NBER WORKING PAPER SERIES

COMPLEMENTARITY AMONG VERTICAL INTEGRATION DECISIONS: EVIDENCE FROM AUTOMOBILE PRODUCT DEVELOPMENT

Sharon Novak
Scott Stern

Working Paper 13232
http://www.nber.org/papers/w13232

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
July 2007

Eugene Orlov and Mercedes Delgado provided outstanding research assistance. We thank George Baker, Tom Hubbard, Mike Mazzeo, Todd Zenger, three anonymous referees, and seminar participants at various universities and conferences for helpful comments and suggestions. This research was partially funded by MIT Center for Innovation and Product Development and the International Motor Vehicle Program at MIT. All errors or omissions remain our own. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

Complementarity Among Vertical Integration Decisions: Evidence from Automobile Product Development
Sharon Novak and Scott Stern
NBER Working Paper No. 13232
July 2007
JEL No. L24,L62,O32

ABSTRACT

This paper examines complementarity among vertical integration decisions in automobile product development. Though most research assumes that contracting choices are independent of each other, contracting complementarity arises when the returns to a single vertical integration decision are increasing in the level of vertical integration associated with other contracting choices. First, effective coordination may depend on the level of (non-contractible) effort on the part of each agent; contracting complementarity results if coordination efforts are interdependent and vertical integration facilitates a higher level of non-contractible effort. Second, effective coordination may require the disclosure of proprietary trade secrets, and the potential for expropriation by external suppliers may induce complementarity among vertical integration choices. We provide evidence for complementarity in product development contracting by taking advantage of a detailed dataset that includes the level of vertical integration and the contracting environment for individual automobile systems in the luxury automobile segment. Using an instrumental variables framework that distinguishes complementarity from unobserved firm-level factors, the evidence is consistent with the hypothesis that contracting complementarity is an important driver of vertical integration choices. The findings suggest that contracting complementarity may be particularly important when coordination is important to achieve but difficult to monitor.

Sharon Novak
Policy Department
D505
UCLA Anderson School of Management
Box 951481
Los Angeles, CA 90095
snovak@anderson.ucla.edu

Scott Stern
Management and Strategy Department
Kellogg School of Management
2001 Sheridan Road
Evanston, IL 60208
and NBER
s-stern2@northwestern.edu

I. Introduction

The modern theory of the firm has made considerable progress in explaining the determinants of vertical integration and firm boundaries, assuming that the level of vertical integration results from independent transactional choices (Masten and Saussier, 2002; Richman and Macher, 2006). For most organizations, however, firm boundaries are not determined by independent vertical integration decisions but depend on interrelated choices spanning functional activities (Holmstrom, 1999; Nickerson 1997). For example, in automobile product development, the degree of vertical integration for a single manufacturer is the consequence of hundreds of individual procurement choices, ranging from simple supply contracts for commodity components to complex arrangements for cutting-edge technology development. If these individual contracting choices are interdependent with each other, the decision to outsource a single function (e.g., the supply for an individual component) impacts the vertical integration calculation for related procurement decisions. This will be particularly true if overall performance depends on coordination among agents responsible for these functional areas and the degree of coordination is sensitive to governance structure.

Interdependence among governance choices has important testable implications for patterns of vertical integration. When the marginal returns to vertical integration for a given vertical integration choice are increasing in the level of vertical integration on related choices, there will be complementarity among governance choices, which we refer to as contracting complementarity. The goals of this paper are to identify conditions under which contracting complementarity may be an important driver of vertical integration decisions, and to evaluate the empirical evidence for contracting complementarity in the context of automobile product development governance choices.

Our analysis suggests that contracting complementarity arises when coordination is important to achieve but difficult to monitor. Consider the coordination required between two automobile product development teams, each of which is responsible for one of two distinct "systems" (e.g., the engine system or the brake system). While some incentives for coordination between the teams can be written into formal contracts, effective coordination requires non-contractible coordination effort by each team. The benefits from coordination are likely to depend on the level of interaction between the teams: a high level of coordination effort by one team will be of little benefit unless reciprocated with effort by the other team. In other words, coordination efforts are complements. Moreover, while external teams may be more responsive than in-house teams to explicit incentives for system-specific performance, external teams may be less effective than in-house teams in terms of devoting effort towards cross-system coordination (precisely because such effort is non-contractible). If vertical integration in any one system induces a higher level of coordination effort by team members for that system, and the marginal returns to coordination effort is increasing in the level of coordination effort by other teams, the vertical integration choices for each system will themselves be complements. Trade secrecy concerns may also result in contracting complementarity. While effective coordination requires disclosing strategic technical choices, such information may also result in expropriation if that knowledge leaks to competitors. If the risk of expropriation is particularly salient with the first potential leakage of information (i.e., the first external contract), trade secrecy concerns may limit disclosure unless all development is maintained internally. More generally, contracting complementarity arises when the returns to vertical integration for any one system are increasing in the level of vertical integration on other systems.

Our focus on interdependence among vertical integration choices differs from most theoretical and empirical research in economics, which often focuses on the drivers of vertical integration at the level of *transactions* (Williamson, 1979; Hart and Moore, 1990; Whinston, 2003).[1] In contrast, product development researchers have increasingly identified the *interactions among components and systems* as perhaps the most important "problem" in managing new product development (Eppinger, et al, 1994; Ulrich, 1995; Suh, 1999; Baldwin and Clark, 2000). This literature emphasizes the role of interfaces and vertical integration for achieving effective coordination (Alexander, 1964; Suh, 1990; Ulrich and Eppinger, 1995).[2] Motivated by these insights from the product development literature, and our qualitative research on contracting practices in the automobile industry, this paper explores whether coordination requirements and the need to share knowledge across components and systems may result in complementarity across vertical integration choices.

Our analysis of contracting complementarity exploits an original and 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.). Across different systems, we observe a similar 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. Observing multiple system-specific measures allow us to develop and implement an instrumental variables strategy that overcomes several related problems in

---

[1] *See* Masten and Saussier (2002) and Macher and Richman (2006) for recent surveys of the transaction cost economics literature, and Tirole (1999) for a survey of the incomplete contracting literature. Empirical research has primarily focused on individual contracting opportunities in which individual decisions are assumed independent (e.g., Joskow, 1988; Baker and Hubbard, 2004). In the context of product development, this approach has placed emphasis on individual *components,* examining how factors such as asset specificity or relative bargaining power shape contracting at the most "micro" level of decision-making (Monteverde and Teece, 1982; Masten, 1984; Masten, Meehan and Snyder, 1991). While we are not aware of prior studies of contracting complementarity, several recent papers highlight interrelationships in governance choice. For example, building on Nickerson (1997), Nickerson and Silverman (2003) highlight the potential for spillovers across truckers taking orders from a single carrier, while Azoulay (2004) examines the potential for substitutability in drug development contracting choices and argues for a "portfolio" approach to empirical contract analysis.

[2] Though more abstract than this applied paper, Segal (1999) provides theoretical foundations for multi-lateral contracting choice, emphasizing the potential for signaling across contracting decisions.

testing for complementarity among organizational design choices.[3] An instrumental variables approach is required to disentangle contracting complementarity from unobservable firm-level fixed effects in contracting mode (e.g., if a firm adopts "outsourcing" across all systems in response to a fad). We adapt the methodology proposed in Arora (1996) and Athey and Stern (2004) to exploit system-specific variation in the contracting environment within each automobile model. In particular, we estimate the sensitivity of vertical integration on a system *i* to the level of vertical integration on other systems within that model by (a) including the system-specific measures for system *i* directly as control variables and (b) using the system-specific drivers for the *other* systems as instruments for the level of vertical integration on those other systems. Of course, this approach requires that the system-specific measures are themselves exogenous. While we do not observe a single unambiguous natural experiment, the richness of the dataset allows us to explore several alternative identification strategies. In particular, we observe multiple observations for individual model-systems over time (i.e., we observe 2-4 system-specific observations per automobile model), and so we are able to focus exclusively on *within-variation* (i.e., changes in the contracting environment over time within a model-system), exclusively on *between-variation* (e.g., variation in contracting choices across model-systems linked to variation in the *initial* contracting environment for each model-system), or allow for both sources of variation. Observing multiple system-specific drivers of vertical integration, and exploring whether the results depend on cross-sectional or time-series identification strategies, the core of the empirical strategy is based on assuming that we observe exogenous system-specific differences in the contracting environment which also result in differences in contracting choices.

Our findings highlight the potential empirical importance of contracting complementarity. First, using the instrumental variables strategy described above, the probability of vertical integration for each automobile system increases in share of other systems that are vertically integrated. This finding is statistically and quantitatively significant, remains similar in magnitude whether we rely exclusively on time-series or cross-sectional variation (or both), and is robust to focusing exclusively on system-specific measures relating to pre-existing in-house capabilities/resources or exclusively focusing on measures related to the intensity of design and manufacturing challenges. Additionally, the findings are most salient in environments where we expect contracting complementarity to be most important (e.g., among tightly coupled systems within the automobile). Taken together, the evidence is suggestive of contracting complementarity rather than spurious correlation induced by company-level fixed effects in outsourcing.

[3] A growing literature examines complementarity in organizational design more generally from both theoretical and empirical perspectives, with several specific applications to the automobile industry (Milgrom and Roberts, 1990; Holmstrom and Milgrom, 1994; Helper, 1995, 1997; Ichniowski, Shaw and Prenusshi, 1997; Cockburn, Henderson and Stern, 2003; Ichniowski and Shaw, 2003; Van Biesebroeck, 2006; MacDuffie, 1995; Pil and MacDuffie, 1996).

While we interpret this evidence cautiously in light of the size of the dataset and the inherent challenges in assessing the drivers of organizational design, our results do suggest that assuming away contracting complementarity may be problematic in contexts where coordination activities are important yet difficult to monitor. Contracting complementarity may have implications for aggregate patterns of vertical integration. Consider how one might interpret the increased (and clustered) use of outsourcing. While most researchers interpret the increased use of outsourcing of non-core activities as a firm-level "strategy," contracting complementarity suggests that a coordinated shift towards outsourcing might be the result of an unraveling process; under contracting complementarity, the benefits to vertical integration for individual functions depend on maintaining a vertically integrated structure across functions.

The remainder of the paper is organized as follows. The next section introduces a qualitative assessment of product development contracting choices in the automobile industry, and the potential for contracting complementarity in this environment. Section III derives a formal empirical framework for testing for contracting complementarity. After a review of the data in Section IV, Section V presents our empirical findings. A final section concludes.

II. Interactions among Vertical Integration Choices in Automobile Product Development

The Setting.[4] Automobile product development is among the most well-known settings to study the drivers of vertical integration and contracting, beginning with the classical GM-Fisher Body integration choice (Coase, 1937; Klein, et al, 1978; Monteverde and Teece, 1982; Hart, 1995; Casadesus-Masanell and Spulber, 2000; Bigelow, 2003). This is not surprising, as product development and governance choices reflect features of the contracting literature, including the importance of non-contractible investment and the potential for renegotiation.

While most empirical research in economics and strategy assesses the determinants of vertical integration at the level of individual transactions, coordinating activities *across* transactions is at the heart of automobile product development (Ulrich and Eppinger, 1995). The organization of product development activities reflects the technical choices and interfaces of the vehicle itself. After overall vehicle requirements and goals are chosen (e.g., building "the ultimate driving machine" or "the safest car on the road"), work is decomposed into requirements for each automobile system (e.g., engine horsepower, steering column adjustability). These system requirements are then translated into needs for sub-systems or individual components (e.g., engine block characteristics, steering column characteristics).

Though procurement takes place at the level of individual components (e.g., an engine block with a given specification can be made or bought), vehicle performance depends on effective coordination

[4] This section is based on a detailed qualitative understanding of the drivers and impact of contracting and vertical integration in this setting, drawing on a multi-year study by one of the authors (Novak and Eppinger, 2001).

among components and between systems, and performance is only observed after a long lag. For example, in the event of a crash, safety performance depends on seamless integration between the engine, braking and steering systems; as a result, design decisions for the engine block must be coordinated with design decisions in the braking and steering systems. Realized performance of each system will only be observed after the vehicle goes into production, on average five years after the initiation of product development (Novak and Klibanoff, 2004).

Automobile manufacturers achieve this coordination in several ways. First, product development is typically governed by a "vehicle integrity" team, which has responsibility for monitoring and ensuring cross-system coordination throughout the automobile. Second, and perhaps more importantly, direct coordination among individuals responsible for different components or systems is achieved through repeated and ongoing exchanges of information, such as technical requirements for interacting parts or software specifications impacting multiple vehicle systems. In some cases, effective integration requires updating information on even a daily basis. While coordination activities have always been crucial, their importance across vehicle systems has increased dramatically over the past twenty years, with the introduction of advanced electronics that impact multiple systems, such as electronic engine controllers, antilock brake systems (ABS), or electronic features such as anti-whiplash protection.

Our goal is to examine how the inability to contract on the level of effort devoted to coordination across systems limits the effectiveness of coordination efforts, particularly when contracting with external parties. We begin by describing the challenges of contracting for cross-system coordination effort, and how secrecy concerns in product development can similarly reduce such effort. We then outline how these forces can result in complementarity across vertical integration choices.

Cross-System Coordination Effort. Effective vehicle performance requires substantial investments in coordination across individual components and systems. However, contracting on the level of effort devoted towards coordination is costly and difficult to enforce. For example, while contracting in terms of specification ranges is feasible (e.g., the gear box for the transmission system must be 12cm wide plus or minus 2 cm), it is difficult to write and enforce contracts which assign responsibility for resolving system-to-system mismatches (e.g., ensuring that the allowable range of gearbox parameters is adjusted when the body dimensions are also at the high end of a given range). This is because the benefits to coordination depend on effort by all parties involved, but a higher probability of failure results from shirking by even one agent. Moreover, the performance consequences of insufficient coordination can rarely be assigned to any one individual or unit (any one party can blame "failure to coordinate" on every other party involved), a problem that is compounded by the fact that failure is often observed only with a long lag (often after the product is commercially introduced). Consequently, while procurement contracts with external suppliers specify that coordination activities must be undertaken, the inability to assign responsibility for coordination failure makes such provisions essentially unenforceable.

