + \mu_{ijt}^{STP}$$
$$PERFORMANCE\ CHANGE_{ijt} = \beta_0^{PERF\Delta} + \beta_{VI}^{PERF\Delta} VERTICAL\ INTEGRATION_{ijt} + \beta_X^{PERF\Delta} X_{ijt} + \beta_{STP}^{PERF\Delta} STP_{ijt} + \mu_{ijt}^{PERF\Delta}$$

where each observation is for system *i* in model *j* in major-model year *t*, and we are interested in whether $\beta_{VI}^{STP} < 0$ and $\beta_{VI}^{PERF\Delta} > 0$.

The challenge in estimating the impact of VERTICAL INTEGRATION on performance is that contract choice is endogenous. Firms that are vertically integrated into a particular activity (e.g., the design and manufacture of a specific component or system for a product) will tend to have higher overall returns to vertical integration for that activity, relative to their assessment of the returns they would have received from outsourcing. Comparing overall performance results between firms can therefore be misleading. For example, even if every firm faces a clear performance tradeoff, a cross-sectional comparison need not find any performance consequence to vertical integration.

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[11] Since our performance data comes in 9 distinct intervals (from 1 to 5 in intervals of 0.5), a categorical data approach (such as ordered probit) is feasible. However, this approach imposes additional structure (e.g., assuming a specific distribution for μ, estimating eight "cut-off" parameters) with little additional insight. We experimented with both ordered probit and logit, and our qualitative results are identical and remain statistically significant.

While readily acknowledging that an ideal experiment would allow us to separately identify the selection process for vertical integration independent of the impact of vertical integration choices on different selection margins, it is important to emphasize that the impact of selection may be limited in the current context. Specifically, we are not examining *total profits*, but are focusing on the implications of vertical integration for specific performance margins. Just as the modern theory of the firm is premised on the idea that organizational choices have *both* costs and benefits, our analysis traces out the (static and dynamic) costs and benefits associated with vertical integration versus outsourcing. An OLS estimator can therefore provide a consistent estimate of the impact of vertical integration on the observed performance margins to the extent that the level of vertical integration is independent of μ. Assuming that μ is random (e.g., determined by random noise (at least in expectation) in the determination of performance ratings), we will observe variation in VERTICAL INTEGRATION under the following two scenarios: (a) conditional on observables, each firm receives a mean-zero relative cost shock that affects the costs of vertical integration (relative to outsourcing) for each system-model-year (Masten and Saussier, 2002), or (b) conditional on observables, each firm receives an independent draw that determines the relative weight placed on short-term versus long-term performance.[12] If variation in VERTICAL INTEGRATION comes from differences in the (unobserved) costs of integration or from differences across models in the relative valuations placed on alternate performance margins, we can consistently estimate the impact of VERTICAL INTEGRATION on each of the performance measures.

Of course, it is possible that the error in the vertical integration equation is in fact correlated with the above performance equations. Those firms who choose a high level of vertical integration for a particular model-system may expect relatively high returns to vertical integration. As such, we also experiment with an instrumental variables approach.[13] To account for the potential endogeneity of

[12] In other words, suppose that each firm receives a random draw, λ_i, on the relative importance of short-term versus long-term performance and the firm maximizes the following over the level of vertical integration: $\underset{VI_i}{Max}\ \lambda_i(SHORT-TERM_i(VI_i))+(1-\lambda_i)(LONG-TERM_i(VI_i))$. While the relationship between each performance measure and VERTICAL INTEGRATION will be fixed (except for the exogenous disturbance), firms will choose different levels of VERTICAL INTEGRATION depending on the realized level of λ.

[13] Our observed measure of vertical integration is a continuous rather than dichotomous variable. Thus, we cannot estimate a standard first-stage selection equation and implement a selection correction procedure (as in, among others, Masten, et al, 1991; Poppo and Zenger, 1998; and Nickerson and Silverman, 2003). We assume that the relationship between performance and vertical integration is fixed across observations, and employ IV to allow for

VERTICAL INTEGRATION, we employ instruments correlated with VERTICAL INTEGRATION for a given system but exogenous to the performance of that system. Building on Novak and Stern (2006), which highlights the potential for complementarity across vertical integration decisions within an automobile model, we calculate instruments based on the drivers of vertical integration for *other* systems within a given automobile model (and control directly for system-specific drivers of vertical integration within each system). In other words, for system *i* in model *j* for model-year *t*, we control directly for SUNK $\text{COST}_{i,j,t}$, and construct SUNK $\text{COST}_{-i,jt}$, which is equal to the average of SUNK COST over other systems within model *j* and year *t*. Using an analogous procedure to define IVs for each system-specific driver, we calculate the following excluded IV vector:[14]

$$Z_{ijt} = \left\{ \text{SUNK COST}_{-i,jt}, \text{LOW CAPACITY}_{-i,jt}, \text{PLATFORM}_{-i,jt}, \text{COMPLEXITY}_{-i,jt}, \text{DESIGN GOAL}_{-i,jt}, \text{SKILL SHORTAGE}_{-i,jt} \right\}$$

Finally, we have experimented extensively with different control structures for each specification. Overall, while the pattern of results remains the same with the use of company fixed effects, these results are not as robust to alternative specifications, particularly in the context of our IV estimation. Rather than overstate the robustness of our results, we limit our presentation to specifications which exploit variation across companies, with standard errors clustered by company, and comment where necessary about the robustness (or not) of individual results to the use of company fixed effects.

