Complementarity Among Vertical Integration Decisions: Evidence from Automobile Product Development

by

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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* may arise when governance choices impact the equilibrium degree of coordination among agents. 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 through an external supply contract may induce complementarity among vertical integration choices. We provide evidence for complementarity in product development contracting by developing an instrumental variables estimator that distinguishes complementarity from unobserved firm-level factors determining contracting mode. While we interpret our findings cautiously, the results suggest that contracting complementarity may be important in contexts where coordination is important to achieve but difficult to monitor.

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I. Introduction

The modern theory of the firm has made considerable progress explaining the determinants of vertical integration and firm boundaries, assuming that the level of vertical integration results from independent transactional choices by the firm. For most organizations, however, firm boundaries are not determined by independent vertical integration decisions but depend on interrelated choices spanning functional activities. 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 projects.

Moreover, in many cases, individual contracting choices are interdependent with other contracting decisions. The decision to outsource a single function (e.g., the supply for an individual component) impacts the vertical integration calculation for related procurement decisions, particularly if overall performance depends on coordination among agents responsible for these two functional areas and the degree of coordination is sensitive to governance structure. Complementarity among governance choices, which we refer to as contracting complementarity, results when the marginal returns to vertical integration for a given vertical integration choice are increasing in the level of vertical integration on related choices. The central 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 theoretical analysis suggests that contracting complementarity arises when coordination is important but difficult to monitor. Consider how coordination is achieved among 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. As well, the benefits from coordination depends 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. Moreover, while external teams may be more responsive than in-house teams to explicit incentives for system-specific performance, external teams may be less sensitive than in-house teams to subjective incentives for non-contractible coordination effort. For example, while liquidity concerns and the ability of in-house teams to hold up the firm on future projects limits the effectiveness of explicit incentives schemes, the potential to base promotion incentives on "soft" information may facilitate the relative effectiveness of in-house subjective incentive schemes. Interdependence in the benefits to coordination effort implies that the marginal returns to coordination effort (enabled by vertical integration) are increasing in the level of coordination effort of the other team, resulting in complementarity among vertical integration choices.

Trade secrecy concerns may also result in contracting complementarity. While effective coordination requires the disclosure of key technical details and strategic choices, such disclosures may also result in expropriation if knowledge leaks out to competitors. This leads to a tradeoff between effective coordination and the potential for expropriation. If the probability of expropriation increases most rapidly when the firm adopts its first external supply contract, trade secrecy concerns limit disclosure unless all development is maintained in-house.

Our focus on interdependence among vertical integration choices stands in sharp contrast to most prior theoretical and empirical research in economics on vertical integration, which often focuses on the drivers of vertical integration at the level of *transactions* (*see* Tirole (1999) and Whinston (2002) for a literature review, and Baker and Hubbard (2003) for an excellent recent example).[1] In contrast, product development researchers have increasingly identified the *interaction among components and systems* as perhaps the most important "problem" in managing new product development (Eppinger, et al, 1993; 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, 1994).

While we are not aware of a prior study of contracting complementarity, several recent papers highlight the importance of interrelationships in governance choice. For example,

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[1] Motivated by the theoretical literature's focus on asset specificity and hold-up, empirical research has mostly focused on individual contracting opportunities in which individual decisions are assumed independent. For example, in Joskow's study of coal plant and coal mine contracting, the precise match between theory and the empirical setting results in persuasive evidence that co-location of the coal plant and coal mine has a substantial impact on coal plant ownership structure (Joskow, 1988). In the context of product development, this approach has placed emphasis on individual technical *components*, examining how factors such as asset specificity or relative bargaining power drive the vertical integration decision at the most "micro" level of decision-making (Monteverde and Teece, 1982; Masten, 1984; Masten, Meehan and Snyder, 1991).

building on the conceptual framework provided in Nickerson (1997), Nickerson and Silverman (2003) suggest that a low level of owner-operator trucking results from the potential for spillovers across truckers taking orders from a given carrier. As well, Azoulay (2002) examines the potential for substitutability in drug development contracting choices and argues for a "portfolio" approach to empirical contract analysis. In addition, a growing literature examines complementarity in organizational design more generally (Milgrom and Roberts, 1990; Holmstrom and Milgrom, 1994; Ichniowski, Shaw and Prenusshi, 1997; Cockburn, Henderson and Stern, 2003; Ichniowski and Shaw, 2003). In this paper, we focus on complementarity among individual contracting choices, while prior research examines the interdependency among distinct organizational practices. Finally, though more abstract than the applied focus of the current paper, Segal (1999) provides theoretical foundations for multi-lateral contracting choice, emphasizing the potential for signaling across contracting decisions.

We test for contracting complementarity in the context of automobile product development, exploiting 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. This approach differs (at least implicitly) from the theoretical literature insofar as we assume that pre-existing system-specific sunk investments by the firm predispose the firm to continue in-house production for that system.

These system-specific drivers allow us to develop and implement an instrumental variables strategy that overcomes a key problem in testing for contracting complementarity. In particular, without an instrumental variables approach, it is not possible to disentangle contracting complementarity from unobservable firm-level fixed effects in contracting mode (e.g., if a firm adopts an "outsourcing" strategy for all systems within the automobile). By observing system-specific variation in the contracting environment, we can estimate the sensitivity of vertical integration on a system *i* to the level of vertical integration on other systems within the same automobile, 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 the other systems. In other words, the instrumental variables strategy is based on *exogenous system-specific differences in the contracting environment which also result in differences in contracting choices.*

Though we are cautious in our interpretation, the findings highlight the 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, robust to the inclusion of firm and system fixed-effects, and present across different functional forms. In other words, the evidence for complementarity is identified from measured differences in the contracting environment across systems within a given automobile model. Second, even when system-specific measures of the contracting environment are included, the contracting environment associated with other systems influence the vertical integration choice for each system. Finally, we identify measures which allow us to explore the salience of effort supply and trade secrecy, respectively. While these results are somewhat noisy, there is limited evidence for the importance of the coordination effort supply effect highlighted in the theoretical model.