In most cases, the inability to enforce formal contract terms relating to coordination limits the effectiveness of formal contracts in inducing effort towards coordination, and suggests that the coordination effort by external suppliers will likely be lower than that achieved by an internal team. First, since the vehicle integrity team is internal to the firm, members of these teams are at a higher level in the organizational hierarchy and so have (formal) authority over internal system engineers (Clark and Fujimoto, 1991); in contrast, external suppliers are less constrained by the authority relationships within the manufacturer's organization. While internal teams can be focused exclusively on a single project (allowing time for investments in coordination activities), suppliers often work on multiple projects, and it is difficult for the manufacturer to observe the precise allocation of time to individual projects. Second, while supplier incentives are closely linked to the verifiable terms of formal contracts, internal teams may be able to be monitored and provided effective subjective performance incentives (Baker, Gibbons and Murphy, 1994; 2002). For example, while the observed seat defect rate is a measure that a seat supplier may agree to incorporate into a contract, a seat supplier likely will not contract on qualitative customer satisfaction ratings (in part, because the manufacturer may distort such data to lower payments). The use of subjective performance signals can be achieved through direct compensation, subjective bonuses, and promotion incentives. While reputational mechanisms can also be used to encourage external suppliers, relational contracting incentives will be more salient for internal employees who have a long-lived relationship with a single firm. Finally, ensuring a given level of coordination is often easier in the context of internal development, where product development teams are more likely to be co-located and share a common language and background (Ulrich, 1995). Together, these factors suggest that the coordination effort by external suppliers will likely be lower than that achieved by an internal team.

Consider the case of rollovers and tire blowout incidents on the Ford Explorer that was traced to the interaction between Ford and its tire supplier, Firestone (Kumar, 2001; Kalogeridis, 2005). While both Ford and Firestone successfully completed the design and production responsibilities laid out in their contract, the parties were not able to effectively manage the interface between their responsibilities. That is, while the tires were within contractually specified maximum and minimum tire inflation specifications and the vehicle body was within maximum and minimum weight specifications, the accidents resulted from a complex interaction between vehicle and tire that neither Ford nor Firestone had considered. When asked about the vehicle failures, Firestone spokeswoman Jill Bratina said. "The vehicle is beyond our area of expertise," and a Ford spokesman stated, "This is a tire issue, not a vehicle issue." (Kumar, 2001). At least in part, this coordination problem was exacerbated by the fact that Ford was unable to manage system-to-system coordination activities with Firestone as effectively as they might had tire design and supply been maintained in-house. Had tire development and body development been in-house at Ford, effective coordination would have unambiguously been a "Ford" issue. Simply put, the ability to coordinate between systems was reduced by outsourcing. While the resultant safety hazard was likely an extreme case, Ford/Firestone highlights the role of coordination among systems in product development.

Trade Secrecy. Trade secrecy concerns also limit the effectiveness of coordination efforts across components and systems within an automobile. Automobile manufacturers expend substantial resources on maintaining design and technology choices as secrets during the product development stage. For example, for most companies, product development for each system occurs within a secure facility, and system-specific or even component-specific access codes are required to access specific areas or computer databases. When a system is outsourced, it is more likely that trade secrets will leak. Not necessarily as a direct consequence of explicit industrial espionage, knowledge about new innovations or design initiatives can inadvertently be revealed to competitors when external suppliers exploit knowledge gained in one partnership in bidding on future projects. For example, in the 2001 lawsuit between Daimler-Chrysler and General Motors, Daimler charged that the GM Hummer H2 grille was "borrowed" from the Jeep design (Kiley, 2001; respondent interviews). The Hummer grille was designed by AM General. AM General received a trademark for the grille in 1996, when it was exclusively designing for Jeep. General Motors signed an agreement with AM General in 1999 to develop and build vehicles based on the Hummer design. The lawsuit was based on the argument that Chrysler's outsourcing of Jeep grilles to AM General resulted in the design being passed on to General Motors, in violation of Jeep intellectual property. While it is possible to "copy" designs by reverse-engineering or benchmarking, a supplier can pass on detailed information such as effective design of distinctive characteristics (such as the sharp edges of the Jeep grille) through related experience on other projects. In the case of the Jeep lawsuit, a study alleged "Nearly two-thirds of all Jeep Grand Cherokee and Jeep Cherokee owners ... incorrectly associated the new H2 grille with a DaimlerChrysler." (Kiley, 2001).

Trade secrecy concerns place restrictions on effective design integration when product development is outsourced through a substantial reduction in the amount and frequency of information that can be exchanged among developers. Whereas internal product development groups can (mostly) exchange information about design details freely, external suppliers may expose highly confidential trade secrets, and so manufacturers place additional limits on their access to pieces of information.[5] Cross-system coordination requires disclosure of design details for each system; limiting the release of technical details because of trade secrecy concerns reduces the ability to coordinate systems during product development.[6]

[5] For example, "early" spy photos of vehicles in development are highly sought after by trade publications, and suppliers have been sued for using their access to cause competitive harm through trade secrecy violations.

[6] Though long-term exclusive contracts might mitigate such concerns, such arrangements are rare in the automobile industry, as a principal benefit of organizing as an independent supplier is the ability to leverage investments across

Since effective integration requires the disclosure of design choices, manufacturers working with external suppliers face the risk of innovations being revealed to competitors before vehicles are introduced to the market.[7] Consider the case of cellular telephones (respondent interviews). In the luxury car market, a design challenge has been the integration of the cellular telephone sub-system into the audio system. In an integrated design, the cellular telephone would share a circuit board and control panel with the audio system, and these would interface with the antennas, speakers, and microphone. In contrast, a modular design would maintain the cell phone's circuitry as separate from the audio system. This facilitates outsourcing production of the cellular telephone components, with little overlap between manufacturer and supplier during product development. While the integrated design has several performance and cost advantages, such as better sound quality and less bulk, the integrated design would also require extensive disclosure by the auto manufacturer to the cellular telephone supplier during product development. For example, an integrated design would reveal to the supplier whether a Global Positioning System ("GPS") was also included, while a modular design need not result in this disclosure. When considering whether to choose the integrated or modular design, the manufacturer must trade off the benefits to coordination with the potential costs of disclosure of proprietary design decisions.

Complementarity among Vertical Integration Decisions. While our discussion so far has focused on how trade secrecy concerns and cross-system coordination impact the returns to outsourcing on a single system, we now examine how these issues result in interdependence among outsourcing choices (i.e., complementarity among vertical integration choices among systems in product development).[8] Let us first consider the role of cross-system coordination effort. Consistent with our qualitative discussion, suppose that (a) cross-system coordination effort is non-contractible and (b) the returns to coordination effort by workers associated with one system is higher if the level of coordination effort by workers on other systems is higher. Moreover, suppose that the level of coordination effort elicited under in-house governance is higher than under outsourcing, perhaps because of the ability to provide subjective incentives for coordination to in-house workers. Finally, while the level of cross-system coordination effort is important, each governance choice is additionally impacted by factors shifting the returns to vertical integration independent of other systems. Then, vertical integration on any one system will be a complement to the level of vertical integration on any other system. An increase in the idiosyncratic

projects for multiple firms. Indeed, while some expropriation may be intentional and violate confidentiality agreements, most information leaks occur because suppliers advertise the innovations developed in an ongoing project in their bids for new projects with other manufacturers.

[7] Secrecy is particularly important since competitive advantage in the automobile industry depends, in large part, on earning "transitory" advantage on innovations during the period in which other firms "catch up" as they imitate value-enhancing new features and performance improvements.

[8] In Appendix A, we develop a simple formal model in which coordination effort and/or trade secrecy concerns results in complementarity among vertical integration choices, which we summarize in this sub-section.

returns to vertical integration for one system (e.g., an increase in system-specific capabilities) will not only raise the marginal returns for in-house contracting for that system, but will have a spillover effect on other systems for the same automobile. For example, the vertical integration of engine system components is highly dependent on the internal capabilities of a given manufacturer (some such as Honda are highly skilled in this area, others less so); when these capabilities allow for vertical integration in that system, this also greatly facilitates coordination of engine development with those of other systems such as the body and transmission. For example, Honda has been able to support a wider range of engine/transmission combinations in the Acura Legend than competitors, through intense coordination between its internal engine, transmission, and body teams (respondent interviews).

A related argument suggests that trade secrecy concerns can also result in complementarity among governance choices. Suppose that outsourcing any single system enhances the risk of loss from disclosure of trade secrecy, and the marginal (expected) losses from disclosure of additional systems are declining. In other words, while outsourcing a single system entails a significant disclosure cost (perhaps because of the need to develop systems or infrastructure to protect information), the incremental disclosure costs arising from outsourcing are lower. When the marginal costs of disclosure are declining in the level of outsourcing, the marginal returns to vertical integration on any one system are higher when a related system is already vertically integrated. For example, as in the cellular phone case discussed above, if an integrated solution has already been shared with an external supplier, thereby revealing the inclusion of GPS technology, further outsourcing of related systems will not further compromise information already revealed about this proprietary feature.

Both the ability to induce coordination effort and the economics of disclosure costs imply complementarity among vertical integration choices, motivating the central hypothesis of the paper: the level of vertical integration on any one automobile system will be sensitive to the level of vertical integration on other automobile systems, and a shift in the system-specific returns to vertical integration for one system will have a spillover effect onto other systems within the same automobile model. The remainder of the paper develops and implements an approach for evaluating the contracting complementarity hypothesis in the context of automobile product development.

III. The Empirical Framework

To test for the presence of contracting complementarity, we build on a recent applied econometrics literature that offers an approach for distinguishing complementarity from extraneous "firm-level" factors driving correlated adoption across distinct choices (Arora, 1996; Athey and Stern, 2004). We begin by developing this empirical framework, adapt that framework to the specifics of the empirical setting, and then discuss checks for the assumptions underlying the identification strategy.

Suppose there are two observable vertical integration choices, Y_A and Y_B, and the separable benefits (and costs) to vertical integration observable to the firm can be decomposed into two distinct parts. Both the firm and the econometrician observe a set of system-specific vertical integration drivers (Z_A, Z_B), and $\eta = (\eta_A, \eta_B)$ is a vector of the choice-specific mean-zero shocks observed by the firm but unobservable to the econometrician. The elements of η may be correlated; for simplicity, we assume a firm-level mean-zero "fixed effect" (ξ) which impacts the overall propensity of the firm to vertically integrate (i.e., for a given system *i* and firm $j, \eta_{i,j} = \xi_j + \varepsilon_{i,j}$). Finally, suppose that the returns to each choice are interdependent: the marginal returns to vertical integration for Y_A depend on whether the firm vertically integrates into Y_B. We assume this interdependence term,λ, is constant across firms all firms.[9] The firm optimizes across its choices of Y_A and Y_B, yielding the following maximization problem:

$$\underset{Y_{A,j},Y_{B,j}}{Max}\ f_j = \lambda(Y_{A,j} * Y_{B,j}) + (\beta_{Y_j} + \beta_{Y_A Z_A} Z_{A,j} + \eta_{A,j})Y_{A,j} + (\beta_{Y_B} + \beta_{Y_B Z_B} Z_{B,j} + \eta_{B,j})Y_{B,j} \quad (1)$$

To understand the relationship between performance, optimal choice behavior, and estimation, consider the adoption condition for each practice:

$$Y_{i,j} = 1\ if \quad \lambda Y_{-i,j} + \xi_j + (\beta_i + \beta_{i,Z_j} Z_{i,j} + \varepsilon_{i,j}) > 0 \quad (2)$$

A firm's choice of integration on Y_i depends on the firm's vertical integration decision on Y_{-i}, the observable choice-specific drivers, $Z_{i,j}$, and the stochastic components, ξ_j and ε_{ij}. λ can be interpreted as the degree of complementarity (or substitutability if $\lambda < 0$) between Y_A and Y_B, and ξ_j is an unobserved firm-level effect which (spuriously) induces correlation among the firm's decision regarding Y_A and Y_B.[10] The empirical objective is to estimate the parameters of the "organizational design production function," focusing on λ, the contracting complementarity parameter. Consider the linear probability model:

$$Y_{i,j} = \alpha_i + \gamma_j + \lambda Y_{-i,j} + \beta_{Z_i} Z_{i,j} + \eta_{i,j} \quad (3)$$

The probability that $Y_{-i} = 1$ is increasing in ξ, so $E(Y_{-i} * \eta_i) = E(Y_{-i} * \xi) > 0$, and so an OLS estimate of (3) will be biased upward due to an omitted variables problem. At the same time, Y_{-i} may suffer from measurement error, particularly if Y_{-i} is constructed as an imperfect index of more fine-grained vertical integration decisions (as it does in our context). The presence of measurement error can lead to attenuation bias, resulting in a downward OLS bias. Whether from an omitted variables problem or from measurement error, $\hat{\lambda}_{OLS}$ will be a biased estimate of the sensitivity of the vertical integration choice Y_{-i} on Y_i. However, an instrumental variables estimator can provide a consistent estimate of λ, if

[9] In line with the model, λ is a function of the benefits from coordination effort and the reduced probability of disclosure. This parameter combines the impact of these distinct mechanisms.
[10] ξ need not be related to performance, and could reflect fads or managerial preferences for outsourcing.

the econometrician observes measures correlated with the vertical integration decision on Y_{-i} but independent of η. Our framework yields a natural set of instruments: for each choice i, Z_{-i} – factors driving the adoption of Y_{-i} but uncorrelated with η_i – are potential instruments to examine the relationship between Y_{-i} on Y_i. For Z_{-i} to be valid instrumental variables, we assume that, conditional on all observables, $E(Z_{-i}\eta_i) = E(Z_{-i}\xi) = 0$. As emphasized by Arora (1996) and Athey and Stern (2004), disentangling complementarity from common shocks that raise the propensity to adopt multiple practices requires a choice-specific instrumental variables framework that addresses omitted variables and measurement error in a single framework.[11]

Our dataset includes choice-specific measures. We observe data for 19 distinct automobile model-generations, where each model-generation corresponds to a major revision for an overall automobile model (we observe each model between two and four times over our sample). For each model-generation, we observe the level of vertical integration and drivers of vertical integration *at the level of individual automobile systems* (e.g., engines, brakes, etc.). These measures are thus specific to each system and independently observed across multiple systems. For example, on a system-specific basis, we observe whether the firm has existing in-house sunk investments in plant and equipment and adequate manufacturing capacity. Suppose that these system-specific measures of sunk assets and available capacity are exogenous determinants of system-level vertical integration (an assumption we discuss below). In our equation for vertical integration for system *i*, we can then simultaneously control for the level of sunk assets and capacity constraints on system *i*, and use the level of sunk assets and capacity constraints on system *-i* as instrumental variables for vertical integration level for system *-i*.