V. Empirical Results

The empirical analysis proceeds in several stages. First, we present descriptive evidence about performance patterns over the product lifecycle, according to the extent of vertical integration. Second, we evaluate the impact of vertical integration on initial performance, the rate of performance improvement, and overall performance, respectively. We then focus on interactions between vertical integration and factors that might impact the returns to outsourcing for specific performance margins.

Performance Dynamics Over the Lifecycle. Our analysis begins with Figure 3, where we plot the mean of PERFORMANCE RATING, by the years since the introduction of the “major,” divided according to whether the system-model is above or below the median level of vertical integration. In the

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potential correlation between the vertical integration and μ. To account for selection appropriately, we would need to implement a selection correction in the presence of a continuous treatment effect (Wooldridge, 2002).

[14] We have also experimented with using VERTICAL $\text{INTEGRATION}_{-i,j,t}$ directly. While this measure is itself endogenous, it is useful to note that the results remain qualitatively identical.

initial model-year, there is a quite pronounced difference in the performance level (3.59 versus 3.07). However, by the fourth year after product introduction, there is convergence in "raw" performance levels. A similar pattern is observed in Table 2, where we divide the average of SHORT TERM PERFORMANCE and LONG TERM PERFORMANCE by the extent of vertical integration. There is a statistically and quantitatively significant difference in SHORT TERM PERFORMANCE, but convergence in the raw levels for LONG TERM PERFORMANCE. Of course, these patterns could simply reflect spurious correlation, and so we turn to a more systematic regression framework.

Short-Term Performance. Table 3 reports the findings associated with SHORT TERM PERFORMANCE. First, reflecting the patterns in Table 2, a simple regression with VERTICAL INTEGRATION has a large and statistically significant negative relationship with SHORT TERM PERFORMANCE. This pattern is robust to the inclusion of a linear time trend, a set of six system-level dummy variables, and clustering the standard errors by company. While there is a significant upward time trend in the level of SHORT TERM PERFORMANCE, this trend is essentially independent of the relationship between VERTICAL INTEGRATION and SHORT TERM PERFORMANCE. In (3-3), we include the complete set of control variables, and once again implement clustered standard errors. While there is a modest decline in the absolute level of the VERTICAL INTEGRATION coefficient, no single regressor (except the time trend) is separately significant. This pattern holds across a wide range of specifications – while no other measure (except the time trend) has a consistent relationship with SHORT TERM PERFORMANCE, the VERTICAL INTEGRATION coefficient is positive, quantitatively significant, and statistically significant at least at the 10% level (in most specifications, the 5% level).[15]

In the final column of Table 3, we turn to an instrumental variables approach. To account for the potential endogeneity of VERTICAL INTEGRATION, we utilize the instrumental variables described above, which are based on the drivers of vertical integration for *other* systems within a given automobile model (and control directly for system-specific drivers of vertical integration within each system). The point estimates associated with the instrumental variables procedure are consistent with the OLS results,

[15] The basic findings for VERTICAL INTEGRATION are statistically significant at the 5% significance level for all regressions using robust standard errors. To account for potential correlation across observations within companies, we implement clustered standard errors. While clustering has no impact on the coefficients, the estimates are somewhat noisier, and so some results are only significant at the 10% level.

with a negative and significant relationship between VERTICAL INTEGRATION and SHORT TERM PERFORMANCE. As in the OLS specification, except for VERTICAL INTEGRATION and the time trend, there is no other robust driver of initial model performance. Not surprisingly given the close relationship between the OLS and instrumental variables estimates, a Hausman test cannot reject the exogeneity of VERTICAL INTEGRATION.[16]

Additionally, we have experimented with a variety of specifications, including firm-level fixed effects, and alternative models of "early" performance (e.g., only looking at performance in the first model year, rather than the average of the first two years). While some specifications are a bit noisy (though always significant at the 10% level), the coefficient on vertical integration remains positive and at a similar magnitude. Overall, using several measures for initial performance, employing OLS or instrumental variables, and controlling (or not) for other potential performance drivers, our data point to a significant relationship between VERTICAL INTEGRATION and SHORT TERM PERFORMANCE.

Performance Change. Table 4 reports an analogous set of specifications for PERFORMANCE CHANGE. In (4-1), we include VERTICAL INTEGRATION, which has a positive and large impact on the predicted level of PERFORMANCE CHANGE (recall that PERFORMANCE CHANGE has a mean of 0.28 and a standard deviation of 0.83). We then include control variables, beginning with a time trend and a set of system dummies (4-2), and then with all of the control variables in (4-3). Compared with Table 3, the only difference is that, in the final two columns of Table 4, we separately include SHORT TERM PERFORMANCE as a regressor. While it is possible to move both up and down in terms of the performance ratings (the range of PERFORMANCE CHANGE goes from -2 to 2), a high (or low) initial rating tends to "constrain" the potential for performance improvement (or erosion). While we think it is useful to control directly for the level of initial performance, it is important to remember that SHORT TERM PERFORMANCE may be endogenous, as the errors in the short-term and performance change

[16] While our small sample size makes us cautious about drawing too strong an inference from asymptotic specification tests, these statistics are useful as a check on the overall results. A standard implementation of the Hausman test is to run a first-stage regression of VERTICAL INTEGRATION on all exogenous regressors, and then see whether the *residuals* from that first-stage equation are significant when included as a regressor in a SHORT TERM PERFORMANCE OLS specification. The coefficient is small and statistically insignificant (p-value = 0.54). We also test the overidentifying restrictions of our model, and find we can marginally reject the overidentifying restrictions (p-value = 0.09). We have also experimented several less restrictive models in which the overidentifying restrictions cannot be rejected, in which we are still able to identify the negative relationship between VERTICAL INTEGRATION and SHORT TERM PERFORMANCE.

equation are likely correlated. As such, in (4-4), we take both VERTICAL INTEGRATION and SHORT TERM PERFORMANCE to be endogenous in our IV specification.