While we interpret this evidence in light of the size of the dataset and the inherent challenges in assessing the drivers of organizational design, the results do suggest that assuming away contracting complementarity may be problematic in contexts where coordination activities are important yet difficult to monitor. Moreover, contracting complementarity may have implications for aggregate patterns of vertical integration. Consider the interpretation for 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 as the benefits to vertical integration for individual functions depends 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 develops a simple formal model of the drivers of contracting complementarity, and Section IV derives a formal empirical framework for testing for contracting complementarity. After a review of the data, Section VI reviews our key empirical findings. A final section concludes.

II. Interactions among Vertical Integration Choices in Automobile Product Development

The Setting[2]

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, 1938; 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 key features of the contracting literature, including the importance of non-contractible investment and the potential for renegotiation. While most empirical economics research assesses the determinants of vertical integration at the level of individual transactions, coordinating activities *across* transactions is at the heart of product development management.

More precisely, the organization of product development activities reflects the key 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 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, typically five years after the initiation of product development.

Automobile manufacturers achieve this coordination in several ways. First, product development is typically governed by a "vehicle integrity" team, which has responsibility for

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[2] 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.

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 such coordination activities have always been crucial, the importance of "integrality" across vehicle systems has increased dramatically over the past fifteen years, with the introduction of advanced electronics that impact multiple systems, such as electronic engine controllers, the ABS brake system, or electronically controlled features such as lumbar support and anti-whiplash protection.

The inability to contract on the level of effort devoted to coordination across systems and secrecy concerns limit the effectiveness of coordination efforts, particularly when contracting with external parties. Section III analyzes how these limitations induce complementarity among vertical integration choices; we motivate this model by first describing the challenges of contracting for cross-system coordination effort and the role of secrecy in product development.

Cross-System Coordination Effort

Effective vehicle performance requires substantial and difficult-to-monitor 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 specifying contracts 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). The benefits to coordination depend on effort by all parties involved, and a higher probability of failure results from shirking by even one agent. From the viewpoint of incentive provision, effort towards coordination not only involves a free-riding problem, but is also non-contractible, and so investment cannot be induced by formal contract requirements.[3]

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[3] While most procurement contracts with external suppliers do specify that coordination activities must be undertaken, the inability to assign responsibility for the *failure* to coordinate makes such provisions unenforceable.

As non-contractible investments, the level of coordination effort depends on the incentives provided to product development team members. 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;[4] 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 within 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 incentives through subjective performance incentives. For example, while the observed seat defect rate is a measure that a seat supplier may agree to have incorporated into a contract, a seat supplier will not accept compensation on the basis of qualitative customer satisfaction ratings (in part, because the manufacturer may be able to distort such data in order to avoid or lower payments). The use of subjective performance signals can be achieved through direct compensation, subjective bonuses, and promotion incentives. Finally, the marginal cost of ensuring a given level of coordination is often much lower in the context of internal development, as product development teams are more likely to be co-located and share a common language and background. Together, these factors suggest that the coordination effort by external suppliers will likely be lower than that achieved by an internal team.

Consider the recent case of the rollovers and tire blowout incidents on the Ford Explorer that was traced to the interaction between Ford and its tire supplier, Firestone (Muller, 2001). 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. 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. While the safety

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Since coordination requires effort by multiple parties, each agent is able to claim that the source of coordination failure is one of the other agents who might have contributed or used information to ensure effective coordination. To our knowledge (based on over 1000 in-depth on-site interviews with individuals involved in automobile product development), no manufacturer has sued a supplier for failing to satisfy contractual obligations associated with coordination across vehicle systems

[4] Clark and Fujimoto (1991) describe the role of the "heavyweight project manager" in Japanese manufacturing.

hazard that resulted from this contracting problem is likely an extreme case (e.g., Firestone was forced into bankruptcy by the resulting liabilities), the Ford/Firestone case highlights the key role of coordination among systems in automobile 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 key design and technology choices secret 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.[5] Trade secrecy issues need not be a direct consequence of explicit industrial espionage; rather, key knowledge about new innovations or design initiatives can inadvertently be revealed to competitors when external suppliers exploit knowledge gained in one partnership in bidding for competitor projects. Maintaining trade secrecy involves more than the physical costs of separate facilities, but a substantial reduction in the amount and frequency of information that can be exchanged among developers for integration efforts. Cross-system coordination requires disclosure of at key design details for each system; limiting the release of technical details because of trade secrecy concerns reduces the ability to coordinate and update systems during product development.

Trade secrecy concerns place more restrictions on effective integration when product development is outsourced. 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 key pieces of information.[6] Though long-term exclusive contracts might mitigate such concerns, such arrangements are rare (even absent) in the automobile industry, in part because one of the principal benefits of organizing as an independent supplier is the ability to leverage investments made in the context of projects for one manufacturer in future projects for other manufacturers. Indeed, while some expropriation may be intentional and violate confidentiality agreements,

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[5] One of the authors was detained for lengthy questioning after borrowing a company pass to access an area where new vehicles were under development. The detainment resulted in a confidentiality agreement requiring that the author never mention this company's new products in writing before they had been put into production.

[6] 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.

most information leaks occur because suppliers advertise the innovations developed in an ongoing project in their bids for new projects with other manufacturers. By achieving effective integration through the disclosure of key design choices, manufacturers face the risk of key innovations revealed to competitors before vehicles are introduced to the market.[7]

Consider the case of cellular telephones. In the luxury car market, a key 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 and integration with the revelation of information about data and design plans within the firm.