This instrumental variables approach is premised on two conditions. First, it requires variation across systems and within model-generations in the system-specific drivers of vertical integration. For example, if the only system-specific driver was a single measure of capacity constraints, and there was no variation across systems (within a model-generation), the measure of vertical integration for system *–i* (instrumented with the measure of capacity constraints for system *–i*) would not be separately identified from the measure of capacity constraints for system *i*. Since the identification strategy depends on system-specific differences in the contracting environment which also result in differences in contracting choices, Section IV presents evidence of variation across systems but within model-generation. The second requirement of the empirical framework is that the system-specific drivers are exogenous. Two distinct issues arise. First, the framework assumes that Z_i is uncorrelated with η_i – the observed system-

[11] In the large literature evaluating the potential for complementarity among organizational design choices (see Ichniowski and Shaw (2003)), only a small number of recent papers have addressed the omitted variables problem directly by adopting a choice-specific instrumental variables framework (Miravete and Pernias, 2006; van Biesebroeck, 2006). *See* also Cassiman and Veugelers (2007) for an alternative approach.

specific drivers of vertical integration are independent of the idiosyncratic returns to vertical integration. Of course, similar to many papers exploiting real data from organizations, the potential for endogeneity is real. It is possible that firms with a high realization of η_i will choose activities that raise the measured level of Z_i. For example, if a firm expects that a particular system is likely to be outsourced in the future, they might limit physical investment and internal capacity.[12] Second, even if the system-specific drivers were exogenous to *each* vertical integration equation, our instrumental variables approach requires that, conditional on the system-specific drivers for system *i*, the system-specific drivers for system –*i* are uncorrelated with the unobserved returns to vertical integration for system *i* (i.e., $E(\eta_i \square Z_{-i} \mid Z_i) = 0$). For example, if the level of sunk assets on any one system is informative about the total extent of sunk assets available across all systems (as might occur if the level of sunk assets are correlated across systems and there is measurement error at the system-specific level), the proposed instrumental variables estimator could be biased.

We address the potential for bias in several ways. First, in Section IV, we build on our qualitative knowledge to evaluate the potential for endogeneity for each system-specific measure. Though no single measure offers an unambiguous natural experiment, different measures likely mitigate different sources of potential bias, and we examine the robustness of our findings to alternative specifications for Z_i. Second, we exploit the sensitivity of our results to exploiting two distinct sources of variation in our data: across automobile models, and across generations of a given automobile model. While some system-specific measures exhibit significant variation across manufacturers but are fixed over time (e.g., the presence of sunk investments), other system-specific measures exhibit significant variation across time within model-systems (e.g., the degree of technological complexity for a given model-generation).

These separate sources of variation facilitate more focused identification approaches. If time-series variation in the system-specific contracting environment is uncorrelated with changes in the unobserved returns to vertical integration, λ can be identified by relying exclusively on variation within automobile models over time. Adapting (3) to allow for multiple generations (*t*) of a given automobile model *j*, we can specify an instrumental variables estimator with fixed effect for each model-system:

$$Y_{i,j,t} = \alpha_{i,j} + \delta_t + \lambda Y_{-i,j,t} + \beta_{Z_i} Z_{i,j,t} + \eta_{i,j,t} \qquad (4)$$

$Z_{-i,j,t}$ are the (excluded) instruments for $Y_{-i,j,t}$: conditional on a complete set of model-system and generation fixed effects, (4) relies on variation in the contracting environment (over time but within

[12] Indeed, it is possible that the current values of Z_i will directly reflect prior vertical integration choices (e.g., the decision to outsource in one period leads to constrained capacity in a subsequent period). In this case, Z_i will be a function of the lagged endogenous variable, $Y_i(-1)$. As discussed below, we account for this possibility directly, by comparing our results using a fixed effects IV approach, a first-differencing IV approach, and an initial conditions IV approach (*see* Table 3 and Appendix C).

model-systems) resulting in variation in vertical integration choices (over time but within model-systems).[13]

Alternatively, if the system-specific differences across automobile models are determined by circumstances independent of current vertical integration decisions, a consistent estimate of λ can be identified by relying exclusively on differences across automobile models. In particular, we can identify the interdependence among systems by relying exclusively on differences across different model-systems:

$$\overline{Y}_{i,j} = \gamma_j + \lambda \overline{Y}_{-i,j} + \beta_{Z_i} \overline{Z}_{i,j} + \eta_{i,j} \tag{5}$$

where $\overline{Z}_{-i,j}$ are the (excluded) instruments for $\overline{Y}_{-i,j}$.[14] By assuming that the variation across firms in their contracting environment are independent of the idiosyncratic returns to vertical contracting over time, this estimator is identified by the presence of variation across different automobile models and across systems within automobile models.

Finally, we can also implement a reduced-form strategy in the spirit of Arora (1996), where we include *both* the system-specific drivers ($Z_{i,j,t}$) of vertical integration as well as the system-specific drivers of other systems within the same automobile model ($Z_{-i,j,t}$):

$$Y_{i,j,t} = \alpha_i + \gamma_j + \delta_t + \theta_{Z_i} Z_{i,j,t} + \theta_{-Z_i} Z_{-i,j,t} + \varepsilon_{i,j,t} \tag{6}$$

Because our dataset includes (a) similar measures of the contracting environment for each system, and (b) we control for the system-specific drivers in our analysis, the identification in this paper results from *measured differences in the contracting environment across systems within a given automobile model*. The reduced-form approach highlights this feature; if the correlation was driven by similarities in the environment across systems, then the instrumental variables would be collinear with the system-specific direct effects included in each model (i.e., $H_0 : \theta_{-Z_i} = 0$).

Our empirical work explores each of these approaches, evaluating how our results differ when employing estimators that rely on both cross-sectional and time-series variations or focus exclusively on one dimension or the other. By comparing results across alternative strategies, we obtain a more

---

[13] Alternatively, we can implement (4) in first-differences: $\Delta Y_{i,j,t} = \Delta \delta_t + \lambda \Delta Y_{-i,j,t} + \beta_{Z_i} \Delta Z_{i,j,t} + \Delta \eta_{i,j,t}$
This specification relies exclusively on variation in the contracting environment and vertical integration levels across adjacent product generations, and, by clustering the standard errors at the model-system level, treats serial correlation within model-systems. Unfortunately, due to our small sample size (and the fact that we observe exactly two model-generations for several models), implementing a more efficient Arellano-Bond dynamic GMM panel data estimator results in dropping more than 50% of our sample. Consequently, we limit our analysis to the traditional first-differences IV estimator rather than the Arellano-Bond estimator (Arellano and Bond, 1991).

[14] Alternatively, we can implement an *initial conditions* model, relying exclusively on variation in the initial contracting environment across different automobile models. Assuming that variation in the *initial* contracting environment is independent of the idiosyncratic returns to vertical integration over time, we can estimate $Y_{i,j,t} = \gamma_j + \delta_t + \lambda Y_{-i,j,t} + \beta_{Z_i} Z_{i,j,0} + \eta_{i,j,t}$, where $Z_{-i,j,0}$ are the (excluded) instruments for $Y_{-i,j,t}$.

complete assessment of the robustness of our results to alternative potential sources of endogeneity. Moreover, since we observe multiple system-specific measures, we are able to perform a number of specification tests, including a Hausman test of the exclusion restrictions imposed by our IV estimator.

Implementing these approaches requires adapting the framework to our application. First, while several of the examples in Section II focused on interactions within automobile systems, our empirical focus is on system-to-system interactions; though more aggregated than the case studies, this is the best feasible alternative, since we only observe variation in the contracting environment at the system level. Second, for each automobile model-generation, we observe seven different automobile systems; rather than estimate the potential for complementarity between system pairs, we adapt the framework to evaluate sensitivity of vertical integration on any one system to the "average" level of vertical integration on all other systems within that automobile-generation.[15] Third, while we observe instrumental variables at the level of automobile systems (e.g., the brake system, the engine system, etc.), our measure of vertical integration (in-house or external supplier) is at a more fine-grained component level (e.g., the gearbox, the cylinder head, etc.). To accommodate this imbalance, we average the component decisions on each system for each model to calculate the *degree* of vertical integration for each model-system (the resulting integration measure thus varies between 0 and 1).

Finally, this framework allows us to evaluate whether the degree of complementarity varies with observable factors, focusing on two types of interaction effects. First, we consider whether the degree of complementarity is higher in environments where the returns to coordination and/or secrecy may be particularly high. For example, we observe whether the firm designates a system for "high" performance, in which the returns to coordination with other systems may be reduced. To test this hypothesis, we interact this "high performance" measure with Y_{-i}, and construct additional instruments by interacting this measure with Z_{-i}. Second, we consider whether complementarity among systems is particularly high among systems that are tightly coupled in terms of design and coordination requirements. Using our qualitative knowledge, we group each system-to-system pair as a "high" or "low" interaction, and evaluate a separate parameter for the sensitivity of vertical integration decisions among systems within these two groups (i.e., are vertical integration choices that are rated to be highly interdependent more sensitive to each other?). By extending our framework to evaluate whether the salience of contracting complementarity varies with the product development environment, we are able to provide a more careful assessment of the sources and nature of contracting complementarity in our empirical environment.

---

[15] To do so, we first calculate, for each system, the sum of vertical integration for *other* systems on that automobile model. We then adapt our instrumental variables strategy by calculating the *sum* of Z_{-i} for each observation, yielding instruments for Y_{-i} in the empirical analysis.

IV. The Data

Sample and Methods. This paper uses a proprietary and original dataset based on a multi-year study of contracting and product architecture in the global auto industry. We study luxury performance cars (defined by *Consumer Reports* as vehicles priced above $30,000 in 1995) and the companies in the sample are drawn from Europe, the U.S. and Japan, accounting for roughly 90% of revenues in the global luxury performance market. As these are flagship vehicles developed in different environments over time, wide variation in contracting practices (and the contracting environment) was expected. By focusing on a single vehicle segment, we limit the measurement problems arising from combining information from different vehicle types.

The unit of analysis is an automotive system for a model-generation, where a model-generation is linked to the major model change for a given automobile model. For each model-generation, we observe information for seven systems: engine, transmission, body, electrical, suspension, steering, and brakes. For each of these systems, we observe information for nineteen model-generations, covering a fifteen year window for seven models.[16] 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-generation.[17]

Data was collected through interviews conducted on-site at each company. To ensure accuracy, interviewees were given an overview of the research project, definitions for terms and a list of questions pertaining to the design and sourcing of components within their respective systems. The questions focused on objective information (e.g. number of parts in the body side) so as to minimize the likelihood of response bias. The overall sample is composed of 133 model-generation-system observations. Table 1 provides variable names, definitions, and summary statistics (Appendix B provides pairwise correlations).

Contracting Variables. The dependent variable is VERTICAL INTEGRATION, the percentage of the system produced in-house, with 1 indicating in-house production of all components within that system. For each component, system, vehicle model, and generation, we collected data on the make / buy outcome. VERTICAL INTEGRATION at the system level is calculated as the average across the individual components for that system, with each component weighted equally.[18] VERTICAL

[16] The coverage is between 1980 and 1995, and each of the model-generations are observed at (roughly) five-year intervals, depending on the rhythm of product development for each manufacturer. Relative to the initial data collection (Novak and Eppinger, 2001), we drop one automobile model due to lack of comprehensive data.
[17] All participants were assured that only aggregate data would be presented, and confidentiality agreements were signed with each company.All interviewees were given the option of being interviewed in their native languages. Professor Kentaro Nobeoka graciously provided Japanese interview interpretation.
[18] Parts supplied 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 group), were treated as outside suppliers. Our core findings are robust whether we define partially owned suppliers as in-house or external.

INTEGRATION exhibits substantial variation across the sample, ranging from 0 (fully outsourced) to 1 (in-house production), with a mean of .48 and a standard deviation of .32. Moreover, much of this variation is "model-specific." Figure A plots 90% confidence intervals for VERTICAL INTEGRATION for each of the 19 model-years in the sample.[19] Relative to the variation in means across models, there is significantly less variation within most models. In an OLS regression of VERTICAL INTEGRATION on individual model-year dummies, $R^2 = 0.58$, most model-year effects are individually significant, and the overall F-test statistic is highly significant at 8.74. VERTICAL INTEGRATION is "clustered" according to model-year; our empirical approach disentangles whether this clustering is due to complementarity or results from unobservable "fixed effects" in governance.

We also calculate VERTICAL INTEGRATION_{-i}, which is the sum of VERTICAL INTEGRATION across all *other* systems within that model. Consistent with the empirical framework, VERTICAL INTEGRATION_{-i} will be treated through the bulk of the analysis as endogenous; we calculate the instruments for VERTICAL INTEGRATION_{-i} from within-model-generation variation in the system-specific contracting environment.

System-Specific Contracting Environment Measures. The identification strategy utilizes four *system-specific* measures of the contracting environment. Each of these variables is measured at the model-system level, can vary across systems within a given model-generation, and shifts the relative returns to vertical integration at the system level. These measures allow us, in principle, to control for the system-specific contracting environment ($Z_{i,j,t}$) and calculate instruments, within each model- generation, for VERTICAL $\text{INTEGRATION}_{-i,j,t}$ ($Z_{-i,j,t}$). Our empirical approach depends on combining our qualitative knowledge of these system-specific contracting measures with the empirical approaches outlined in Section III.

The dataset includes two different types of system-specific measures: factors relating to pre-existing in-house capabilities/resources (SUNK COSTS and LOW CAPACITY), and factors relating to the intensity of design and manufacturing challenges (COMPLEXITY and PLATFORM). We begin with the measures related to the level of pre-existing capabilities. 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, the relative returns to outsourcing are increased. For this reason, we predict a negative relationship between VERTICAL INTEGRATION and LOW CAPACITY.

SUNK COST is a dummy variable indicating whether there is pre-existing in-house sunk investments for each system (mean = 0.13). Specifically, managers were asked whether or not existing

[19] Confidentiality issues prohibit us from reporting exact levels and dispersion of vertical integration for individual manufacturers.

plant equipment directly affected their design choices for the system, as systems are often designed around plant-specific process equipment investments. Overall, 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.

Turning to factors related to system-specific design and technology choice, 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. Platform requirements could support in-house production through economies of scale achieved through parts sharing. For this reason, we expect a positive relationship between PLATFORM and VERTICAL INTEGRATION.

As well, the degree of system-specific complexity should be positively related to VERTICAL INTEGRATION. As developed in Novak and Eppinger (2001), 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.[20] 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 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 (Novak and Eppinger, 2001). The measure COMPLEXITY (mean = .41) is the result of applying this procedure for each component within each system.