Across each of the four specifications, there is a positive and significant relationship between VERTICAL INTEGRATION and PERFORMANCE CHANGE. The OLS coefficients suggest that a shift of VERTICAL INTEGRATION from 0 to 1 is associated with between a 0.6 and 0.8 change in performance. Though more noisy, the instrumental variables coefficient is larger than the OLS coefficient.[17] Further, the data suggest a "mean reversion" effect, so that models receiving higher levels of initial performance ratings tend to experience a lower level of PERFORMANCE CHANGE (the coefficient on SHORT TERM PERFORMANCE is consistently negative). Finally, while UNION and SKILL SHORTAGE are associated with a lower level of performance improvement, COMPLEXITY and SUNK COST are associated with a positive boost in the change in performance. Together, Tables 3 and 4 provide consistent evidence for a negative relationship between vertical integration and initial performance, but a positive relationship between vertical integration and performance improvement.[18]

Overall Performance. Appendix D reports on the relationship between VERTICAL INTEGRATION and OVERALL PERFORMANCE. In the absence of controls, there is a small (and marginally significant) negative correlation. However, with the inclusion of a time trend and system dummies, the effect is insignificant. When controlling for the economic and strategic environment (D-3), the VERTICAL INTEGRATION coefficient is positive. These results illustrate a general pattern: across a wide set of specifications, the relationship between VERTICAL INTEGRATION and OVERALL PERFORMANCE is noisy. Rather than a relationship between vertical integration and aggregate performance, our results highlight the relationship between integration and performance *margins*.[19]

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[17] The IV vector remains the same as in (3-4). As before, a Hausman test cannot reject the exogeneity of VERTICAL INTEGRATION, but we marginally reject the overidentifying restrictions associated with the complete model. Given our small sample size, we are cautious about the inferences from asymptotic specification tests.

[18] We have also experimented extensively with simultaneous equation estimates which estimate both the SHORT TERM PERFORMANCE and PERFORMANCE CHANGE equations together (either by SUR or 3SLS). The overall pattern of results remains the same. However, the precise magnitude and statistical significance of the coefficients on VERTICAL INTEGRATION depend on the precise specification and IV vector employed.

[19] The absence of a relationship between vertical integration and aggregate performance can result if differences in aggregate performance are competed away through supplier entry (if the returns to outsourcing are high) or internal investment (if the returns to vertical integration are high). Though we do not emphasize this interpretation (given data limitations), a zero coefficient on overall performance is consistent with an equilibrium model in which (expected) marginal returns to outsourcing are equated to the (expected) marginal returns to integration..

Does the Strategic and Institutional Environment Matter? Our final empirical exercise is to examine how the impact of vertical integration along short-term and long-term performance margins is impacted by the strategic and institutional environments. We are motivated both by our case studies and our underlying model of the mechanisms by which vertical integration may influence difference performance margins. Consider the role of labor unions. One of BT's insights is that improvement in performance at later stages of the product lifecycle requires an environment in which renegotiation and ex post adaptation are feasible. While ex post adjustment on noncontractible dimensions may be easier to achieve under "pure" vertical integration, the ability to adapt internal operations may be more limited when in-house production is also governed by a detailed labor union contract. As such, we expect that the returns to vertical integration in the later stages of the product lifecycle may be lower when production is governed by an in-house labor union contract. For example, union requirements may restrict cross-functional development that could lead to quality improvements.

Table 5A reports two OLS regressions with SHORT TERM PERFORMANCE and PERFORMANCE CHANGE as the dependent variables, respectively. These OLS specifications are identical to (3-3) and (4-3) except for the inclusion of an interaction effect between UNION and VERTICAL INTEGRATION. While the presence of a union is associated with a small moderation of the penalty to vertical integration in terms of initial performance (though this interaction is statistically insignificant), the UNION dummy has a large and significant negative impact on the benefits to vertical integration in terms of PERFORMANCE CHANGE. Specifically, both VERTICAL INTEGRATION and UNION*VERTICAL INTEGRATION are statistically significant and about equal in magnitude; the presence of a union completely eliminates the "benefits" of vertical integration realized along the PERFORMANCE CHANGE margin. We interpret this finding as consistent with a model in which at least some of the benefits associated with vertical integration require the ability to adapt to unforeseen circumstances, a condition which is mitigated in the presence of strong labor union contract provisions.

We undertake similar exercises for interactions with SUNK COST and PLATFORM. The knowledge-based theory of the firm (Kogut and Zander, 1996; Argyres, 1996; Nickerson and Zenger, 2003) suggests that firms with a deeper knowledge base and a higher level of experience in a particular areas may be able to mitigate some of the ex ante costs of vertical integration (in terms of reduced performance) and be able to take particular advantage of learning opportunities over the lifecycle. For example, Toyota used its deep knowledge base in design-for-manufacturing techniques to rapidly improve product design in the Lexus luxury vehicle. Despite having only entered the luxury segment in 1989, Toyota was leading the field by 1995. In Table 5B, we examine interactions between VERTICAL INTEGRATION and SUNK COST; as before, we report two OLS specifications (for each performance margin) with the same controls as in (3-3) and (4-3). Though the results are a bit noisy (and are statistically insignificant or not depending on the precise specification), the interaction between SUNK COST and VERTICAL INTEGRATION has a positive coefficient across a wide range of specifications. In other words, firms with significant sunk assets in a particular area (which we take as a proxy for experience in that area) are able to achieve a higher level of performance, for both performance margins, under vertical integration. This is consistent with a model in which some of the benefits from vertical integration arise from opportunities for significant organizational learning.