Together, coordination incentives and trade secrecy concerns limit the effectiveness of integration efforts in product development, particularly when development is outsourced to an external supplier. Our qualitative evidence suggests that, while individual transactions are conducted at the component (or sub-system) level, the increased importance of system-to-system interactions suggests that it is important to incorporate such effects in order to evaluate the key incentive and coordination problems that firms face in the product development process. In the next section, we develop a simple model in which coordination effort and/or trade secrecy concerns results in complementarity among vertical integration choices; the remainder of the paper evaluates the empirical evidence for complementarity in automobile product development.

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[7] The importance of 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 learn of value-enhancing new features and performance improvements.

III. A Simple 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 key 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 key 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 ($f_d^I = d \bullet Z_d^I$). 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.[8] Taken together, these assumptions yield the firm's overall objective function:

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

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 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. 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.[9] 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.[10] 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

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[8] 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 $c(\theta | d=1, y_A=0, y_B=0) - c(\theta_H) \leq c(\theta_H) - c(\theta_L)$.

[9] 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 key assumption is that the expected ability to renegotiate contracts differs across in-house versus external suppliers at the time of initial contracting.

[10] 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.

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.[11] 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 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 for a subjective incentive scheme than an external team:

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

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[11] 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.

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 (2003)), the effectiveness of cross-firm subjective contracting (relative to internal contracting) is limited by the inability for external teams to commit to a long-term relationship with the firm.[12]

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.

Proof: See Appendix A

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

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[12] 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.

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.

Simplifying notation so that Z_i are system-specific factors favoring vertical integration for system i, Proposition 1 implies the key 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 (1995, Proposition 4).

In other words, an increase in pre-existing in-house capabilities for one system not only increases the marginal returns for in-house contracting for that system, but also increases the marginal returns to in-house contracting for other systems for that automobile model. We exploit this intuition in the empirical work in the remainder of the paper.

IV. An Empirical Framework

Our empirical strategy to test for the presence of complementarity among organizational design decisions builds on a recent applied econometric literature that offers a precise approach for distinguishing complementarity from extraneous "firm-level" factors driving correlated adoption across distinct choices (Arora, 1996; Athey and Stern, 2003). We begin by developing an empirical framework building on the model from Section III, and then extend and adapt that framework to our specific empirical setting. As well, we discuss potential checks to test the key assumptions we are making in this specific empirical application.

Suppose that for both Y_A and Y_B, the separable benefits (and costs) to vertical integration observable to the firm is a vector composed of two distinct parts. Both the firm and econometrician observe the vector Z_i, while the scalar χ_i is a choice-specific mean-zero shock observed by the firm but unobservable to the econometrician. Moreover, the elements of χ may be correlated; we assume there is a firm-level mean-zero "fixed effect" (ξ_t) which impacts the overall propensity of the firm to vertically integrate (i.e., $\chi_{i,t} = \xi_t + \varepsilon_{i,t}$). As well, in line with Proposition 1, the returns to each choice are interdependent: the marginal returns to vertical integration for Y_A increase when the firm vertically integrates into Y_B. We assume this interdependence takes the form of a fixed component across all firms, which we define as λ.[13] The firm optimizes across its choices of Y_1 and Y_2, yielding the following maximization problem:

$$f_t = \lambda(Y_{A,t} * Y_{B,t}) + (\beta_{Y_A} + \beta_{Y_A Z_A} Z_{A,t} + \chi_{A,t})Y_{A,t} + (\beta_{Y_B} + \beta_{Y_B Z_B} Z_{B,t} + \chi_{B,t})Y_{B,t}$$

To understand the relationship between this performance equation, optimal choice behavior, and the key issues associated with empirical measurement, it is useful to consider the demand condition for each practice:

$$Y_{i,t} = 1 \, if \;\; \lambda \bullet Y_{-i,t} + \xi_t + (\beta_i + \beta_{iZ_i} Z_{i,t} + \varepsilon_{i,t}) > 0, \; Y_i = 0 \text{ else}$$

In this context, $\lambda > 0$ can be interpreted as the degree of complementarity between Y_A and Y_B, and ξ is an unobserved firm-level effect which (perhaps spuriously) induces correlation among the firm's decision regarding Y_A and Y_B.[14] The goal of empirical work in this context is to estimate the underlying parameters of the "organizational design production function," focusing in particular on λ, the contracting complementarity parameter. It is relatively straightforward to see that the conditional correlation between Y_A and Y_B will result in a biased estimate of λ. Consider a linear probability model:

$$Y_{it} = \beta_i + \lambda Y_{-i,t} + \beta_{Z_i} Z_{i,t} + \eta_{i,t}$$

where the error component can be rewritten:

$$\eta_{i,t} = \xi_t + \varepsilon_{i,t}$$

Since $E(Y_{-i} * \eta) > 0$ (since the probability that $Y_{-i} = 1$ is increasing in ξ), $\hat{\lambda}_{OLS}$ is biased.

An instrumental variables estimator, however, does provide a consistent estimate of λ. As well, if exogenous choice-specific drivers are observable (i.e., the econometrician observes Z_i), this framework yields a rich set of instruments. In particular, for each choice i, Z_{--i} – factors which drive the adoption of Y_{-i} but are uncorrelated with χ_i – provides a natural set of instruments to examine the relationship between Y_{-i} on Y_i. The key assumption underlying the use of Z_{--i} is that, conditional on all observables, $E(Z_{-i}\chi_i) = E(Z_{-i}\xi) = 0$. As emphasized by Arora (1996) and Athey and Stern (2003), the lack of choice-specific instruments has limited the feasibility of empirical work on complementarity in many contexts.

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[13] In line with the model, λ is a function of the benefits from coordination effort and the reduced probability of disclosure. We are estimating an overall parameter that combines these structural effects.