Exogeneity of the System-Specific Contracting Environment Measures. Ideally, variation in the contracting environment (i.e., variation in each of these four measures) would result from strictly exogenous shocks (e.g., unanticipated demand shocks for vehicle models in unrelated segments that share facilities with the luxury models). While we do not observe an unambiguous natural experiment, our assumption that these system-specific measures are exogenous reflects several related aspects of the contracting environment, our dataset, and our econometric approach.

First, our qualitative knowledge of the contracting environment suggests that we can (at least in part) exploit the path-dependent nature of vertical integration choices and the relative independence managers had during the time of our sample period over individual contracting choices. From an historical perspective, investments in sunk assets and production capacity are made many years (perhaps decades) in advance of individual model-generation contracting choices (e.g., Ford has maintained multiple engine plants continuously since the 1940s) and design and technology choices are made well in

[20] Each system-specific complexity measure is based on system engineering principles (Novak and Eppinger, 2001).

advance of the vertical integration choices for individual components within individual systems, primarily based on factors unrelated to vertical integration. For example, while GM's commitment to develop anti-lock braking systems in 1980 greatly increased the complexity associated with their braking systems throughout the 1990s, this technology commitment was made well in advance of information about opportunities for contracting with specific external suppliers for this system.[21] Historical factors are particularly significant when relying on variation across automobile manufacturers, rather than within model-systems over time. Additionally, during our sample period, individual managers maintained a high level of discretion over the outsourcing choice at the component (or, at most, system) level, and managers were able to vertically integrate or not in response to idiosyncratic circumstances.[22] For example, a component-level manager had the latitude to choose a specific supplier (over an in-house option) based on that supplier's *component-specific* reputation or skills (respondent interview). Of course, the fact that the system-specific contracting measures are determined in advance of the contracting choice and managers maintain discretion over this choice does not ensure exogeneity. Instead, our argument is that the specific system-specific measures we observe shape the contracting environment but are largely independent of an important idiosyncratic component (i.e., the econometric error) that also contributes to contracting choices.

Second, our instrumental variables strategy relies exclusively on variation in the contracting environment across model-systems within the same model-generation. Our approach is to use measures (such as LOW $CAPACITY_{-i}$) as instrumental variables for VERTICAL $INTEGRATION_{-i}$, while at the same time controlling directly for LOW $CAPACITY_{i}$. As a practical matter, this approach only has empirical bite if there is variation between our instrumental variables (e.g., LOW $CAPACITY_{-i}$) and our control variables (e.g., LOW $CAPACITY_{i}$). If a firm makes a fixed investment in contracting (e.g., lawyers, accountants, etc.), and under-invests in capacity in response to this investment, this would lead to a LOW CAPACITY = 0 for *all* systems within that manufacturer. In contrast, we observe a high level of variation across systems within individual models, as documented in the final column of Table 1. Of the 19 model-years in our sample, 13 exhibit variation across systems in SUNK COST, 17 exhibit variation in LOW CAPACITY, and all models display variation in the PLATFORM and COMPLEXITY measures.

---

21 As the specification and integration challenges vary significantly from one model generation to another, and from one component to the next, the legal and transactional costs of contracting are largely independent of integration choices on prior product generations or other components. For example, even when a manufacturer seeks to contract for a *single* component for two separate automobile models (e.g., an Autoliv airbag for a mid-size model and for a luxury model), the contracting process (and associated costs) are mostly independent: the effort associated with specifying the mid-market airbag neither raises nor lowers the costs associated with the detailed contracting process for the feature-rich and specifications-oriented luxury version (respondent interview).

22 While outsourcing multiple systems to a particular supplier might be expected to result in economies of scope and scale, this practice was only observed in practice after our sample period. Over the past ten years, at least in part to take advantage of outsourcing opportunities while maintaining some level of coordination, manufacturers have outsourced multiple systems to Tier 1 suppliers such as Lear and Johnson Controls.

This means that within a specific model, some systems were low capacity and others were not. For example, for one of the models, SUNK COST = 0 on suspensions and SUNK COST = 1 for engines. While the historic presence of an engine plant continues to lower the in-house cost for engine component production, pre-existing assets did not lower the costs of in-house production for suspensions relative to outsourcing. We exploit this variation across systems to identify the interdependence among governance choices for those systems.

Finally, as discussed in Section III, the instrumental variables framework can be adapted to (a) rely exclusively on variation over time within model-systems (i.e., a fixed effects or first-differences IV estimator), (b) exclusively on variation across model-systems (the initial conditions IV estimator or the between effects IV estimator), or (c) incorporate both sources of variation. These alternative control structures allow us to control for distinct sources of potential correlation between the system-specific contracting measures and the unobserved returns to vertical integration, and to rely on different sources of variation within our data. For example, while the fixed effects estimator assumes that *changes* in the contracting environment within model systems over time are uncorrelated with *changes* in the system-specific returns to vertical integration, the initial conditions estimator assumes that the *initial level* of the contracting environment is exogenously given, and controls for any changes arising during our sample period.[23] These alternative control structures exploit distinct types of variation in the system-specific measures. While SUNK COST and LOW CAPACITY primarily vary across model-systems (indeed, SUNK COST has no variation within a model-system over time), COMPLEXITY and PLATFORM exhibit variation both within model-systems over time and across model-systems. Moreover, since we observe multiple system-specific contracting measures, we can evaluate how the estimates change with the inclusion or exclusion of individual variables, and test the exclusion restrictions implied by the model (i.e. a Hausman test for the exogeneity of VERTICAL INTEGRATION and an overidentification test for the exogeneity of the instruments). Our empirical approach is thus justified by the use of a range of alternative specifications, our qualitative understanding of the origins of variation in the contracting environment, and our ability to exploit variation across systems within individual automobile models.

Technology and Location Controls. Our dataset also includes technology and location measures which are not predicted to have a direct impact on VERTICAL INTEGRATION but may impact the degree of contracting complementarity.[24] First, DESIGN GOAL is a dummy variable equal to 1 if an individual system is associated with "high" system-specific performance and design goals. The

[23] Moreover, the estimates of λ turn out to be quite stable across alternative identification approaches, suggesting that no single source of spurious correlation contaminates our main findings.

[24] While each of these measures was originally collected as instrumental variables for COMPLEXITY (discussed in Novak and Eppinger (2001)), they may also serve to mediate the relative importance of coordinating contracting choices across systems.

importance of these 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 system performance. Certain performance goals necessitate more complex product designs, such as more integral architectures (Ulrich, 1995). For example, a high top-speed capability requires a body system consisting of tightly interconnected parts. Since systems for which performance goals are very high are likely to be associated with high system-specific complexity, integration with *other* systems may be less important, and so DESIGN GOAL may reduce the importance of contracting complementarity in contracting choice. Similarly, 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. Because SKILL SHORTAGE may constrain the system-specific contracting choices for individual components and systems, SKILL SHORTAGE may reduce the degree to which an auto manufacturer can coordinate contracting choices over systems.

While small sample size prevents us from directly identifying complementarities between specific systems (e.g., engine and transmission), we can still divide the system pairs into those with a tight coupling during product development, and thus with significant expected complementarities, and those with loose coupling during product development, where we would not expect to see resulting complementarities.[25] We define tight coupling as a frequent (hourly or daily vs. monthly or longer) need for coordination of systems i and j during product development.[26] For example, in order to make any major changes to suspension specifications, it is essential to check the possible effects of such changes to the steering system specifications to ensure their joint performance. Given this need for coordination, we define this pair as highly coupled and would expect to see strong complementarity between such coupled pairs. Of our 21 possible system pairs, we identify 14 as tightly coupled and 7 as loosely coupled.

System, Year, and Company Fixed Effects. We also observe a potential driver of contracting at the model-year 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. If a system is produced in a plant with a union agreement, the union may exert pressure to produce as much of the system in-house as possible (in order to ensure in-house employment). To the extent that this pressure is successful, we expect a positive relationship between UNION and VERTICAL INTEGRATION (of course, we exclude this measure in specifications with model-year fixed effects). Finally, we calculate fixed effects for seven automobile

[25] We thank one of the anonymous referees for this helpful suggestion.
[26] For each system pair, company experts evaluated "high" vs. "low" coupling in terms of frequency of coordination need. See Steward (1981) for a discussion and methodology for identifying coupling among development tasks.

system (SEATS are the excluded category), three model generation dummies (the first observation for a given model is the excluded category) and eight company dummies (company dummies are suppressed to preserve confidentiality). The empirical analysis explores each of these control structures to identify the variation driving the core findings and to highlight the robustness of the results to alternative sources of variation.

V. Empirical Results

Our empirical analysis is divided into several steps. First, we present our core findings, examining the sensitivity of the degree of vertical integration in any one system to the "average" vertical integration choice of other systems in that model. Our instrumental variables strategy allows us to distinguish contracting complementarity from a firm-level "taste" for vertical integration, and to evaluate the robustness of this finding to alternative control structures and specifications. We next present a reduced-form approach (in the spirit of Arora, 1996), examining the impact of the instrumental variables themselves on contracting choice. We then turn to more detailed findings, examining how the degree of contracting complementarity depends on factors in the contracting environment, and whether the interdependence among systems determines the degree of complementarity. Though the modest size of the dataset makes us cautious in interpreting the findings, our results accord with a model where the inability to contract with external suppliers for effective coordination induces contracting complementarity among system-level vertical integration choices.

An Instrumental Variables Approach to Testing for Contracting Complementarity. We begin in Table 2 with two OLS regressions of VERTICAL INTEGRATION on VERTICAL INTEGRATION_{-i} and our main control variables. To account for potential correlation within model-systems over model-generations, all standard errors in Table 2 are clustered at the model-system level. While (2-1) includes a very simple specification with only two control variables (SUNK COST and LOW CAPACITY), (2-2) includes the complete set of control variables, including all of the system-specific contracting measures, system and model-generation dummy variables, and the UNION dummy. Many of these individual system effects are significant (and different than each other), and LOW CAPACITY is negatively related to VERTICAL INTEGRATION in both specifications. The most striking result is the quantitatively large and statistically significant coefficient on VERTICAL INTEGRATION_{-i}.[27] According to these OLS specifications, a shift of one unit in VERTICAL INTEGRATION_{-i}. is associated with a 14 percentage point increase in the VERTICAL INTEGRATION share for that system.

[27] Though the bulk of the remaining results reflect our instrumental variables approach, the OLS findings highlighted in the first two columns of Table 2 are robust across a wide range of specifications. The coefficient on VERTICAL INTEGRATION_{-i} in a univariate regression (with a constant) is 0.143 (with a standard error of 0.021). Also, as reported in the first two columns of Appendices C-1, C-2 and C-3, a similar coefficient (from 0.13 to 0.15 and always highly significant) is estimated in the context of an OLS between estimator and an OLS initial conditions estimator over a wide variety of specifications.

These OLS results may be spurious, driven by firm-specific unobservables inducing a high correlation among the contracting choices of the firm across systems. We address this with an instrumental variables strategy. In the final two columns of Table 2, we instrument for VERTICAL $INTEGRATION_{-i}$ with the sums of contracting measures such as SUNK COST or LOW CAPACITY for other systems within that model-year but for system i. While the excluded instruments for (2-3) are LOW $CAPACITY_{-i}$ and SUNK $COST_{-i}$, the excluded instruments for (2-3) also include $PLATFORM_{-i}$ and $COMPLEXITY_{-i}$. Except for our treatment of VERTICAL $INTEGRATION_{-i}$ as endogenous, (2-3) and (2-4) are identical to the OLS specifications in (2-1) and (2-2), respectively. In both specifications, the instrumental variables coefficient on VERTICAL $INTEGRATION_{-i}$ is positive and significant (and larger in magnitude than the OLS coefficient). While a Hausman test cannot reject the exogeneity of VERTICAL $INTEGRATION_{-i}$ in (2-3), the Hausman test rejects the OLS specification at the 10% level in the more detailed specification (2-4).[28] The overall magnitude is similar to the OLS estimates – a shift in the contracting environment that induces a one unit change in VERTICAL $INTEGRATION_{-i}$ is associated with a 15-18 percentage point increase in the predicted level of VERTICAL INTEGRATION for an individual system. This result is consistent with the importance of coordination in contracting – namely that once an outside shock such as a change in underlying technology results in in-house development of a system such as the suspension, there are incremental gains to be had by locating development of related systems, such as the engine, in the same organization.

These results are reinforced when we focus on specific sources of variation in Table 3.[29,30] In (3-1), we present the results of an instrumental variables "between" estimator which relies exclusively on variation across models. This estimator abstracts away from all variation within model-systems over time and the instrumental variables vector is calculated using the average of the system-specific contracting measures (e.g., SUNK COST) across all model-generations. The estimate is consistent with our earlier

---

[28] The exogeneity of the instrumental variables cannot be rejected in any of these specifications.

[29] Appendix C includes a number of robustness checks focusing on specific sources of variation, and alternative specifications. Each table in Appendix C includes OLS and IV estimates for a particular specification, presenting the "between" estimator and the "initial conditions" estimator for that specification. While the between estimator abstracts away from all variation within model-systems over time, the initial conditions estimator drops the first observation associated with each model-system, and estimates the sensitivity of subsequent governance choices (i.e., subsequent model-generations) to the contracting environment associated with the *initial* contracting environment. Our core finding – complementarity among system-level governance choices – is robust across all of these checks. We have also explored a range of 3SLS estimator which jointly estimates the VERTICAL INTEGRATION and VERTICAL $INTEGRATION_{-i}$ equations, accounting for correlation across equations and including detailed controls (including model-system fixed effects). The results remain similar in magnitude and significance.

[30] In unreported specifications, the IV results are robust across a wide number of additional checks. The results are similar using other system-specific measures, such as a measure of technology use and the severity of the major model change. In addition, the results are robust to the use of company-specific time trends, and alternative treatments of partially owned suppliers and spin-offs. Finally, the results are robust to treating the continuous measure VERTICAL INTEGRATION as a discrete variable (e.g., based on a "threshold" level such as .25, .5, and .75), and implementing an IV probit accounting for the discrete nature of the dependent variable.

findings, and our qualitative evidence. For example, one model in our sample features a vehicle body associated with a high level of sunk costs and platform requirements throughout the sample, while its steering system has a low level of system-specific sunk assets and few platform requirements. Despite system-specific conditions favoring outsourcing in the steering system, the majority of steering system components have been consistently maintained in-house, at least in part to facilitate coordination between the steering system and in-house body development (respondent interviews).