Finally, we explore the interaction between VERTICAL INTEGRATION and PLATFORM. Our case evidence suggests that, for platform technologies, firms may invest more significantly over the product lifecycle, since the returns to a strong knowledge base and renegotiation are realized across a wider range of automobile models. Consequently, there may be economies of scope in learning and adaptation. While the coefficient on PLATFORM*VERTICAL INTEGRATION is indeed positive in the performance change equation (6C-2), the estimates are quite noisy (and are rarely significant). At least in part, this imprecision likely arises since the rationale for a platform technology (and the effort firms use to improve performance within a platform technology) varies considerably across the firm in our sample.

VI. Concluding Remarks

This paper examined the impact of vertical integration on the dynamics of performance in the context of automobile product development. Our insight is that vertical integration will have differential impacts on different performance margins. Specifically, we looked at how vertical integration is related to the performance profile over the product lifecycle. On the one hand, outsourcing facilitates access to cutting-edge technology and the use of high-powered performance contracts. On the other hand, vertical integration allows firms to adapt to unforeseen contingencies and customer feedback, to maintain more balanced incentives over the product lifecycle, and to develop firm-specific capabilities over time. These effects suggest that outsourcing will be associated with higher levels of *initial* performance, while vertical integration will be associated with a higher rate of performance improvement over the product lifecycle.

A series of case examples reinforces each of these insights. While outsourcing yields benefits at the time of initial product introduction, vertical integration is associated with performance improvement over time. We then subjected these ideas to a more systematic empirical analysis. Our data combine detailed performance measures over time with nuanced measures of the extent of vertical integration, as well as measures of the contracting and technology environment. We are cautious in interpreting our results: the size of our dataset is modest, and we have not attempted to fully account for the heterogeneous impact of vertical integration on performance across observations (which would necessitate the use of an average treatment effects estimator). With these caveats in mind, we use both OLS and an instrumental variables estimator to establish four key results. First, initial performance is declining in the level of vertical integration. Second, the level of performance improvement is significantly increasing in the level of vertical integration. Moreover, even after controlling for other factors impacting performance, the magnitude of these two effects are roughly identical – there is no relationship between vertical integration and "overall" performance. Finally, taking advantage of outsourcing during the early part of the product lifecycle and internal development during the latter years of the lifecycle depends on the institutional and strategic environment. For example, the long-term benefits to vertical integration are erased for those firms with a strong union presence. Overall, the empirical findings highlight that vertical integration is associated with both costs *and* benefits and that different performance margins will reflect the tradeoffs associated with alternate contracting modes.

While the current analysis focuses on two specific performance margins, further analysis could yield additional insight into the economic and strategic logic underlying the relationship between vertical integration and performance dynamics. For example, while our evidence suggests that both the contracting costs approach and the KBV influence the performance dynamics that we observe, it would be extremely useful to disentangle these mechanisms more precisely, and evaluate the circumstances and conditions under which each is salient. Our approach has been to let the data speak for itself; however, we would like to separately explore more structural approaches, by accounting explicitly for selection into the chosen level of vertical integration. Finally, our analysis highlights the interaction between contracting choices at a point in time and the dynamic performance of organizations. A more complete theoretical and empirical framework for the co-evolution of firm boundaries and performance is an important agenda for future research.

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FIGURE 1
Timing of Procurement and Ex-Post Adaptation

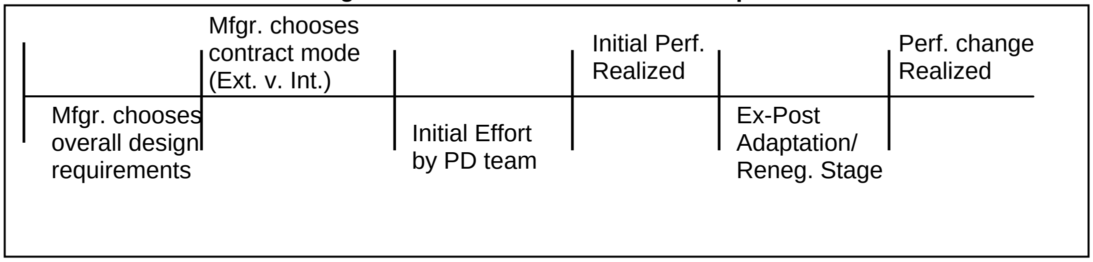

FIGURE 2
The Costs and Benefits of Outsourcing:

	Vertical Integration	External Sourcing
Ex Ante Contracting Opportunities	• Deep vehicle- specific knowledge base • Less knowledge of system-specific technology • Difficult to enforce specific performance criterion	•Global supply opportunities •Opportunity for well-defined performance contracts
Ex Post Renegotiation Outcomes	• Continuing authority relationship allows for redirection • Potential for learning	• Hard to enforce contracts after key requirements have been met • Fewer continuing relationships

Synthesizing the Case Evidence

FIGURE 3
Average Performance Rating By High or Low Vertical Integration, by Years Since "Major" Model Introduction