[14] As well, ξ may reflect fads or managerial preferences not actually linked to long-term performance.

Our dataset, described in Section V, includes exogenous factors specific to each system that provide instruments for the vertical integration drivers for each system. In other words, for each system Y_i, we include Z_i directly and then use Z_{-i} as instruments for Y_{-i} within that model for that system. For example, for each system, we observe whether the firm has existing in-house sunk investments in plant and equipment. By including these variables directly into the equation and relying on instruments from other systems to identify the complementarity parameter, our identification is the consequence of *system-specific differences in the contracting environment which also result in differences in contracting choices.*[15]

While this discussion of a two-system choice highlights the main econometric issues, applying this framework requires that we consider the interactions among seven distinct systems within each automobile in our dataset. We address the potential for multiple interactions in two distinct ways. First, we adapt our framework to estimate the "average" level of system-to-system contracting complementarity. To do so, we first calculate, for each system, the "average" level of vertical integration for *other* systems on that automobile model. We then adapt our instrumental variables strategy by calculating the "average" Z_{--i} for each observation, yielding instruments for Y_{-i} in our empirical analysis. Second, we supplement this "average" analysis with a nuanced assessment of the impact of individual systems (e.g., how the level of vertical integration in the engine system (instrumented by drivers specific to the engine system) impacts the vertical integration level in other systems of the automobile. Exploiting our qualitative evidence and engineering knowledge regarding specific systems, we are able to test whether the evidence for contracting complementarity is most salient for those systems where non-contractibility (and non-observability) of effort is likely most problematic.

We also consider the possibility that the degree of complementarity may depend on the product development environment itself. For example, when the firm designates a system for system-specific performance (a designation observable in our dataset), the returns to coordination with other systems may be reduced relative to the incentives for system-specific effort. As a result, the sensitivity of vertical integration to the level of vertical integration on other systems may be reduced (as the degree of contracting complementarity has been reduced). We test for this type of variation by interacting measures, Wi, such as the designation as a

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[15] This strategy is analogous to the increased use of the characteristics or prices of "other" products as an instruments for price in the context of differentiated products demand models (Berry, Levinsohn, and Pakes, 1995; Bresnahan, Stern, and Trajtenberg, 1997; Hausman, 1997).

“performance” system, with the “average” vertical integration choice on other systems. Extending our earlier argument regarding instrumental variables, we construct instruments by considering combinations of W_i and Z_{-I} (e.g., $(W*Z_{-i})'$). In so doing, we are extending the empirical framework to test for how the salience of contracting complementarity might vary across different product development environments.

Finally, while we observe the instrumental variables at the level of automobile systems (e.g., the brake system, the engine system, etc.), our observations of contracting (in-house or external supplier) are 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). While not inconsistent with the key ideas of the theoretical model, we can also test whether allowing a continuous vertical integration measure impacts our results. Specifically, we can define vertical integration to be a dummy at the system level by defining a threshold over which the dummy is equal to 1 (0 else). By implementing the empirical procedure described above for various threshold levels (e.g., .25, .5, and .75), we are able to test how the definition of vertical integration impacts the empirical evidence for contracting complementarity.

V. The Data

Sample and Methods

This study uses a proprietary and original dataset based on a multi-year study of contracting and product architecture in the global auto industry. We studied luxury performance cars (defined by *Consumer Reports* as vehicles priced above $30,000 in 1995) and the companies included in the sample are drawn from Europe, the U.S. and Japan, accounting for roughly 90% of revenues in the global luxury performance market. As 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 that arise from combining combines information from different vehicle types.

The unit of analysis is an automotive system for a specific model-year, and, after dropping one model-year due to incomplete data, includes comprehensive information about seven systems for nineteen automobile model-years between 1980 and 1995.[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-year. All participants were assured that only aggregate data would be presented, and confidentiality agreements were signed with each company.

Data collection proceeded in several stages. After signing an agreement with each firm, a letter was sent requesting interviews with relevant project managers, system engineers, design engineers, purchasing managers and manufacturing engineers for each vehicle for each time period. The relevant parties were identified by the corporate liaison for each company, and on-site meetings were arranged. To ensure data accuracy, interviewees were given an overview of the research project and definitions for key terms. Subjects were given a list of questions pertaining to the design and sourcing of components within their respective systems. The questions focused on principally objective information (e.g. number of parts in the body side) so as to minimize the likelihood of response bias. The interviews were conducted on-site at each company, in time intervals ranging from three days to three months. All interviewees were given the option of being interviewed in their native languages. US and European interviews were conducted in English and Japanese interviews were conducted in Japanese.[17]

The overall sample is composed of 133 model-year systems, drawn from nineteen distinct model-years and across seven distinct systems: engine, transmission, body, electrical, suspension, steering, and brakes. Table 1 provides variable names, definitions, and summary statistics (Appendix B provides the pairwise correlations for the whole dataset).

Contracting Variables

The dependent variable throughout the analysis is VERTICAL INTEGRATION, the percentage of the system produced in-house, with 1 indicating in-house production of all components within that system.[18] For each component, system, vehicle model, and time period, we have collected data on the make / buy decision outcome. The vertical integration measure at the system level is calculated as the average across the individual components for that systems,

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[16] More precisely, the overall dataset includes information about 8 distinct car models, many of which are observed at (roughly) five-year intervals, with 19 total “model-years” for which complete data were available.

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

[18] Masten et al (1989) use a similar measure at the component level.

and each component is weighted equally. Parts supplied to firms by wholly-owned subsidiaries, such as the Delphi division of General Motors, are treated as in-house. Parts produced by partially owned suppliers, such as Nippondenso (Toyota group), were treated as outside suppliers.