The final two columns of Table 3 shift the focus towards variation within model-systems over time. These IV estimators rely exclusively on whether changes in the system-specific contracting environment are associated with changes in the level of vertical integration. By focusing on variation within model-systems, these estimators account directly for the possibility that our cross-sectional results may result from a spurious correlation between the system-specific contracting environment and the level of vertical integration. For example, it is possible that those firms who choose a lower level of vertical integration (across all systems) maintain a low level of system-specific capacity and sunk assets. While our qualitative evidence mitigates against this possibility, and our identification strategy relies on variation in the contracting environment within a given model, it is useful to examine whether our evidence for complementarity among governance choices depends on the cross-sectional variation in our dataset. We present two alternative approaches. While (3-2) reports the results from a model-system fixed effects instrumental variables estimator, (3-3) presents estimates associated with a first-differenced IV estimator.[31] As discussed in Section IV, while there is no variation in SUNK COSTS within model-systems over time (and very limited variation in LOW CAPACITY), there is a considerable amount of "within" variation in COMPLEXITY and PLATFORM, and so our within-model-system results depend on the inclusion of these two measures. Though these results focus on a very narrow form of variation within our dataset, the core results are similar; the coefficient on VERTICAL INTEGRATION_{-i} is precisely estimated and of a similar magnitude than results relying on cross-sectional variation. Though the limited size of our dataset makes us cautious in interpreting these results, the evidence suggests that the high level of correlation in vertical integration choices across systems does not simply reflect an unobserved firm-level effect but seems to be grounded in observable variation in the contracting environment across the different systems of a given automobile model.

A Reduced-Form Approach to Testing for Contracting Complementarity. Table 4 explores the logic further by examining how contracting for a given system is impacted by the contracting environment for other systems by directly including the excluded instruments from Table 2 in an OLS specification. This reduced-form strategy follows Arora (1996), who derives the conditions under which

[31] While (3-2) includes 133 observations and 49 model-system fixed effects, (3-3) uses only 84 first-differenced observations; both specifications include controls for model-generation.

a reduced-form approach to testing for complementarity in organizational design is possible. In particular, our identification approach depends on measured differences in the contracting environment across systems within a given automobile model. The reduced-form approach highlights this feature; if the correlation was driven by similarities in the environment across systems, then the instrumental variables would be collinear with the system-specific direct effects included in each model.[32]

In (4-1), both LOW CAPACITY and SUNK COSTS are included, as well as LOW CAPACITY$_{-i}$ and SUNK COSTS$_{-i}$. Both the direct effects of LOW CAPACITY and LOW CAPACITY$_{-i}$ are statistically and quantitatively significant (interestingly, a one-standard deviation of either variable is predicted to have a similar impact). The remaining specifications, which include PLATFORM (and PLATFORM$_{-i}$) and COMPLEXITY (and COMPLEXITY$_{-i}$) display a similar pattern. Specifically, even after controlling for system fixed effects and year controls, both individual direct effects (e.g. SUNK COST) and individual instrumental variables (e.g., SUNK COSTS$_{-i}$) are individually significant. This is consistent with our earlier example where an environment that favored vertical integration on the body system seems to have induced vertical integration on related systems such as steering. Overall, Table 4 suggests that correlation in contracting across systems is not simply a firm-specific effect but is related to variation in the contracting environment across systems within a given model-generation.

Does the Interdependence Among Systems Depend on Technological or Locational Constraints? While our results so far suggest that governance choices are empirically linked, the sensitivity of the vertical integration choice on one system to other choices in the same model might depend on other facets of the environment. In particular, our qualitative work suggests that the importance of coordination with other systems may matter less for decision-making when a firm faces technological or locational constraints. For example, when one firm faced a lack of skills in complicated manual welding, the decision was made to outsource body development, despite the strong need for coordination with other in-house systems (respondent interview). Table 5 explores the impact of interactions between VERTICAL INTEGRATION$_{-i}$ and measures that might mitigate the importance of coordinated contracting. In (5-1), we consider an interaction with DESIGN GOAL, under the hypothesis that coordination with other systems may be less important when a particular system must achieve a high level of technological performance. In (5-2), we examine whether constraints on the location-specific availability of system-specific resources (i.e., SKILL SHORTAGE = 1) reduces the relative importance of coordinated contracting. For each of these specifications, we extend our instrumental variables strategy, constructing

[32] Within our dataset, there are significant differences between the control variables Z_i and the instrumental variables, Z_{-i}. On a pairwise basis, SUNK COST and S_SUNK COST are negatively correlated ($\rho = -0.16$), LOW CAPACITY and S_LOW CAPACITY are also negatively correlated ($\rho = -0.38$), PLATFORM and S_PLATFORM are essentially uncorrelated ($\rho = 0.04$) and COMPLEXITY and S_COMPLEXITY are positively correlated ($\rho = 0.32$). These patterns are consistent with our earlier discussion suggesting that there exists significant within-model across-system variation in the observed contracting environment.

instruments by multiplying each system-specific vertical integration driver and the instrumental variables for VERTICAL INTEGRATION$_{-i}$ employed in Table 2. The results, though noisy, are suggestive. First, the direct effect of VERTICAL INTEGRATION$_{-i}$ continues to be quantitatively and statistically significant across both specifications. Turning to the interaction effects, VI$_{-i}$*DESIGN GOAL is negative though insignificant. While this coefficient is sometimes significant with the inclusion of additional variables, we present this noisy result to emphasize its limited statistical power. On the other hand, the coefficient on VI$_{-i}$*SKILL SHORTAGE is negative and significant. These basic patterns are consistent across a wide range of specifications, including one where we include both VI$_{-i}$*PERFORMANCE and VI$_{-i}$*SKILL SHORTAGE in the same regression. Taken together, the results are consistent with the hypothesis that the level of complementarity might be related to the marginal returns to system-to-system coordination activities, a process which is more effectively conducted through joint in-house contracting.

Does Complementarity Arise Among Systems with a High Level of Interdependency? Finally, we recognize that the relative returns to effective cross-system coordination may be different for different systems. For example, while the level of interaction between suspension and steering is quite high, the level of required coordination and interaction between body and brakes is relatively low. We therefore explore whether the sensitivity of vertical integration choices on one system to vertical integration choices on other systems are particularly salient for those systems that are themselves highly coupled. As discussed in Section IV, to examine the impact of the degree of interdependency, we group system-pairs into those with high and low coupling. Among our 21 potential system-pairs, 14 are rated as Tightly Coupled Systems and 7 are rated as Loosely Coupled Systems. For each system, we calculate a measure of the level of vertical integration for those systems that are Tightly Coupled and Loosely Coupled.[33] We also calculate instrumental variables for these two measures of vertical integration on other systems within the same model-generation. Table 6 reports the OLS and IV estimates using this approach (these specifications include system and model-generation dummies, and are clustered at the model-system level). While the estimate of complementarity among tightly coupled systems is significant and similar in magnitude to earlier results, the sensitivity to Loosely Coupled systems is insignificant, small in absolute value, and negative in sign. This engineering-driven definition of the relationship among systems provides additional evidence for the sensitivity to governance choices across systems.

VI. Conclusions

This paper examines the impact of contracting complementarity across vertical integration decisions in automobile product development. Building on a detailed qualitative understanding of the

[33] In order to make the magnitudes of the coefficients comparable with our earlier results, we calculate this measure as 7*(average level of vertical integration for systems with a given level of coupling).

potential for interdependencies in contracting decisions, we test this hypothesis using an instrumental variables approach that allows us to distinguish contracting complementarity from firm-level factors inducing correlation among the firm's governance choices. We find a consistent pattern of support for the complementarity hypothesis. Using instrumental variables to account for the endogeneity of the vertical integration choices for other systems within a model, the probability of vertical integration for each automobile system increases in share of other systems that are vertically integrated. This finding is robust to the inclusion or exclusion of various control variables, and does not depend on whether we focus exclusively on time-series or cross-sectional variation. The evidence in favor of complementarity turns out to be strongest in those environments where we expect strong interdependence among vertical integration choices (i.e., tightly coupled systems).

While we interpret these findings cautiously, it is possible to draw out some implications from the analysis. First, our results suggest that assuming away contracting complementarity may be problematic in contexts where coordination and integration activities are both important and difficult to monitor. As emphasized by a number of "insider econometrics" studies (Ichniowski and Shaw, 2003), organizational design choices are interdependent and economic analysis of individual choices in isolation are likely to be biased. Second, the analysis suggests that there are empirical implications to contracting even when where there are no ex ante differences in the ability to write contracts but there are ex post differences in the ability to enforce and/or monitor agreements. In other words, our hypothesis is a simple but novel implication of a model in which firms must make multiple interdependent and long-lived contracting choices. Finally, the econometric framework offered by this paper offers a refinement on prior research emphasizing the importance of choice-specific instruments in testing for complementarity in organizational design. Specifically, by collecting the data so that each choice-specific measure is observed in a symmetric fashion across choices, this paper proposes and implements a less ad-hoc instrumental variables test for complementarity in organizational design.

These findings have a range of implications for future work. In Novak and Stern (2007), for example, we explore the performance implications of vertical integration over the product development lifecycle. Building on recent work in organizational economics and strategy, we investigate whether outsourcing may be associated with a performance premium at the earliest stages of the lifecycle (as external suppliers exploit their specialized capabilities in meeting the terms of initial contracts), while vertical integration may be associated with performance improvement over the lifecycle (as internal teams can be motivated even after formal contractual requirements are fulfilled). We are able to exploit the instrumental variables strategy developed in this paper to account for the endogeneity of vertical integration within that analysis.

As well, the analysis highlights an important distinction between the need for coordination effort across divisional boundaries and the expropriation risk that arises when proprietary information is shared across firm boundaries. While our current analysis does not allow us to disentangle these two drivers of contracting complementarity, identifying the drivers of interdependency among vertical integration decisions seems like a promising avenue. At the same time, research should also consider how concerns about the formal nature of contracts interact with potential for relational contracting, within and across firms. For contract theory to have empirical relevance, theory must have implications for potential observables, and empirical research must be tailored to measure these subtle but observable factors.

REFERENCES

Alexander, C. (1964), *Notes on the Synthesis of Form*, Harvard University Press, Cambridge, MA.

Arellano, M. and S. Bond (1991), "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations," *Review of Economic Studies* 58(2): 277-97.

Arora, A. (1996), "Testing for Complementarities in Reduced Form Regressions: A Note," *Economics Letters* 50(1): 51-55.

Athey, S. and S. Stern (2004), "An Empirical Framework for Testing Theories of Complementarity in Organizational Design," mimeo, Northwestern University.

Azoulay, P. (2004), "Capturing Knowledge Within and Across Firm Boundaries: Evidence from Clinical Development," *American Economic Review* 94(5): 1591–1612.

Baker, G. and T. Hubbard (2004), "Contractibility and Asset Ownership: On-Board Computers and Governance in U.S. Trucking," *Quarterly Journal of Economics* 119: 1443-1479.

Baker, G., R. Gibbons and K. Murphy (1994), "Subjective Performance Measures in Optimal Incentive Contracts," *Quarterly Journal of Economics* 109: 1125-56.

Baker, G., R. Gibbons and K. Murphy (2002), "Relational Contracts and the Theory of the Firm," *Quarterly Journal of Economics* 117: 39-84.

Baldwin, C. and K.B. Clark (2000), *Design Rules: Volume I, the Power of Modularity*, MIT Press, Cambridge, MA.

Bigelow, L. (2003), "Make-or-Buy Revisited: A Longitudinal, Population-wide Test of Transaction Cost Alignment," mimeo, Olin School of Management, Washington University.

Casadesus-Masanell, R. and D.F. Spulber (2000), "The Fable of Fisher Body," *Journal of Law and Economics* 43(1): 67-104.

Cassiman, B. and R. Veugelers (2007), "In Search of Complementarity in the Innovation Strategy: Internal R&D and External Knowledge Acquisition," *Management Science,* forthcoming.

Clark, K. and T. Fujimoto (1991), *Product Development Performance, Strategy, Organization, and Management in the World Auto Industry*, Harvard Business School Press, Boston, MA.

Coase, R. (1937), "The Nature of the Firm," *Economica* 4(16): 386-405.

Cockburn, I., R. Henderson and S. Stern (2003), "Balancing Incentives: The Tension between Basic and Applied Research," mimeo, Northwestern University.

Eppinger, S. D., D.E. Whitney, R.P. Smith and D.A. Gebala (1994), "A Model-Based Method for Organizing Tasks in Product Development," *Research in Engineering Design* 6(1): 1-13.

Hart, O. (1995), *Firms, Contracts, and Financial Structure*, Clarendon Press, Oxford, England.

Hart, O. and J. Moore (1990), "Property Rights and the Nature of the Firm," *Journal of Political Economy* 98: 1119-1158.

Helper, S. (1995), “Supplier Relations and the Adoption of New Technology: Results of Survey Research in the U.S. Auto Industry,” NBER Working Paper 5278.

Helper, S. (1997), “Complementarity and Cost Reduction: Evidence from the Automobile Supply Industry,” NBER Working Paper 6033.

Holmstrom, B. (1999), “The Firm as a Subeconomy,” *Journal of Law, Economics, and Organization* 15(1): 74-102

Holmstrom, B. and P. Milgrom (1994), “The Firm as an Incentive System,” *American Economic Review* 84: 972-991.

Ichniowski, C. and K. Shaw (2003), “Beyond Incentive Pay: Insiders' Estimates of the Value of Complementary Human Resource Management Practices,” *Journal of Economic Perspectives* 17(1): 155-180.

Ichniowski, C., K. Shaw and G. Prennushi (1997), “The Effects of Human Resource Management Practices on Productivity,” *American Economic Review* 87(3): 291-313.

Joskow, P. (1988), “Asset Specificity and the Structure of Vertical Relationships: Empirical Evidence,” *Journal of Law, Economics and Organization* 4: 95-117.

Kalogeridis, C. (2005), “The Ford/Firestone Fiasco: Coming to Blows,” *Automotive Industries* 185(1): 22-24.

Kiley, D. (2001), “Lawsuits broil over grille similarities,” *USA Today* February 15, 2001.

Klein, B., R. Crawford and A. Alchian (1978), “Vertical Integration, Appropriable Rents and the Competitive Contracting Process,” *Journal of Law and Economics* 21: 297-326.

Kumar, A. (2001), “After the Rollover Series: Deadly Combination: Ford, Firestone & Florida,” *St. Petersburg Times* May 21, 2001.