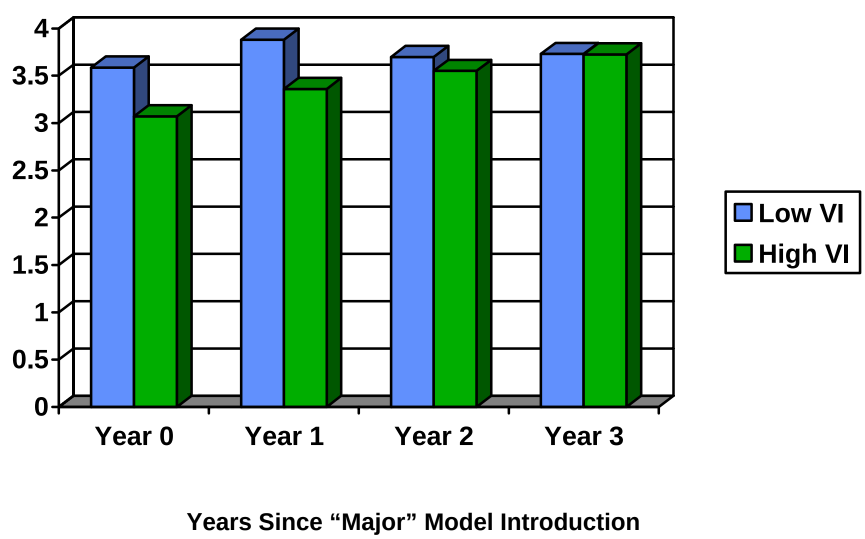

TABLE 1
Variables & Definitions

VARIABLE	DEFINITION	MEAN	STD. DEV.
PERFORMANCE MEASURES			
PERFORMANCE RATING	*Consumer Reports* rating (from 1-5, w/ 5 as the "highest rating") for system *i* on model *j* in year *t* after a major model change. The rating that is chosen for a given model-year is the "first" *CR* rating available for that model-year	3.541	.970
SHORT TERM PERFORMANCE	Average of PERFORMANCE RATING_{ij0} and PERFORMANCE RATING_{ij1}, as available. When only one *CR* rating is available, only one is used.	3.419	.965
LONG TERM PERFORMANCE	Average of PERFORMANCE RATING_{ij2} and PERFORMANCE RATING_{ij3}, as available. When only one *CR* rating is available, only one is used.	3.705	.967
PERFORMANCE CHANGE	LONG TERM PERFORMANCE – SHORT TERM PERFORMANCE	0.286	.832
OVERALL PERFORMANCE_i	Average of SHORT TERM PERFORMANCE and LONG TERM PERFORMANCE	3.563	.871
CONTRACTING MEASURES			
VERTICAL INTEGRATION	Percentage of the system produced in house between 0 and 1 (1 indicates all in-house production)	.513	.318
SYSTEM-SPECIFIC CONTRACTING AND PERFORMANCE DRIVERS			
SUNK COST	Dummy = 1 if pre-existing in-house sunk costs and/or plant investment for system *i*	.143	.351
LOW CAPACITY	Dummy = 1 if plant has insufficient capacity to manufacture system design in-house	.170	.377
PLATFORM	Dummy = 1 the component was designed to be used for more than one vehicle model	.527	.502
COMPLEXITY	Degree of System Complexity, ranging from 0 to 1	.392	.275
DESIGN GOAL	Measure for desired performance goals at the system level, ranging from 0 (low) to 1 (high)	.457	.311
SKILL SHORTAGE	Dummy = 1 if key worker skills are missing in existing plant locations	.161	.369
MODEL-YEAR MEASURES			
UNION	Dummy = 1if one of the individual component is produced in-house and covered under union agreement	.464	.501

TABLE 2
Performance Rating Margins
By High or Low Vertical Integration

VERTICAL INTEGRATION	SHORT TERM PERFORMANCE	LONG TERM PERFORMANCE	PERFORMANCE CHANGE
"Below" Median	3.70	3.73	0.03
"Above" Median	3.25	3.69	0.44

Median VERTICAL INTEGRATION = 0.50

TABLE 3
Short-Term Performance

Dependent Variable : SHORT TERM PERFORMANCE (N=112)				
	(3-1)	(3-2)	(3-3)	(3-4)
	Ordinary Least Squares			Instrumental Variables
VERTICAL INTEGRATION	-0.794** (0.279)	-0.679** (0.249)	-0.456* (0.263)	-0.664** (0.311)
SUNK COST			-0.269 (0.474)	-0.268 (0.478)
LOW CAPACITY			0.001 (0.423)	-0.033 (0.439)
PLATFORM			-0.001 (0.123)	-0.017 (0.126)
COMPLEXITY			0.277 (0.292)	0.291 (0.294)
DESIGN GOAL			-0.552 (0.456)	-0.579 (0.440)
SKILL SHORTAGE			-0.055 (0.315)	-0.069 (0.321)
UNION			-0.322 (0.209)	-0.267 (0.243)
YEAR		0.090 (0.024)	0.078** (0.027)	0.076** (0.028)
CONSTANT	3.827 (0.168)	3.949 (0.268)	4.119 (0.340)	4.257 (0.349)
Parametric Rest.		#Restr F-stat p-value	#Restr F-stat p-value	#Restr F-stat p-value
SYSTEM DUMMIES		6 4.84 .037	6 2.69 .127	6 3.83 .063
R-Squared	0.068	0.407	0.438	
RHS Endogenous Variables				VERTICAL INTEGRATION
Instrumental Variables				For system *i* of model *j* in year *t,* sums of each model-specific measure for all other systems but system *i*. This can be defined as: $Z_{-i,j,t} = \left(\sum_{l=1,...,7} Z_{ljt} - Z_{ijt} \right)$ $Z = \left\{ \begin{matrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \\ \text{DESIGN GOAL} \\ \text{SKILL SHORTAGE} \end{matrix} \right\}$

Notes: Standard errors, clustered by company, are given in parentheses.
Stars denote statistical significance at 5%(**), and 10% (*) significance level.