VERTICAL INTEGRATION exhibits substantial variation across the sample, ranging from 0 (fully outsourced) to 1 (in-house production), with a mean of .48 and a standard deviation of .32. Moreover, much of this variation is "model-specific." In Figure A, we plot the 90% confidence intervals for VERTICAL INTEGRATION for each of the 19 model-years in the sample. It is useful to note that, 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 of the individual model-year effects are individually significant, and the overall F-test statistic is highly significant at 8.74. In other words, the level of vertical integration is "clustered" within each model-year; our empirical approach is designed to disentangle whether such clustering is due to complementarity or is the result of unobservable "fixed effects" in governance.

We also calculate VERTICAL INTEGRATION$_{-i}$, which is the average value of VERTICAL INTEGRATION across all *other* systems within that model (by construction, the mean is identical to VERTICAL INTEGRATION). Consistent with the empirical framework described in Section V, 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 variation in the system-specific contracting environment.

System-Specific Contracting Environment Measures

The key measures for our identification strategy are four *system-specific* measures of the contracting environment. Since each of these variables is measured at the system level, there is (potentially) variation across systems within a given model-year. This allows us to calculate instruments, within each model year, for VERTICAL INTEGRATION$_{-i}$ that are not collinear with VERTICAL INTEGRATION in that model-year. 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 the design and manufacturing challenge associated with that system (COMPLEXITY and PLATFORM). It is important to recognize that, from the perspective of the contracting choice for each system, there is a strong argument that each of these measures, described in some detail below, is econometrically exogenous. Investments in sunk assets and production capacity are made many years (perhaps decades) in advance of individual model-year contracting choices, and design and technology choices are made well in advance of the vertical integration choices for individual systems, based on factors unrelated to vertical integration.[19] However, recognizing that the argument for exogeneity for the factors relating to design/technology choices is less strong than for those variables relating to pre-existing capabilities, we first focus our analysis on the first of variables, before incorporating the full set of system-specific measures into the analysis.

We now turn to a more specific discussion of each of these measures. 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 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

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[19] Novak and Eppinger (2001) consider the exogeneity of COMPLEXITY directly, finding that the exogeneity of COMPLEXITY cannot be rejected by a Hausman test.

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.[21] The measure used in our analysis, COMPLEXITY (mean = .41), is the result of applying this procedure for each component within each system.

Model-Level Contracting Environment Measures

We also observe two potential drivers of contracting at the model-year level (VOLUME and UNION). While these will not facilitate the identification of contracting complementarity across systems, these variables serve as controls to account for correlation in contracting choices at the model-year level. As well, the analysis will include specifications incorporating company fixed effects; because there is not sufficient variation across models, we exclude these model-year factors when we include company fixed effects in our empirical work.

Our first model-year measure, VOLUME, is the variable for vehicle volume. The volume measure is the overall company volume of automobiles produced in the model year.[22] While economies of scale in production favor in-house production if these scale economies cannot be realized with external contractors, it is possible that scale may interact in subtle ways with the ability to write and enforce contracts with external suppliers. For this reason, we make no prediction about the direction of the relationship between VOLUME and VERTICAL INTEGRATION. Second, 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, it may be very difficult to outsource any of the components in the system due to the extreme cost and risks associated with union renegotiation. For this reason we expect a positive relationship between UNION and VERTICAL INTEGRATION.

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

[21] *See* Novak and Eppiinger (2001).

[22] Our resullts do not change if we use a measure based on the *share* of volume devoted to luxury car production.

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. 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.

First, PERFORMANCE is a dummy variable equal to 1 if an individual system is associated with "high" system-specific performance goals. The importance of performance goals were provided by vehicle product managers, on a 0-10 scale, with 0 indicating no importance for product performance goals and 10 indicating that the vehicle competes based on high performance. Certain performance goals necessitate more complex product designs, such as more integrated 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 PERFORMANCE may reduce the importance of contracting complementarity in contracting choice. Similarly, SKILL SHORTAGE (mean = .15) is a dummy variable equal to 1 if key 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.

System, Year, and Company Fixed Effects

We also calculate fixed effects for each of the seven automobile systems (SEATS are the excluded category), two time category dummies (1986-1990 and 1991-1996, with pre-1986 models falling into 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 precise source of variation in the dataset driving our key findings and to highlight the robustness of key results to focusing on alternative sources of variation.

VI. Empirical Results

We now turn to the key empirical findings. The 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. This instrumental variables strategy allow us to distinguish contracting complementarity from a firm-level "taste" for vertical integration, and the robustness of the results to various controls and alternative specifications. We then turn to a reduced-form approach which examines the impact of the instrumental variables themselves on contracting choice (in the spirit of Arora, 1996). We then examine how the degree of contracting complementarity depends on factors in the contracting environment. In so doing, we attempt to shed light on the mechanism by which contracting complementarity arises. Though the modest size of the dataset makes us cautious in our interpretation of our 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 several simple OLS regressions of VERTICAL INTEGRATION on VERTICAL INTEGRATION_{-i}. We first present the relationship with no controls, and then introduce a complete set of system effects (SEATS is the excluded category). While most of the system effects are significant (and different than each other), the most striking result is the large and significant coefficient on VERTICAL INTEGRATION_{-i}. The final column of Table 2 include the complete set of system-specific drivers of vertical integration drivers, as well as a full set of system and year controls. While the estimated size of the effect is reduced by about 20% relative to (2-1), the correlation between VERTICAL INTEGRATION and VERTICAL INTEGRATION_{-i} remains extremely large, particularly compared to the size of the effects associated with the system-specific drivers of vertical integration. Each of the estimated elasticities for the system-specific drivers is smaller than the estimated elasticity of VERTICAL INTEGRATION and VERTICAL INTEGRATION_{-i} (.70).