Levin, J. (2003), “Relational Incentive Contracts,” *American Economic Review* 93(3): 835-855.

MacDuffie, J. (1995), “Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production Systems in the World Auto Industry,” *Industrial and Labor Relations Review* 48(2): 197-221.

Masten, S. (1984), “The Organization of Production: Evidence from the Aerospace Industry,” *Journal of Law and Economics* 27: 403-417.

Masten, S., Meehan, J. and E. Snyder (1991), “The Costs of Organization,” *Journal of Economic Behavior and Organization* 7: 1-25.

Masten, S. and S. Saussier (2002), “The Econometrics of Contracts: An Assessment of Developments in the Empirical Literature on Contracting,” in *The Economics of Contracts: Theory and Application*, E. Brousseau and J-M. Glachant, eds., Cambridge University Press, Cambridge, England.

Milgrom, P. and J. Roberts (1990), “The Economics of Modern Manufacturing: Technology, Strategy, and Organization,” *American Economic Review* 80(6): 511-528.

Milgrom, P. and C. Shannon (1994), “Monotone Comparative Statics,” *Econometrica* 62(1): 157-80.

Miravete, E.J. and J.C. Pernias (2006), “Innovation Complementarity and Scale of Production,” *Journal of Industrial Economics* 54(1): 1-29.

Monteverde, K. and D. Teece (1982), “Supplier Switching Costs and Vertical Integration in the Automobile Industry,” *Bell Journal of Economics* 13: 206-213.

Nickerson, J. (1997), “Toward an Economizing Theory of Strategy: The Choice of Strategic Position, Assets, and Organizational Form,” Dissertation, U.C.Berkeley.

Nickerson, J. and B. Silverman (2003), “Why Aren’t All Truck Drivers Owner-Operators? Asset Ownership and the Employment Relation in Interstate For-Hire Trucking,” *Journal of Economics and Management Strategy* 12(1): 91-118.

Novak, S. and S.D. Eppinger (2001), “Sourcing by Design: Product Complexity and the Supply Chain,” *Management Science* 47(1): 189-204.

Novak, S. and P. Klibanoff (2004), "Contracting, Directed Parts, and Complexity in Automotive Outsourcing Decisions." mimeo, Northwestern University.

Novak, S. and S. Stern (2007), "How Does Outsourcing Affect Performance Dynamics? Evidence from the Automobile Industry," NBER Working Paper.

Pil, F. and J. MacDuffie (1996), "The Adoption of High-Involvement Work Practices," mimeo, Wharton School of Business.

Richman, B.D. and J. Macher (2006), "Transaction Cost Economics: An Assessment of Empirical Research in the Social Sciences," mimeo, Georgetown University.

Segal, I. (1999), "Contracting with Externalities," *Quarterly Journal of Economics* 114(2): 337-388.

Steward, D.V. (1981), "The Design Structure System: A Method for Managing the Design of Complex Systems," *IEEE Transactions on Engineering Management* 28(3): 71-74.

Suh, N. (1990), *The Principles of Design*, Oxford University Press, New York, NY.

Suh, N. (1999), "A Theory of Complexity, Periodicity, and the Design Axioms", *Research in Engineering Design* 11: 116-131.

Tirole. J. (1999), "Incomplete Contracts: Where Do We Stand?" *Econometrica* 67(4): 741-782.

Ulrich, K. (1995), "The Role of Product Architecture in the Manufacturing Firm," *Research Policy* 24: 419-440.

Ulrich, K. and S. D. Eppinger (1995), *Product Design and Development*, McGraw-Hill, New York, NY.

Van Biesebroeck, J. (2006), "Complementarities in Automobile Production," NBER Working Paper 12131.

Whinston, M.D. (2003), "On the Transaction Cost Determinants of Vertical Integration," *Journal of Law, Economics and Organization* 19(1): 1-23.

Williamson, O. E .(1979), "Transaction-Cost Economics: The Governance of Contract Relations," *Journal of Law, Economics and Organization* 22: 3-61.

FIGURE A
Confidence Intervals for Vertical Integration
By Model-Year
(90% confidence bands)

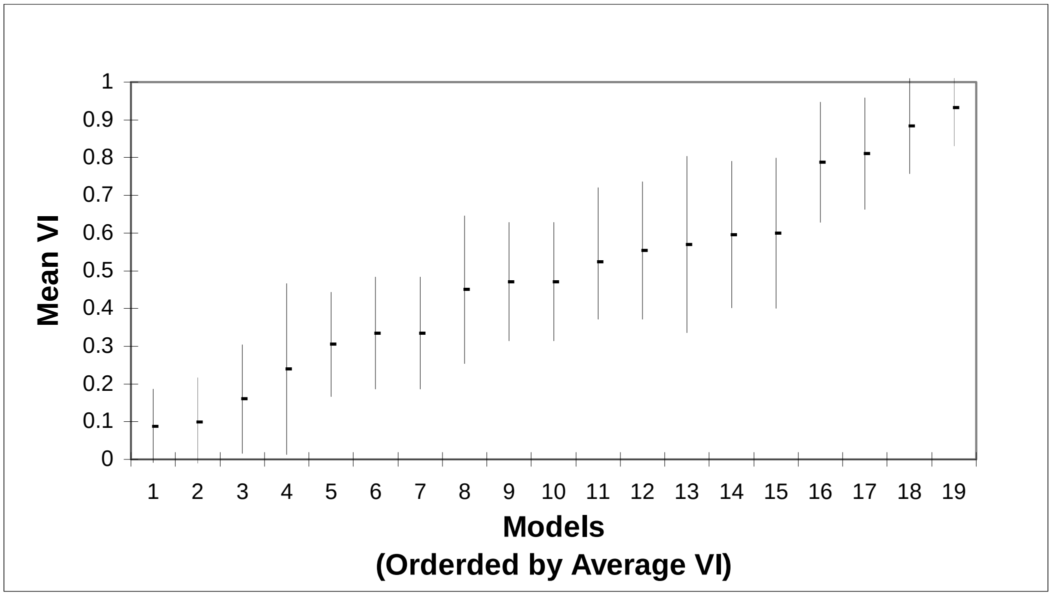

TABLE 1
Variables & Definitions

VARIABLE	DEFINITION	MEAN	STD. DEV.	# OF MODELS w/ $V(X_j) > 0$
CONTRACTING VARIABLES				
VERTICAL INTEGRATION	Percentage of the system produced in house between 0 and 1 (1 indicates all in-house production)	.485	.324	19
VERTICAL INTEGRATION$_{-i}$	Sum of VERTICAL INTEGRATION for all systems excepting *i* on model j	2.910	1.495	19
SYSTEM-SPECIFIC CONTRACTING ENVIRONMENT MEASURES				
SUNK COST	Dummy = 1 if pre-existing in-house sunk costs and/or plant investment for system *i*	.128	.335	13
LOW CAPACITY	Dummy = 1 if plant has insufficient capacity to manufacture system design in-house	.172	.378	17
PLATFORM	Dummy = 1 if component are designed to be used for more than one vehicle model	.526	.501	19
COMPLEXITY	Degree of System Complexity, ranging from 0 to 1 (See Novak and Eppinger, 2001).	.415	.272	19
DESIGN GOAL	Measure for design-oriented performance goals at the system level, ranging from 0 (low) to 1 (high)	.449	.309	19
SKILL SHORTAGE	Dummy = 1 if key worker skills are missing in existing plant locations	.150	.359	17
MODEL-YEAR MEASURE				
UNION	Dummy = 1if a component has been produced in-house and is covered under union agreement	.421	.496	0
GENERATION *X*	Dummy = 1 if model-generation is equal to *X*, 0 else (X = 2, 3, or 4)			

TABLE 2
OLS and IV Regressions

Dependent Variable : VERTICAL INTEGRATION (N=133)				
	OLS Regressions		Instrumental Variables Regressions	
	(2-1)	(2-2)	(2-3)	(2-4)
VERTICAL INTEGRATION$_{-i}$	.140***	.142***	.153***	.179***
	(.018)	(.023)	(.036)	(.046)
SUNK COST	-.003	.113	-.011	.138
	(.084)	(.093)	(.093)	(.106)
LOW CAPACITY	-.153***	-.160***	-.146***	-.163***
	(.059)	(.067)	(.061)	(.069)
PLATFORM		.018		.040
		(.047)		(.058)
COMPLEXITY		.085		.087
		(.092)		(.095)
UNION		.048		-.047
		(.100)		(.146)
SYSTEM AND MODEL-GENERATION DUMMY VARIABLES				
SUSPENSION		-.414***		-.422***
		(.127)		(.119)
BRAKES		-.131		-.139*
		(.083)		(.081)
TRANSMISSION		-.139*		-.150*
		(.077)		(.081)
ENGINE		-.189**		-.208**
		(.098)		(.102)
STEERING		-.475***		-.505***
		(.095)		(.107)
BODY		-.222**		-.238**
		(.093)		(.094)
GENERATION 2		-.007		-.006
		(.025)		(.026)
GENERATION 3		-.017		-.007
		(.031)		(.031)
GENERATION 4		-.070		-.045
		(.066)		(.072)
CONSTANT	.106*	.257***	.066	.183*
	(.058)	(.064)	(.104)	(.101)
R^2	.472	.690		
RHS Endogenous Variables			VERTICAL INTEGRATION$_{-i}$	VERTICAL INTEGRATION$_{-i}$
Instrumental Variables			For system i of model j, sum each model-specific measure for all systems but j: $Z_{-i,j,t} = \left(\sum_{l=1,\dots,7} Z_{ljt} - Z_{ijt} \right)$	
			$Z = \begin{Bmatrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \end{Bmatrix}$	$Z = \begin{Bmatrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \end{Bmatrix}$

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Standard errors are clustered at the model-system level.
(3) Equation (2-3): A Hausman test cannot reject exogeneity of VERTICAL INTEGRATION$_{-i}$ (p-value = 0.494). A Hausman test cannot reject exogeneity of instruments (p-value = 0.87)
(4) Equation (2-4): A Hausman test rejects exogeneity of VERTICAL INTEGRATION$_{-i}$ at the 10% level (p-value = 0.089). A Hausman test cannot reject exogeneity of instruments (p-value = 0.85)

TABLE 3
Instrumental Variables Regressions:
"Between" and "Within" Estimators

	Instrumental Variables Regressions				
	(3-1) "Between" IV Estimator (N = 133, 49 groups)			(3-2) Model-System Fixed Effects IV Estimator (N = 133)	(3-3) Model-System First-Differenced IV Estimator (N = 84)
VERTICAL INTEGRATION$_{-i}$	.170**			.143**	.158**
	(.035)			(.071)	(.076)
SUNK COST	.148				
	(.122)				
LOW CAPACITY	-.159			.068	-.014
	(.111)			(.068)	(.073)
PLATFORM	.036			.028	.030
	(.072)			(.058)	(.059)
COMPLEXITY	.056			.087	.058
	(.146)			(.074)	(.080)
GENERATION 2				-.002	
				(.023)	
GENERATION 3				-.017	-.004
				(.040)	(.042)
GENERATION 4				-.035	-.019
				(.071)	(.081)
UNION	.228*				
	(.118)				
CONSTANT	-.089			.013	-.003
	(.217)			(.221)	(.021)
Parametric Restrictions	#Restr	F-Stat	p-value		
SYSTEM DUMMIES	6	33.80	0.00		
σ_u				.238	.257
σ_ε				.110	.151
ρ (% variance due to μ_i)				.822	.742
RHS Endogenous Variables	VERTICAL INTEGRATION$_{-i}$			VERTICAL INTEGRATION$_{-i}$	VERTICAL INTEGRATION$_{-i}$
Instrumental Variables	For system *i* of model *j*, sum each model-specific measure for all systems but *j*: $Z_{-i,j,t} = \left(\sum_{l=1,\dots,7} Z_{ljt} - Z_{ijt} \right)$				
	$Z = \left\{ \overline{\text{SUNK COST}}, \overline{\text{LOW CAPACITY}}, \overline{\text{PLATFORM}}, \overline{\text{COMPLEXITY}} \right\}$			$Z = \left\{ \text{LOW CAPACITY}, \text{PLATFORM}, \text{COMPLEXITY} \right\}$	

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Robust standard errors throughout.
(4) Equation (3-2): H_0: $\mu_i = 0$ (all fixed effects are zero) is rejected : $F(48,77) = 10.73$; p-value = 0.00)

TABLE 4
Reduced-Form Regressions

Dependent Variable : VERTICAL INTEGRATION (N=133)				
	(4-1)	(4-2)		
SUNK COST	.027	.244***		
	(.067)	(.089)		
LOW CAPACITY	-.338***	-.103***		
	(.062)	(.090)		
PLATFORM		.043		
		(.050)		
COMPLEXITY		.163		
		(.089)		
S_ SUNK COST$_{-i}$	.040	.125*		
	(.060)	(.068)		
S_LOW CAPACITY$_{-i}$	-.212***	.041		
	(.050)	(.081)		
S_ PLATFORM$_{-i}$		.0002		
		(.021)		
S_ COMPLEXITY$_{-i}$		.073**		
		(.037)		
Parametric Restrictions		#Restr	F-Stat	p-value
COMPANY DUMMIES		7	24.18	.000
SYSTEM DUMMIES		6	5.55	.000
GENERATION DUMMIES		3	4.46	.008
Constant	.729***	.283*		
	(.088)	(.176)		
R^2	.234	.588		

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Standard errors are clustered at the model-system level.
(3) S_X$_{-i}$ denotes the sum of X across all systems but system *i*.