TABLE 4
Performance Change

Dependent Variable : PERFORMANCE CHANGE (N=112)										
	(4-1)		(4-2)			(4-3)			(4-4)	
	Ordinary Least Squares								Instrumental Variables	
VERTICAL INTEGRATION	0.611**		0.845**			0.828**			1.255*	
	(0.243)		(0.392)			(0.383)			(0.723)	
SUNK COST						0.392**			0.438*	
						(0.174)			(0.221)	
LOW CAPACITY						0.100			0.156*	
						(0.079)			(0.091)	
PLATFORM						-0.099			-0.072	
						(0.097)			(0.089)	
COMPLEXITY						0.412			0.340	
						(0.321)			(0.326)	
DESIGN GOAL						-0.090			0.052	
						(0.413)			(0.368)	
SKILL SHORTAGE						-0.593*			-0.559**	
						(0.322)			(0.290)	
UNION						-0.608**			-0.645*	
						(0.274)			(0.344)	
YEAR			0.036*			0.078**			0.067	
			(0.020)			(0.020)			(0.044)	
SHORT TERM						-0.697**			-0.521	
PERFORMANCE						(0.090)			(0.381)	
CONSTANT	-0.028		-0.217			2.425			1.472	
	(0.146)		(0.282)			(0.522)			(1.558)	
Parametric Rest.		#Restr	F-stat	p-value	#Restr	F-stat	p-value	#Restr	F-stat	p-value
SYSTEM DUMMIES		6	444.18	.000	6	14.38	.003	6	1.42	.340
R-Squared	0.055		0.126			0.583				
RHS Endogenous Variables									VERTICAL INTEGRATION SHORT TERM PERFORMANCE	
Instrumental Variables									For system *i* of model *j* in year *t,* sums of each model-specific measure for all other systems but system *i*. This can be defined as: $Z_{-i,j,t} = \left(\sum_{l=1,\ldots,7} Z_{ljt} - Z_{ijt} \right)$ $Z = \left\{ \begin{matrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \\ \text{DESIGN GOAL} \\ \text{SKILL SHORTAGE} \end{matrix} \right\}$	

Notes: Robust standard errors, clustered by company, are given in parentheses.
Stars denote statistical significance at 5%(**), and 10% (*) significance level.

TABLE 5A
Interaction Effects: Union

Dependent Variable	(5A-1) SHORT TERM PERFORMANCE	(5A-2) PERFORMANCE CHANGE
	Ordinary Least Squares	
VERTICAL INTEGRATION	-0.735*	1.439**
	(0.416)	(0.348)
VI * UNION	0.578	-1.245**
	(0.412)	(0.328)
UNION	-0.634	0.071
	(0.247)	(0.309)
System-Specific Controls	Included	Included
System Fixed Effects	Included	Included
Year Trend	Included	Included
R-squared	0.443	0.618

TABLE 5B
Interaction Effects: Sunk Costs

Dependent Variable	(5B-1) SHORT TERM PERFORMANCE	(5B-2) PERFORMANCE CHANGE
	Ordinary Least Squares	
VERTICAL INTEGRATION	-0.507**	0.774*
	(0.252)	(0.367)
VI * SUNK COST	1.457*	1.250
	(0.768)	(0.856)
SUNK COST	-0.993	-0.234
	(0.735)	(0.540)
System-Specific Controls	Included	Included
System Fixed Effects	Included	Included
Year Trend	Included	Included
R-squared	0.451	0.596

TABLE 5C
Interaction Effects: Platform

Dependent Variable	(5C-1) SHORT TERM PERFORMANCE	(5C-2) PERFORMANCE CHANGE
	Ordinary Least Squares	
VERTICAL INTEGRATION	-0.519*	0.569*
	(0.313)	(0.303)
VI * PLATFORM	0.156	0.637
	(0.496)	(0.501)
PLATFORM	-0.075	-0.406
	(0.247)	(0.291)
System-Specific Controls	Included	Included
System Fixed Effects	Included	Included
Year Trend	Included	Included
R-squared	0.438	0.596

Notes: Standard errors, clustered by company, are given in parentheses.
Stars denote statistical significance at 5%(**), and 10% (*) significance level.

Appendix A

Contracting in Automobile Product Development

Our analysis focuses on the product lifecycle for automobile models. While autos are incrementally upgraded annually, an automobile model undergoes a “major” model change approximately every five years. A “major” model change is an opportunity to significantly alter product positioning, technologies, and contracting choices for an automobile model. While a manufacturer is constrained by the history of the vehicle, sunk investments, etc., the process underlying a major model change is substantial, and allows for significant changes in the design and organization of the automobile model.

Product development of a new vehicle or a major model change begins with a “vehicle integrity” team which chooses broad vehicle performance and positioning (i.e. “The Ultimate Driving Machine”). Work is decomposed into key system technology requirements (e.g., Engine Horsepower) and further decomposed into sub-systems and then individual components. Once the key positioning and technology choices have been made, sourcing and procurement take place at the component level. The purchasing decision determines the extent of external product development contracting. Although purchasing decisions are made at the component level, there are significant technological interdependencies at the system level. For example, the energy absorbing device is a seemingly simple sheet metal piece that functions as part of the steering system. By its appearance (“simple” design, readily available materials and processes), it looks as if its production should be outsourced, but every automobile manufacturer produces it in-house because of the important role it plays and of the complex interactions it has with virtually every other component of the steering system. These interactions require it to be developed from a system level perspective and not a component level, as any changes to the energy absorbing device must be carefully coordinated with all other parts, as they can drive changes to any or all of them in product development. The key technology and contracting choices made for the “major” model change can significantly constrain contract choice for the life of the major. Firms lack flexibility to transition from in-house production to outsourcing because it is extremely costly to contract for external suppliers if the project has been maintained internally in its initial stages. The difficulty of finding external suppliers for a "short" contract is compounded by the significant penalties external suppliers impose for supplier switching during contract life if they meet observable performance requirements. However, though the decisions are fixed in the "medium-term," the underlying contracts combine detailed specifications with a large degree of contractual incompleteness.