Of course, the conditional correlation captured in Table 2 may be spurious, driven by firm (or model)-specific unobservables inducing a high correlation among the contracting choices of the firm across system. We address this by exploiting the instrumental variables strategy described in Section IV. For each of the regressions in Table 3, the instruments for VERTICAL INTEGRATION$_{-i}$ are the mean levels of the other variables included in the specification for other systems but for model *i*. Since some measures, such as UNION or L(VOLUME) do not vary across systems within each car model, the excluded instruments depend only on the system-specific drivers of vertical integration. For the first three specifications ((3-1)-(3-3)), the excluded instruments are the average (for other systems for that model-year) of LOW CAPACITY and SUNK COST. While (3-1) only includes SUNK COST and CAPACITY with no additional controls, (3-2) includes system fixed effects, year effects, and the company-level measures UNION and VOLUME. When these controls are included, both LOW CAPACITY and SUNK COST are individually significant (at the 10% level); more importantly, the instrumental variables coefficient on VERTICAL INTEGRATION$_{-i}$ is positive and significant (and larger in magnitude than the OLS coefficient). Further, in (3-3), we include a complete set of model fixed effects; the significant coefficient on VERTICAL INTEGRATION$_{-i}$ is therefore identified solely by exploiting variation among systems across individual models. In terms of quantitative importance (using the estimates from (3-1) as a conservative benchmark), a shift in the contracting environment that induces a one standard deviation shift in VERTICAL INTEGRATION$_{-i}$ (0.25) is predicted to have a .23 shift in the predicted value for VERTICAL INTEGRATION for an individual system.

The final two columns of Table 3 include PLATFORM and COMPLEXITY. Consistent with our earlier approach, we continue to instrument for VERTICAL INTEGRATION$_{-i}$ with the average level of the system-specific measures for other systems in that model. While we are cautious about interpreting these results since there may be model-specific factors impacting both technology choices such as COMPLEXITY and contracting, it is useful to compare how the inclusion of these factors impact the estimated degree of contracting complementarity. While neither of the two new measures is individually significant when other controls are included, the coefficients on VERTICAL INTEGRATION$_{-i}$, SUNK COST, and COMPLEXITY remain similar (at similar levels of statistical and quantitative significance). Indeed, even when system, year and company fixed effects are included in (3-5), the coefficient and precision of VERTICAL INTEGRATION$_{-i}$ remains similar and larger than the impact under OLS.[23]

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[23] In unreported specifications, the IV results are robust to the use of other measures, including a measure of technology use, and whether the vehicle is undergoing a “major” revision, as well as a variety of functional forms.

In addition, in Table 4, we examine whether the results depend on the measurement of VERTICAL INTEGRATION as a continuous variable. We transform VERTICAL INTEGRATION into a dummy variable based on three different "threshold" levels (.25, .5, and .75), defining VERT_X = 1 if VERTICAL INTEGRATION > X (0 else). As well, we use the resulting VERT_X measure to calculate VERT_X$_{-i}$ (in other words, the endogenous RHS measure in these regressions is the average of VERT_X (a dummy variable) across all systems within a model-year excluding *i*. Finally, since VERT_X is a dummy variable, we apply our instrumental variables approach in the context of an instrumental variables probit procedure.[24] For each of the three specifications, the coefficient on VERT_X$_{-i}$ is quantitively and statistically significant. Overall, the magnitudes (in terms of probability derivatives calculated at the mean) are similar to those from the IV regressions in Table 3, and the complementarity coefficient increases with the level of the threshold measure.

Taken together, the results in Tables 2-4 provide evidence in favor of interdependency in the level of vertical integration across systems within automobile product development. Relative to factors incorporated from a transaction-specific approach to vertical integration, VERTICAL INTEGRATION$_{-i}$ has the single most decisive influence on explaining within-system variation in the degree of vertical integration. Moreover, rather than reflecting unobserved firm-level factors, the interdependency between vertical integration choices is shown to be identified even if one controls for observed system-specific drivers directly and only depends on the portion of VERTICAL INTEGRATION$_{-i}$ that is driven by system-specific drivers on other systems.

A Reduced-Form Approach to Testing for Contracting Complementarity

Table 5 explores how contracting for a given system is impacted by the contracting environment for *other* systems by directly including the excluded instruments from Table 3 in an OLS specification. This reduced-form strategy follows Arora (1996), who derives the conditions under which a reduced-form approach to testing for complementarity in organizational design is possible. Unfortunately, in most applications, the ability to provide persuasive evidence of complementarity through instrumental variables (or the reduced-form approach) is limited by the inability to provide persuasive evidence for the exogeneity of specific instruments. However, in the current application, the identification argument is more subtle. Specifically, because our

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[24] We implement IV probit using Amemiya GLS as discussed in Whitney (1987) and Harkness (2001).

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.

In (5-1), 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 the direct effects and instrumental variables are individually significant.[25] Along with the IV results from the previous sub-section, Table 5 suggests that the strong pattern of correlation in contracting across systems within a model is not simply a firm-specific effect but is related to *variation* in the contracting environment within a given auto model-year.

Coordination versus Secrecy as the Driver of Contracting Complementarity

The theoretical model highlights two distinct drivers of contracting complementarity: complementarities in coordination effort and trade secrecy concerns. Though not mutually exclusive, it is interesting to assess the relative salience of these mechanisms in shaping the "average" complementarity parameter estimated in Table 3. In our final analyses, we therefore measure variation in the complementarity parameter across different contracting and technology environments and relate this variation to each mechanism.

Table 6 presents an analysis of the relative impact of individual systems on vertical integration of other systems.[26] Each regression includes the four system-specific drivers from the last two columns of Table 3 and the (instrumented) level of VERTICAL INTEGRATION for a specific system within the automobile. Though only suggestive, the results provide some support for both the role of secrecy and coordination effort. For those systems where cross-

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[25] It is useful to note that , while the basic pattern of correlation remains, the results on individual coefficients becomes noisier when all of the variables in our dataset are included simultaneously.