TABLE 5
Instrumental Variable Regressions:
Interaction Terms

Dependent Variable : VERTICAL INTEGRATION (N=133)						
	(5-1)			(5-2)		
VERTICAL INTEGRATION$_{-i}$	.233***			.183***		
	(.067)			(.037)		
VI$_{-i}$*DESIGN GOAL	-.111					
	(.082)					
VI$_{-i}$*SKILL SHORTAGE				-.062**		
				(.030)		
SUNK COST	.118			.159*		
	(.094)			(.096)		
LOW CAPACITY	-.174***			-.185**		
	(.066)			(.079)		
PLATFORM	.053			.011		
	(.062)			(.050)		
COMPLEXITY	.105			.088		
	(.090)			(.086)		
DESIGN GOAL	.089					
	(.235)					
SKILL SHORTAGE				.210***		
				(.103)		
UNION	-.109			-.029		
	(.147)			(.121)		
Parametric Restrictions	#Restr	F-Stat	p-value	#Restr	F-Stat	p-value
SYSTEM DUMMIES	6	6.27	.000	6	4.80	.000
GENERATION DUMMIES	3	0.12	.946	3	0.22	.883
Constant	.136			.181**		
	(.169)			(.081)		
RHS Endogenous Variables	VERTICAL INTEGRATION$_{-i}$ VI$_{-i}$*DESIGN GOAL			VERTICAL INTEGRATION$_{-i}$ VI$_{-i}$*SKILL SHORTAGE		
Instrumental Variables	For system *i* of model *j*, sum of each model-specific measure for all systems but *j* and interactions with DESIGN GOAL $Z_{-i,j,t} = \left(\sum_{l=1,\ldots,7} Z_{ljt} - Z_{ijt}\right) \bullet \begin{Bmatrix} 1 \\ \text{DESIGN GOAL} \end{Bmatrix}'$ $Z = \begin{Bmatrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \\ \text{DESIGN GOAL} \end{Bmatrix}$			For system *i* of model *j*, sum of each model-specific measure for all systems but *j* and interactions with SKILL SHORTAGE $Z_{-i,j,t} = \left(\sum_{l=1,\ldots,7} Z_{ljt} - Z_{ijt}\right) \bullet \begin{Bmatrix} 1 \\ \text{SKILL SHORTAGE} \end{Bmatrix}'$ $Z = \begin{Bmatrix} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \\ \text{SKILL SHORTAGE} \end{Bmatrix}$		

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Standard errors are clustered at the model-system level.
(3) VI$_{-i}$ abbreviates VERTICAL INTEGRATION$_{-i}$

TABLE 6
Testing the Impact of the Degree of Complementarity

Dependent Variable : VERTICAL INTEGRATION (N=133)						
		(6-1) OLS Estimator			(6-2) Instrumental Variables Estimator	
VERTICAL INTEGRATION (TIGHTLY COUPLED SYSTEMS)$_{-i}$		.127***			.170**	
		(.032)			(.078)	
VERTICAL INTEGRATION (LOOSELY COUPLED SYSTEMS)$_{-i}$		-.002			-.007	
		(.020)			(.054)	
SUNK COST		.093			.111	
		(.080)			(.086)	
LOW CAPACITY		-.142**			-.137**	
		(.058)			(.057)	
PLATFORM		-.006			.009	
		(.047)			(.059)	
COMPLEXITY		.065			-.058	
		(.088)			(.093)	
UNION		.047			-.060	
		(.096)			(.140)	
Parametric Restrictions	#Restr	F-Stat	p-value	#Restr	F-Stat	p-value
SYSTEM DUMMIES	6	5.61	.000	6	4.44	.001
GENERATION DUMMIES	3	0.10	.957	3	0.04	.989
Constant		.269			.191**	
		(.070)			(.114)	
R-squared		.697				
RHS Endogenous Variables					VERTICAL INTEGRATION (TIGHTLY COUPLED SYSTEMS)$_{-i}$ VERTICAL INTEGRATION (LOOSELY COUPLED SYSTEMS)$_{-i}$	
Instrumental Variables					For system *i* of model *j*, sums of each model-specific measure for all systems but *j* which are coupled at coupling level *k* (*k* either TIGHT OR LOOSE) $Z_{-i,k,j,t} = \left(\sum_{l \in k} Z_{ljt} - Z_{ijt} \right)$ $Z = \left\{ \begin{array}{c} \text{SUNK COST} \\ \text{LOW CAPACITY} \\ \text{PLATFORM} \\ \text{COMPLEXITY} \end{array} \right\}$	

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Standard errors are clustered at the model-system level.

APPENDIX A

A Model of Contracting Complementarity

This section develops a simple model of contracting complementarity even when the *ex ante* cost of specifying contracts is the same whether or not the system is outsourced. We link complementarity to specific features of the contracting environment, identifying the economic forces giving rise to contracting complementarity when the firm makes multiple vertical integration decisions across (interdependent) functional activities. Rather than develop a complete multilateral bargaining model, this "reduced-form" model assumes how the value of internal and external contracting depends on other aspects of the contracting environment. In so doing, we highlight the impact of multi-dimensional effort supply and trade secrecy concerns on contracting complementarity.

The Firm's Objective Function

We consider a simple production environment where the automobile producer (the "firm") must contract for the development of two automobile systems, A and B, in order to produce a new automobile model. While system-specific performance is important, overall performance also depends on the level of system-to-system coordination. Effective coordination imposes additional costs on the firm, and some of these costs depend on the chosen vertical structure. We assume that a higher level of coordination can be achieved by inducing a higher level of (non-contractible) coordination effort and/or by the disclosure of crucial model-level design details to each team. However, these benefits are traded off against a lower level of system-specific effort and an increased probability that trade secrets are publicly revealed.

Total profits depend on the performance of each system (f^A and f^B), the degree of coordination between the systems (f^I) and whether the design remains a secret ($c(\theta)$). System-specific performance is a function of the level of system-specific effort, which depends on whether the system is outsourced or not and the incentive scheme employed by the firm. For each system i, let y_i = 0 be defined as an outsourced team and y_i = 1 as in-house development. Moreover, the firm can choose to implement an explicit or subjective incentive scheme for each system. Let x_i = 0 be defined as employing explicit incentive scheme for agents responsible for system i and x_i = 1 a subjective performance evaluation scheme. Further, the firm can improve the degree of integration by disclosing design choices to both teams (*d* = 1; 0 else). Finally, for f^i , let Z_i be exogenous factors impacting the returns to i. This structure yields the following total profit function:

$$\Pi = f^A(x_A, y_A; Z_A) + f^B(x_B, y_B; Z_B) + f^I(x_A, x_B, y_A, y_B, d; Z_I) - c(\theta(y_A, y_B, d))$$

For each system, performance depends on the pre-existing capability level of the team chosen, the system-specific effort level, and a random component. As such, our approach differs implicitly from the theoretical literature insofar as we are assuming that one cannot acquire external teams. In other words, pre-existing system-specific sunk investments or capabilities that have historically maintained by the firm internally predispose the firm to continue in-house production.

Moreover, the system-specific effort level (e_i^{SS}) depends on the chosen incentive scheme and whether the system is outsourced or not, resulting in the following expression for system-specific performance:

$$f_i^{y_i} = h(Z_i^{y_i}) + \mathrm{e}_\mathrm{i}^{\mathrm{SS}}(x_i, y_i) + \eta_i \qquad (x_i \in \{0,1\}; y_i \in \{0,1\})$$

There will be variation across model-systems as to whether external or in-house teams have a greater pre-existing capability level (or current capacity to complete the work). Indeed, this form of variation – factors impacting system-level performance but unrelated to the interdependencies among systems – is the key to the empirical identification strategy described in Section IV.

For simplicity, we assume that the benefits from increased coordination can be separably decomposed into the benefits arising from the interaction between the incentive scheme and the outsourcing choice (f_x^I), and the benefits from a higher level of disclosure (f_d^I). The benefits to coordination, f_x^I, is sensitive to the level of coordination effort by each team (e_i^{INT}, $i = A, B$). Because effective coordination depends on interactions between the parties, we specify the net benefits from integration effort as the *product* of the coordination effort by each team:

$$f_x^I = \prod_{i=A,B} e_i^{INT}(x_i, y_i) \qquad (x_i \in \{0,1\}; y_i \in \{0,1\})$$

As well, beyond a baseline level, effective coordination depends on disclosure (d = 1), the benefits of which may depend on specific features of the product development environment (Z_d^I) but are independent of the chosen ownership structure ($f_d^I = d \cdot Z_d^I$). However, the probability that model-level design information is disclosed to competitors , θ, increases from θ_L to θ_H when d = 1 and either $y_A = 0$ *or* $y_B = 0$. In other words, in the case where the integration benefit is realized, the disclosure probability depends on whether at least one of the systems is outsourced.[34] Taken together, these assumptions yield the firm's overall objective function:

$$\underset{x_A, x_B, y_A, y_B, d}{Max} \ \Pi = \sum_{i=A,B} (h(Z_i^{y_i}) + \mathrm{e}_\mathrm{i}^{\mathrm{SS}}(x_i, y_i)) + \prod_{i=A,B} e_i^{INT}(x_i, y_i) + d \cdot Z_d^I - (d(1 - y_A y_B)(c(\theta_H) - c(\theta_L)))$$

Incentives, the Contracting Environment and Effort Supply

Optimal contracting and incentive scheme choices are based on the relative benefits of in-house versus supplier development and how these choices interact with the potential costs of disclosure. For each development team, the firm chooses between an explicit and subjective incentive scheme. While the

[34] The baseline probability of disclosure is greater than zero in order to be consistent with the idea that disclosure itself is non-contractible, as the "source" of competitive intelligence cannot be verified. As well, while the current model assumes that the potential for expropriation does not increase when *both* teams are outsourced (relative to θ_H), we can accommodate this extension as long as $c(\theta \mid d = 1, y_A = 0, y_B = 0) - c(\theta_H) \le c(\theta_H) - c(\theta_L)$.

explicit scheme is contract-based and payoffs are contingent on observable and verifiable criteria, the subjective scheme depends on "soft" information across a wider range of dimensions (Baker, Gibbons and Murphy, 1994; 2002; Levin, 2003). We assume that explicit contract terms can only be provided for system-specific performance measures, and the ability to contract on the degree of coordination is limited by the absence of verifiable information. As mentioned earlier, even though formal contracts in the automobile industry do specify that coordination requirements, the inability to document the source of failure over a coordination issue limits the effectiveness of formal contracts for this purpose. In other words, while the *ex ante* costs of writing contract specifications is the same for in-house and external teams, *ex post* differences in the contracting environment lead to differences in the effort levels of in-house versus external teams under each incentive scheme.

Under an identical explicit incentive scheme, external teams will provide a higher equilibrium level of system-specific effort than in-house teams. This difference arises because performance is observed with a long lag, and the terms of contracting are subject to renegotiation when performance is observed.[35] Once performance is observed, external suppliers can expect to have little bargaining power, as they will likely have no ongoing contractual relationship with the firm.[36] As such, when contract specifications are not met (e.g., a verifiable system-specific failure occurs), the manufacturer can (and will) enforce whatever contractual penalties are specified. By writing an enforceable contract with severe penalties in the case of system failure, the firm can induce a high level of system-specific effort by choosing an external supplier. Auto manufacturers and their suppliers can (and do) litigate disputes through arbitration or formal litigation on a regular basis. In contrast, enforcing severe penalties against in-house product development teams is more difficult. By the time performance is observed, team members will be working on *new projects* for the firm; as a result, the threat of hold-up counter-balances the threat of penalties by the firm. The continuing involvement of the in-house teams with the firm reduces the ability of the firm to commit to explicit contract-based penalties associated with system failure.[37] As a result, even though the ex ante costs of specifying contracts is identical, the equilibrium level of system-specific effort will be lower for in-house development teams under ($e_i^{SS}(0,0) > e_i^{SS}(0,1),\ i = A, B$). Further, because coordination effort is non-contractible, employing an explicit incentive scheme limits the ability to induce effort towards coordination, and there is no difference in the level of effort devoted by an in-house or external team. For simplicity, we normalize

[35] More precisely, the timing associated with observing a *failure* is uncertain, as it depends on the accumulation of user evidence (e.g., consumer complaints, crash rates, etc.). The assumption is that the expected ability to renegotiate contracts differs across in-house versus external suppliers at the time of initial contracting.
[36] Typically, time between major changes is 3-5 years, and it is unlikely that the same supplier is working on a new project for the same manufacturer in the same vehicle segment at the time when failure is observed.
[37] Moreover, the ability to specify performance incentives for individual employees is limited by the fact that (a) employees are dispersed throughout the firm and so the cost of enforcing provisions may have a large impact on projects throughout the firm and (b) individual liquidity constraints constrain the ability of the firm to specify monetary damages of the type that are routinely used in supplier contracts.

the level of coordination effort under explicit incentives to 0 for both in-house and external teams (i.e., $e_i^{INT}(1,0) = e_i^{INT}(1,1) = 0$).

In contrast to an explicit incentive contract, a subjective incentive scheme can induce effort along both dimensions, even though coordination effort is non-contractible. More specifically, the firm can use the potential for repeated interaction to establish relational contracts inducing effort on dimensions over which managers can make (non-verifiable) inferences about the level of effort (Baker, Gibbons and Murphy, 1994; 2002; Levin, 2003). Inducing effort on non-contractible dimensions comes at the expense of high-powered incentive contracting on dimensions for which contracting is feasible; as a result, for a given team (in-house or external), the equilibrium level of system-specific effort is lower under subjective relative to explicit incentives ($e_i^{SS}(0,\ .) > e_i^{SS}(1,\ .)$). However, relative to an external team, an in-house team provides a higher level of coordination effort under subjective incentives than an external team:

$$e_i^{SS}(1,\ 0) < e_i^{SS}(1,\ 1)$$
$$e_i^{INT}(1,\ 0) < e_i^{INT}(1,\ 1)$$

Those factors limiting the ability of the firm to enforce formal contract terms against in-house employees are precisely those which allow the firm to implement relational contracting. For example, while a long-term employment relationship with the firm limits the power of formal contracts (because of the potential for hold-up), this relationship allows the firm to use subjective promotion decisions to induce effort on non-contractible dimensions. While relational contracting across firms may also be feasible (as emphasized in Baker, Gibbons and Murphy (2002)), the effectiveness of inter-firm subjective contracting is limited – relative to what is achievable for employees within the firm -- by the lower probability of a repeated relationship across firm boundaries.[38]

Finally, we also assume that the firm cannot specify specific penalties for trade secrecy violations; while an occasional instance of industrial espionage will result in a supplier being caught "red-handed," most expropriation occurs without the firm's knowledge and with few clues as to the precise source of the disclosure of competitive intelligence.

Optimal Contracting, Disclosure and Complementarity

The firm simultaneously chooses whether to vertically integrate each product development team, the incentive scheme to provide each team, and whether to facilitate coordination through disclosure. Interdependencies across vertical choices arise through the coordination effort decisions and through the disclosure decision.

Proposition 1: $\Pi(x_A, x_B, y_A, y_B, d)$ is supermodular in x_A, x_B, y_A, y_B, and d.

---

[38] If overall effort supply is inelastic, it is possible that $e_i^{SS}(1,\ 0) > e_i^{SS}(1,\ 1)$. This does not change the overall analysis as long as subjective incentives are pairwise complements with in-house production.