Contracts contain detailed provisions governing initial contract performance requirements for external contracts, including the ability to pass key safety and production thresholds, commitments to satisfy specific technical requirements, etc. Although the contract language includes requirements for continued involvement and updating in response to customer feedback, and incremental model improvement, there are very few mechanisms to enforce these contract provisions.

Appendix B

Data Collection

All participants were assured that only aggregate data would be presented, and confidentiality agreements were signed with each company. Data collection proceeded in several stages. After signing an agreement with each firm, a letter was sent requesting interviews with relevant project managers, system engineers, design engineers, purchasing managers and manufacturing engineers for each vehicle for each time period. The relevant parties were identified by the corporate liaison for each company, and on-site meetings were arranged. To ensure data accuracy, interviewees were given an overview of the research project and definitions for key terms. Subjects were given a list of questions pertaining to the design and sourcing of components within their respective systems. The questions focused on principally objective information (e.g. number of parts in the body side) so as to minimize the likelihood of response bias. The interviews were conducted on-site at each company, in time intervals ranging from three days to three months. All interviewees were given the option of being interviewed in their native languages. US and European interviews were conducted in English and Japanese interviews were conducted in Japanese.[1]

As flagship vehicles developed in different environments over time, wide variation in contracting practices (and the contracting environment) was expected, and competitive advantage in this segment is likely highly sensitive to quality (relative to price tradeoffs). By focusing on a single vehicle segment, we limit the measurement problems that arise from combining information from different vehicle types.

The unit of analysis is an automotive system for a specific "major" for a given automobile model. As discussed earlier, "major" model changes," which are typically implemented at approximately five-year intervals, provide an opportunity to significantly alter product positioning, technologies, and contracting choices for an automobile model. Overall, the dataset includes comprehensive information about seven systems for 19 automobile "major"

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[1] All interviews were conducted by one of the authors. Professor Kentaro Nobeoka, a scholar with extensive experience in the Japanese auto industry, provided Japanese interview interpretation.

model versions between 1980 and 1995.[2] The data were collected through on-site interviews with over 1000 people, including CEOs, chief engineers, project managers and the system engineers involved in the development of each model-year.

The original sample consists of 133 model-year systems, drawn from nineteen distinct "major" model changes (associated with seven different automobile models) and across seven distinct systems for each model: engine, transmission, body, electrical, suspension, steering, and brakes. From this initial dataset of 19 models, each of which includes seven distinct systems, 2 models were excluded from the analysis for inadequate data, leaving 119 observations. A small number of system-specific performance measures were unavailable for individual years and systems (largely due to "inadequate data").[3]

The final dataset consists of 112 observations of system-specific contracting choice, the contracting environment, and performance.

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[2] The overall dataset includes information about 8 distinct car models, many of which are observed at five-year intervals, with 19 total "model-years" for which complete data were available. For further detail Novak and Eppinger (2001).

[3] We actually have complete data for 114 observations for our regression related to short-term performance and 112 observations for regressions related to the long-term performance measure. The results do not change if the 2 observations for which no data on long-term performance are included or excluded from the analysis.

Appendix C

System-specific Contracting and Performance Drivers

Our analysis also includes a set of system-specific contracting and performance drivers, included to control for model-specific performance drivers that may be correlated with VERTICAL INTEGRATION, and also serve as a source of instrumental variables for the level of VERTICAL INTEGRATION on other systems within the same automobile model. There are six key measures.

SUNK COST is a dummy variable indicating whether there is pre-existing in-house sunk investments for each system (mean = 0.14). Specifically, managers were asked whether or not existing plant equipment directly affected their design choices for the system, as systems are often designed around plant-specific process equipment investments. On the one hand, the existence of pre-existing in-house capital investment will tend to favor a positive relationship between VERTICAL INTEGRATION and SUNK COST at the system level; as such, we employ SUNK $COST_{-i}$ as an instrumental variable for VERTICAL INTEGRATION in the IV analysis. When SUNK COST = 1, this likely indicates that a company has significant experience and capabilities in a given system (favoring a positive relationship with performance, and potential for learning over the product lifecycle.[4]

LOW CAPACITY is a dummy variable indicating that, prior to contracting, the level of in-house capacity is insufficient to manufacture the system in-house (mean = 0.17). If a certain system, like a one-piece body side, exceeds the capacity of current plant equipment, this will necessitate new physical investment. The relationship to performance is ambiguous. Specifically, LOW CAPACITY may indicate a lack of capabilities in a given system (favoring a negative relationship with performance), or perhaps suggest an increased propensity to adopt frontier technology (perhaps leading to a positive relationship with performance, particularly in

[4] It is also possible that SUNK COST will be associated with high barriers to adopting frontier technology and production methods, perhaps limiting performance (particularly early in the lifecycle). We explore the interaction between VERTICAL INTEGRATION and SUNK COSTS on both the short-term and long-term performance margin in Table 6.

the earliest parts of the product lifecycle).[5]