[26] The interpretations for this table are based on extensive interviews with industry experts, managers, and engineers.

system coordination effort is particularly important (such as the engine and body), the strongest statistical and quantitative relationship emerges. As well, though the brake system is relatively modular and requires only a modest level of coordination effort, the brake system is a key system for trade secrecy concerns (particularly as braking systems have come to rely on sophisticated and proprietary software interfaces). While we do not overemphasize these findings as they are based on modest differences in magnitude of the coefficients and depend on a nuanced interpretation of system-specific effects, they do suggest that both coordination effort and trade secrecy concerns may be important for understanding contracting complementarity.[27]

Finally, we consider the impact of interactions between VERTICAL INTEGRATION$_{-i}$ and system-specific measures impacting the relative importance of coordinated contracting. Because of the limited size of our dataset, we explored these interactions by combining our qualitative understanding of automobile product development with the theoretical model developed in Section IV. Among the system-specific drivers of vertical integration, two relationships seemed most promising. First, the relative returns to effective *cross-system* coordination may be lower for those systems which have been designated for high system-specific performance. When a particular system is the focus of system-specific performance improvement, the degree of observed contracting complementarity may be lower. As well, when location-specific factors constrain the system-specific resources available for effective development or manufacturing, the returns to coordination across systems may be reduced relative to the willingness to contract with available system-specific contracting opportunities.

We explore both of these hypotheses in Table 7. For each specification, we extend the instrumental variables strategy from Table 3, constructing instruments by multiplying each system-specific vertical integration driver and the instrumental variables for VERTICAL INTEGRATION$_{-i}$ employed in Table 3. The results, though noisy, are suggestive. First, the direct effect of VERTICAL INTEGRATION$_{-i}$ continues to quantitatively and statistically significant across specifications. Turning to the interaction effects, VI$_{-i}$*PERFORMANCE is negative though insignificant in this specification. While this coefficient tends to be significant with the inclusion of additional variables, we present this noisy result to emphasize its limited

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[27] Appendix C reports a suggestive analysis including all system "pairs" simultaneously. To do so, we collapse the dataset into seven system-specific groups of 19 observations each (for each car model) and examine the conditional correlations across systems. The results, though speculative, are suggestive. When interactions are likely quite important (such as between the brake and suspension systems), there is a close correlation, while pairs where interactions are less important (such as between suspension and electronic systems) exhibit a *negative* correlation.

statistical power. As well, VI_{-i}*SKILL SHORTAGE is consistently negative and significant (across a wide range of specifications we explored). Though we do not emphasize these results too strongly, they are consistent with the hypothesis that complementarity might be related to the marginal returns to system-to-system coordination activities, a process which is more effectively conducted through coordinated in-house contracting.

VII. Conclusions

This paper examines the impact of contracting complementarity across product development systems in the automobile industry. Building on a detailed qualitative understanding of the potential for interdependencies in contracting decisions, we test this hypothesis using an instrumental variables approach that allowed 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. First, 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. Second, even when including system-specific measures of the contracting environment, the contracting environment associated with other systems has a significant impact on governance. Third, the degree of correlation in contracting is empirically related to measures which may be associated with the marginal returns to system-to-system integration activities.

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 empirical implications of contract theory can be derived even in the context of a model 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 central hypothesis is a simple but novel implication of a model in which firms must make multiple interdependent 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.

Our analysis also suggests several directions for further study. Perhaps most importantly, the current analysis highlights the consequences of an interaction between differences in the ex post contracting environment and the need for coordination and integration activities within the firm. While our theoretical discussion highlights two distinct drivers of contracting complementarity, our empirical work does not distinguish between these two mechanisms in a dispositive manner. Investigating the sources of the interaction between the nature of contracts and the incentives and investments required for coordination is 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 over time. 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.

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APPENDIX A

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

TABLE 1
Variables & Definitions

VARIABLE	DEFINITION	MEAN	STD. DEV.
CONTRACTING VARIABLES			
VERTICAL INTEGRATION	Percentage of the system produced in house between 0 and 1 (1 indicates all in-house production)	.485	.324
VERTICAL INTEGRATION$_{-i}$	Average level of VERTICAL INTEGRATION for all systems excepting *i* on model j	.485	.249
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
LOW CAPACITY	Dummy = 1 if plant has insufficient capacity to manufacture system design in-house	.172	.378
PLATFORM	Dummy = 1 the component was designed to be used for more than one vehicle model	.526	.501
COMPLEXITY	Degree of System Complexity, ranging from 0 to 1 (See Novak and Eppinger, 2001).	.415	.272
PERFORMANCE	Measure for desired performance goals at the system level, ranging from 0 (low) to 1 (high)	.449	.309
SKILL SHORTAGE	Dummy = 1 if key worker skills are missing in existing plant locations	.150	.359
MODEL-YEAR MEASURES			
UNION	Dummy = 1if a component has been produced in-house and is covered under union agreement	.421	.496
VOLUME	Absolute company vehicle volume	2.889	1.978

Notes: VOLUME measured in millions.

TABLE 2
OLS Regressions

Dependent Variable : VERTICAL INTEGRATION (N=133)	**(2-1)**	**(2-2)**	**(2-3)**
VERTICAL INTEGRATION$_{-i}$	.862***	.916***	.701***
	(.078)	(.058)	(.152)
SUNK COST			.102
			(.068)
LOW CAPACITY			-.147**
			(.063)
PLATFORM			.012
			(.035)
COMPLEXITY			.052
			(.078)
UNION			.010
			(.062)
Ln (VOLUME)			.036
			(.032)
SYSTEM DUMMY VARIABLES			
SUSPENSION		.280***	.222***
		(.059)	(.068)
BRAKES		-.102	-.178**
		(.068)	(.084)
TRANSMISSION		.181***	.097
		(.056)	(.064)
ENGINE		.211***	.095
		(.046)	(.067)
STEERING		.151**	.049
		(.063)	(.078)
BODY		-.145**	-.234***
		(.063)	(.074)
YEAR CONTROLS			
Year 2			-.011
			(.046)
Year 3			-.038
			(.042)
Constant	.067	-.042	-.375
	(.042)	(.044)	(.417)
R^2	.439	.660	.694

Notes: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**), and 10% (*) significance level.