Proof of Proposition 1: The proof proceeds by showing pairwise complementarity among each of the choice variables. Letting Δ_i refer to the difference in Π from shifting *i* from 0 to 1 (and Δ_{ij} is analogously the double-difference operator), we need to show that

$$\forall \text{ pairs } (i, j) \in \{x_A, x_B, y_A, y_B, d\},$$

$$\Delta_{ij} - \Delta_i - \Delta_j > 0 \quad \forall\, x_A, x_B, y_A, y_B, d$$

We begin with the pair (x_A, y_A). Since *d* does not interact with x_A, we abstract away from the level of *d*. As well, when $x_B = 0,\ f_x^I = 0 \quad \forall\, x_A, y_A, y_B$. In the case when $x_B = 0$, we thus need only show $e_A^{SS}(1,1) + e_A^{SS}(0,0) - e_A^{SS}(1,0) - e_A^{SS}(0,1) > 0$. This follows from two observations:

$e_A^{SS}(1,1) > e_A^{SS}(1,0)$ (in-house subjective effort is higher than external subjective effort)

$e_A^{SS}(0,1) < e_A^{SS}(0,0)$ (in-house explicit effort is lower than external explicit effort).

When $x_B = 1$, we also consider whether

$$e_B^{INT}(1,.) * (e_A^{INT}(1,1) + e_A^{INT}(0,0) - e_A^{INT}(1,0) - e_A^{INT}(0,1)) > 0.$$

Complementarity among (x_A, y_A) is ensured because $e_A^{INT}(0,0) = e_A^{INT}(0,1) = 0$, . An identical argument holds for (x_B, y_B).

We next consider (y_A, y_B). When x_A or x_B = 0 *and d* = 0, there is no interaction between (y_A, y_B). When x_A and x_B = 1 (maintaining *d* = 0) , we must determine the sign of:

$$e_A^{INT}(1,1)\, e_B^{INT}(1,1) + e_A^{INT}(1,0)\, e_B^{INT}(1,0) - e_A^{INT}(1,0)\, e_B^{INT}(1,1) - e_A^{INT}(1,1)\, e_B^{INT}(1,0).$$

This can be rewritten as:

$$e_A^{INT}(1,1)\,(e_B^{INT}(1,1) - e_B^{INT}(1,0)) - e_A^{INT}(1,0)\,(e_B^{INT}(1,1) - e_B^{INT}(1,0))$$

which can be further rewritten as:

$$(e_A^{INT}(1,1) - e_A^{INT}(1,0))\,(e_B^{INT}(1,1) - e_B^{INT}(1,0))$$

Each of these terms is positive by assumption since in-house subjective incentives induce higher effort than external subject incentives. Finally, when *d* = 1, we must also consider the term $c(\theta_H) - c(\theta_L)$, which is also positive by assumption, yielding complementarity between (y_A, y_B).

We next consider (x_A, y_B). When $x_B = 0$, there is no interaction between these two variables. Assuming $x_B = 1$, we can write the inequality for complementarity as:

$$e_A^{INT}(1,.)\, e_B^{INT}(1,1) + e_A^{INT}(0,.)\, e_B^{INT}(1,0) - e_A^{INT}(0,.)\, e_B^{INT}(1,1) - e_A^{INT}(1,.)\, e_B^{INT}(1,0) > 0$$

Since $e_A^{INT}(0,.) = 0$, this reduces to $e_A^{INT}(1,.)(e_B^{INT}(1,1) - e_B^{INT}(1,0)) > 0$ which follows from the assumption that in-house subject incentives induce higher effort than external subjective incentives. An identical argument holds for (x_B, y_A).

We now consider complementarity between (x_A, x_B), or the sign of the following:

$$e_A^{INT}(1,.)\, e_B^{INT}(1,.) + e_A^{INT}(0,.)\, e_B^{INT}(1,.) - e_A^{INT}(1,.)\, e_B^{INT}(0,.) - e_A^{INT}(0,.)\, e_B^{INT}(0,.) > 0$$

This inequality is strict because $e_A^{INT}(0,.) = e_B^{INT}(0,.) = 0$, and $e_i^{INT}(1,.) > 0$.

The final pairwise complementarity to check is (y_A, d). The complementarity inequality for this pair reduces simply to $(1 - y_A)(c(\theta_H) - c(\theta_L)) \geq 0$ which holds by assumption about the costs of disclosure.

There are two distinct drivers of complementarity among vertical integration choices in this model. First, because coordination requires interaction (and so coordination efforts are complements) and in-house development teams are more sensitive to subjective incentive schemes that induce a positive level of coordination effort, the contracting choices for the two teams become interdependent. In other words, contracting complementarity results because the benefits of coordination are sensitive to the *least* effort provided, and the level of coordination effort is sensitive to the vertical integration choice. As well, contracting complementarity arises because of the non-contractibility of the trade secrecy clause and the fact that the probability of expropriation increases most steeply with the first instance of external contracting. Another interpretation of this second channel for contracting complementarity is that the types of investments to ensure against expropriation result in economies of scale in outsourcing; the marginal "costs" of external governance are declining in the level of external governance.

Simplifying notation so that Z_i are system-specific factors favoring vertical integration for system i, Proposition 1 implies the comparative statics motivating the empirical strategy:

Remark: $x_A^*, x_B^*, y_A^*, y_B^*$, and d^* are weakly increasing in Z_A and Z_B, and weakly decreasing in Z_D and $c(\theta_H) - c(\theta_L)$.

Proof: Since each of the exogenous variables has a monotone relationship with each of the y_i, the comparative statics with respect to Z_i and $c(\theta_H) - c(\theta_L)$ are a direct consequence of Milgrom and Shannon (1994, Proposition 4).

APPENDIX B
Pairwise Correlations

	VI	SUNK COST	LOW CAP	PLATFORM	COMPLEXITY	UNION	DESIGN GOAL	SKILL SHORTAGE
VERTICAL INTEGRATION	1.00							
SUNK COST	-.01	1.00						
LOW CAPACITY	-.25*	.30*	1.00					
PLATFORM	.07	.05	-.00	1.00				
COMPLEXITY	-.15	.02	-.11	-.13	1.00			
UNION	.55*	.22*	-.15	.17	-.31*	1.00		
DESIGN GOAL	-.13	-.14	-.17	-.10	.24*	-.23*	1.00	
SKILL SHORTAGE	-.26*	.47*	.59*	.10	-.06	-.02	-.14	1.00

Note: A star denotes statistical significance at 5% significance level.

APPENDIX C-1
BETWEEN ESTIMATORS AND INITIAL CONDITIONS ESTIMATORS
(BOTH OLS AND INSTRUMENTAL VARIABLES)
PRE-EXISTING CAPABILITIES AND RESOURCES SPECIFICATION

Dependent Variable : VERTICAL INTEGRATION				
	OLS Regressions		Instrumental Variables Regressions	
	(C1-1) Between Estimator (N=133, 49 groups)	(C1-2) Initial Conditions Estimator (N = 84)	(C1-3) Between IV Estimator (N = 133, 49 groups)	(C1-4) Initial Conditions IV Estimator (N = 84)
VERTICAL INTEGRATION$_{-i}$	.138***	.133***	.155***	.153***
	(.023)	(.022)	(.029)	(.034)
SUNK COST	.022		.011	
	(.115)		(.116)	
LOW CAPACITY	-.192**		-.180*	
	(.098)		(.099)	
SUNK COST$_0$		.017		.008
		(.072)		(.084)
LOW CAPACITY$_0$		-.217***		-.209
		(.062)		(.065)
CONSTANT	.107*	.142*	.062	.079
	(.072)	(.077)	(.087)	(.105)
R^2 Within	.016			
R^2 Between	.498			
R^2 Overall	.470	.440		
RHS Endogenous Variables			VERTICAL INTEGRATION$_{-i}$	VERTICAL INTEGRATION$_{-i}$
Instrumental Variables			For system *i* of model *j*, sum each model-specific measure for all systems but *j*: $Z_{-i,j,t} = \left(\sum_{l=1,\dots,7} Z_{ljt} - Z_{ijt} \right)$	
			$Z = \left\{ \begin{matrix} \overline{\text{SUNK COST}} \\ \overline{\text{LOW CAPACITY}} \end{matrix} \right\}$	$Z = \left\{ \begin{matrix} \text{SUNK COST}_0 \\ \text{LOW CAPACITY}_0 \end{matrix} \right\}$

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Equation (C1-1) and (C1-3): Standard errors are unadjusted as procedure is at the model-system level.
(3) Equation (C1-2) and (C1-4): Standard errors are clustered at the model-system level.
(4) Equation (C1-2) and (C1-4): Z_0 is the initial value for the system-specific measure Z for a given model-system (Z is either SUNK COST or LOW CAPACITY). The initial observation for each model-system is dropped so that the initial conditions estimators relies exclusively on variation across models in the level of pre-existing capabilities and resources prior to the time of the first vertical integration contracting choice for that model-system.

APPENDIX C-2
BETWEEN ESTIMATORS AND INITIAL CONDITIONS ESTIMATORS
(BOTH OLS AND INSTRUMENTAL VARIABLES)
DESIGN AND MANUFACUTING CHALLENGE INDICES

Dependent Variable : VERTICAL INTEGRATION				
	OLS Regressions		Instrumental Variables Regressions	
	(C2-1) Between Estimator (N=133, 49 groups)	(C2-2) Initial Conditions Estimator (N = 84)	(C2-3) Between IV Estimator (N = 133, 49 groups)	(C2-4) Initial Conditions IV Estimator (N = 84)
VERTICAL INTEGRATION$_{-i}$	.146***	.151***	.179***	.195***
	(.024)	(.025)	(.061)	(.039)
PLATFORM	.038		.042	
	(.073)		(.075)	
COMPLEXITY	.038		.082	
	(.157)		(.177)	
PLATFORM$_0$		.089		.102
		(.078)		(.082)
COMPLEXITY$_0$		.164		.240
		(.137)		(.159)
CONSTANT	.019	-.056	-.089	-.219
	(.118)	(.108)	(.217)	(.173)
R^2 Within	.074			
R^2 Between	.456			
R^2 Overall	.447	.404		
RHS Endogenous Variables			VERTICAL INTEGRATION$_{-i}$	VERTICAL INTEGRATION$_{-i}$
Instrumental Variables			For system *i* of model *j*, sum each model-specific measure for all systems but *j*: $Z_{-i,j,t} = \left(\sum_{l=1,\ldots,7} Z_{ljt} - Z_{ijt} \right)$	
			$Z = \left\{ \begin{array}{c} \overline{\text{SUNK COST}} \\ \overline{\text{LOW CAPACITY}} \end{array} \right\}$	$Z = \left\{ \begin{array}{c} \text{SUNK COST}_0 \\ \text{LOW CAPACITY}_0 \end{array} \right\}$

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Equation (C2-1) and (C2-3): Standard errors are unadjusted as procedure is at the model-system level.
(3) Equation (C2-2) and (C2-4): Standard errors are clustered at the model-system level.
(4) Equation (C2-2) and (C2-4): Z_0 is the initial value for the system-specific measure Z for a given model-system (Z is either PLATFORM or COMPLEXITY). The initial observation for each model-system is dropped so that the initial conditions estimators relies exclusively on variation across models in the level of design and manufacturing challenges prior to the time of the first vertical integration contracting choice for that model-system.

APPENDIX C-3
BETWEEN ESTIMATORS AND INITIAL CONDITIONS ESTIMATORS
(BOTH OLS AND INSTRUMENTAL VARIABLES)
FULL SPECIFICATION

Dependent Variable : VERTICAL INTEGRATION				
	OLS Regressions		Instrumental Variables Regressions	
	(C3-1) Between Estimator (N=133, 49 groups)	(C3-2) Initial Conditions Estimator (N = 84)	(C3-3) Between IV Estimator (N = 133, 49 groups)	(C3-4) Initial Conditions IV Estimator (N = 84)
VERTICAL INTEGRATION$_{-i}$	.148***	.136***	.170***	.170***
	(.026)	(.031)	(.035)	(.033)
SUNK COST	.135		.148	
	(.120)		(.122)	
LOW CAPACITY	-.162		-.159	
	(.110)		(.111)	
PLATFORM	.025		.036	
	(.070)		(.072)	
COMPLEXITY	.063		.056	
	(.144)		(.146)	
SUNK COST$_0$		.151		.168
		(.096)		(.103)
LOW CAPACITY$_0$		-.228***		-.225***
		(.067)		(.071)
PLATFORM$_0$		-.019		.005
		(.056)		(.057)
COMPLEXITY$_0$		.187		.204
		(.166)		(.171)
UNION	.008	.065	.228*	-.010
	(.091)	(.095)	(.118)	(.105)
Parametric Restrictions	#Restr F-Stat p-value	#Restr F-Stat p-value	#Restr F-Stat p-value	#Restr F-Stat p-value
SYSTEM DUMMIES	6 5.60 0.00	6 4.67 0.00	6 33.80 0.00	6 4.82 0.00
GENERATION DUMMIES		2 0.06 0.94		2 0.04 0.96
CONSTANT	.269**	.230	-.089	.148
	(.110)	(.148)	(.217)	(.143)
R^2 Within	.021			
R^2 Between	.745			
R^2 Overall	.683	.692		
RHS Endogenous Variables			VERTICAL INTEGRATION$_{-i}$	VERTICAL INTEGRATION$_{-i}$
Instrumental Variables			For system *i* of model *j*, sum each model-specific measure for all systems but *j*: $Z_{-i,j,t} = \left(\sum_{l=1,\dots,7} Z_{ljt} - Z_{ijt} \right)$	
			$Z = \left\{ \begin{array}{l} \overline{\text{SUNK COST}} \\ \overline{\text{LOW CAPACITY}} \\ \overline{\text{PLATFORM}} \\ \overline{\text{COMPLEXITY}} \end{array} \right\}$	$Z = \left\{ \begin{array}{l} \text{SUNK COST}_0 \\ \text{LOW CAPACITY}_0 \\ \text{PLATFORM}_0 \\ \text{COMPLEXITY}_0 \end{array} \right\}$

Notes: (1) Stars denote 1 (***), 5 (**), and 10% (*) statistical significance level.
(2) Equation (C3-1) and (C3-3): Standard errors are unadjusted as procedure is at the model-system level.
(3) Equation (C3-2) and (C3-4): Standard errors are clustered at the model-system level.
(4) Equation (C3-2) and (C3-4): Z_0 is the initial value for the system-specific measure Z for each model-system