PLATFORM is a dummy variable equal to one for models with platform requirements where the component was designed to be used by more than one vehicle. Overall, this measure may have a complicated impact on performance over the product lifecycle. In the short-term, platform requirements may enhance or detract from initial performance, depending on a combination of the level of investment, innovation and capabilities underlying the platform development process. However, platform requirements are predicted to have a positive impact on PERFORMANCE CHANGE (as the firm is likely developing relevant competencies, and also has higher incentives to improve in response to feedback). Most importantly, PLATFORM may enhance the potential positive impacts of VERTICAL INTEGRATION over the latter stages of the lifecycle. Specifically, precisely to the extent that platform requirements will be associated with the development of specific capabilities and higher intrinsic incentives for improvement over time, PLATFORM may enhance the boost to performance over time associated with VERTICAL INTEGRATION. PLATFORM is likely itself correlated with VERTICAL INTEGRATION. Platform requirements could support in-house production through economies of scope achieved through parts sharing, and so we control for PLATFORM in assessing the relationship between VERTICAL INTEGRATION and different performance margins.

The degree of system-specific complexity may impact realized performance (as well as be correlated with VERTICAL INTEGRATION). The degree of system-level complexity will impact the need for coordination across component elements of the system, encouraging in-house contracting. Our measure of system complexity draws on several measures, based on detailed system design and manufacturing data. For each system, we estimate product complexity on a scale from 0 to 1 (no complex system interactions to high product complexity) based on an unweighted average of characteristics of design complexity. For some systems, measures include characteristics such as "newness" - the degree to which a design configuration has been used in the company and in the vehicle. For example, product complexity in the suspension system is

[5] However, note that LOW CAPACITY is likely to enhance the relative returns to outsourcing, and so we predict a negative relationship between VERTICAL INTEGRATION and LOW CAPACITY.

calculated as an unweighted average of three (0-1) measures: newness of the design, number of moving parts in the suspension and whether the suspension is active or passive. The measure used, COMPLEXITY (mean = .39), is the result of applying this procedure for each component within each system.

A separate measure of the design requirements is DESIGN GOAL, a variable equal to 1 if an individual system is associated with "high" system-specific performance goals. The importance of performance goals were provided by vehicle product managers, on a 0-10 scale, with 0 indicating no importance for product performance goals and 10 indicating that the vehicle competes based on high performance. While DESIGN GOAL reflects the ex ante objectives of the design process for each system, DESIGN GOAL is predicted to have a positive impact on each of the performance measures. We include it in our analysis as DESIGN GOAL may itself be correlated with VERTICAL INTEGRATION (and also with performance margins). However, the relationship with VERTICAL INTEGRATION may be subtle. Certain performance objectives necessitate more complex product designs, such as more integrated architectures (Ulrich and Eppinger, 1995). The need for such integration enhances the returns to vertical integration. However, as discussed earlier, accessing global frontier technology may necessitate outsourcing. As such, while theory suggests an ambiguous relationship between DESIGN GOAL and vertical integration, we control for this measure directly in order to avoid conflating the impact of VERTICAL INTEGRATION from DESIGN GOAL on individual performance margins.

SKILL SHORTAGE (mean = .15) is a dummy variable equal to 1 if system-specific worker skills are absent within current plant locations. For example, it is much more costly to produce a body design featuring many complex manual welds in an area where workers are not trained in advanced welding. Vehicle product managers were asked whether the absence of worker skills played a role in design considerations for each system. SKILL SHORTAGE may reduce performance across the product lifecycle, though the potential to alleviate a skill shortage through learning and investment over time suggests that SKILL SHORTAGE may be associated with a higher level of PERFORMANCE CHANGE.

We observe one measure at the model (rather than model-system) level, UNION. UNION is a dummy variable which is equal to 1 if *any* component is produced in house and covered under a union agreement. While the role of unions in initial performance is unclear (e.g., UNIONS may be associated with higher or lower *ex ante* capability levels), a high UNION presence may reduce the potential for ex-post adaptation. As such, we expect that UNION will be negatively related to PERFORMANCE CHANGE, and, moreover, that the interaction effect between PERFORMANCE CHANGE and UNION will also be negative.

We calculate fixed effects for each of the seven automobile systems (SEATS are the excluded category), and also introduce an overall (de-meaned) time trend (YEAR). The average observation is from a 1990 major model change, with a range from 1980 to 1996. We have also experimented extensively with alternative time trends, as well as the use of company fixed effects.

Appendix D

Overall Performance Regressions

Dependent Variable : OVERALL PERFORMANCE (N=112)							
	(D-1)	(D-2)			(D-3)		
	Ordinary Least Squares						
VERTICAL INTEGRATION	-0.488*	-0.256			0.117		
	(0.257)	(0.321)			(0.254)		
SUNK COST					0.021		
					(0.307)		
LOW CAPACITY					0.050		
					(0.301)		
PLATFORM					-0.050		
					(0.095)		
COMPLEXITY					0.386		
					(0.284)		
DESIGN GOAL					-0.405		
					(0.313)		
SKILL SHORTAGE					-0.332		
					(0.290)		
UNION					-0.514**		
					(0.101)		
YEAR		0.108**			0.090**		
		(0.018)			(0.018)		
CONSTANT	3.813	3.871			3.897		
	(0.155)	(0.269)			(0.285)		
Parametric Rest.		#Restr	F-stat	p-value	#Restr	F-stat	p-value
SYSTEM DUMMIES		6	70.84	.000	6	4.18	.053
R-Squared	0.032	0.543			0.612		

Notes: Standard errors, clustered by company, are given in parentheses.
Stars denote statistical significance at 5%(**), and 10% (*) significance level.