TABLE 3
IV Regressions

Dependent Variable : VERTICAL INTEGRATION (N=133)	(3-1)	(3-2)	(3-3)	(3-4)	(3-5)
VERTICAL INTEGRATION$_{-i}$	.918***	1.123***	1.194*	.984***	1.242**
	(.154)	(.269)	(.647)	(.102)	(.566)
SUNK COST	-.011	.145*	.145*	-.024	.141*
	(.061)	(.077)	(.077)	(.060)	(.076)
LOW CAPACITY	-.146***	-.168**	-.172***	-.133**	-.173**
	(.055)	(.065)	(.068)	(.057)	(.073)
PLATFORM				.058	.050
				(.044)	(.047)
COMPLEXITY				.056	.106
				(.082)	(.085)
UNION		-.059			
		(.078)			
Ln (VOLUME)		-.017			
		(.039)			
Parametric Restrictions		#Restr F-stat p-value	#Restr F-stat p-value		#Restr F-stat p-value
SYSTEM DUMMIES		6 11.01 .000	6 8.32 .000		6 8.66 .000
YEAR CONTROLS		2 .01 .991	2 .04 .958		2 .18 .840
COMPANY DUMMIES			6 .10 .996		6 .19 .980
Constant	.066	.211	-.074	-.020	-.035
	(.079)	(.474)	(.328)	(.084)	(.121)
Instrumental Variables	Averages of SUNK COST and LOW CAPACITY across all systems but system *i*.			Averages of SUNK COST, LOW CAPACITY, PLATFORM, and COMPLEXITY across all systems but system *i*.	

Notes: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**), and 10% (*) significance level.

Table 4
IV Probit:
"Threshold" Vertical Integration Measures

	DEPENDENT VARIABLE (4-1) **VI_25**	 (4-2) **VI_50**	 (4-3) **VI_75**
VI_25_{-i}	.906*** (.240)		
VI_50_{-i}		1.174*** (.219)	
VI_75_{-i}			1.269*** (.317)
SUNK COST	.264** (.056)	-.172 (.151)	
LOW CAPACITY	-.414*** (.145)	-.257* (.127)	-.075 (.139)
N	133	133	116

Notes: Coefficients are probability derivatives at the mean value of the sample.

VI_25, VI_50, and VI_75 are dummy variables equal 1 if VERTICAL INTEGRATION is greater than .25, .5, and .75 respectively; 0 else.

VI_{-i}_X variables refer to the average within each region across all system but system *i*. They are instrumented using and M_SUNK $COST_{-i}$, M_$CAPACITY_{-i}$.

In column 3, SUNK COST is dropped due to collinearity.

TABLE 5
Reduced-Form Regressions

Dependent Variable : VERTICAL INTEGRATION (N=133)	(5-1)	(5-2)	(5-3)
SUNK COST	.027	.013	.134*
	(.067)	(.080)	(.076)
LOW CAPACITY	-.338***	-.362***	-.374***
	(.062)	(.058)	(.060)
PLATFORM		-.009	-.025
		(.055)	(.046)
COMPLEXITY		-.078	-.050
		(.089)	(.086)
M_ SUNK COST$_{-i}$	.237	.173	.129
	(.230)	(.330)	(.330)
M_LOW CAPACITY$_{-i}$	-1.270***	-1.451***	-1.374***
	(.248)	(.231)	(.209)
M_ PLATFORM$_{-i}$		-.400***	-.400***
		(.150)	(.149)
M_ COMPLEXITY$_{-i}$		-.871***	-.832***
		(.150)	(.204)
Parametric Restrictions			#Restr F-Stat p-value
SYSTEM DUMMIES			6 8.49 .000
YEAR CONTROLS			2 1.63 .200
Constant	.729***	1.384***	1.342***
	(.068)	(.109)	(.122)
R^2	.234	.419	.588

Notes: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**), and 10% (*) significance level.

M_VARIABLE NAME$_{-i}$ denotes the average of VARIABLE NAME across all systems but system *i*.

TABLE 6
IV Regressions:
System-Specific Effects

Dependent Variable: VERTICAL INTEGRATION
(N=114)

	(6-1)	**(6-2)**	**(6-3)**	**(6-4)**	**(6-5)**	**(6-6)**	**(6-7)**
VI_SUSPENSION*	.403						
	(.368)						
VI_BRAKES*		1.038***					
		(.229)					
VI_TRANSMISSION*			.967**				
			(.402)				
VI_ENGINE*				1.441***			
				(.168)			
VI_STEERING*					.820		
					(.666)		
VI_BODY*						.879***	
						(.150)	
VI_ELECTRICAL*							.627***
							(.091)
SUNK COST	.149**	.127	-.104	-.041	-.037	-.022	-.102
	(.070)	(.085)	(.103)	(.081)	(.129)	(.114)	(.074)
LOW CAPACITY	-.283***	-.210***	-.101	-.103	-.093	-.124	-.036
	(.080)	(.076)	(.095)	(.065)	(.138)	(.080)	(.082)
PLATFORM	.081	.130**	-.055	.083*	.013	-.034	.025
	(.062)	(.067)	(.051)	(.047)	(.054)	(.056)	(.046)
COMPLEXITY	-.125	-.029***	-.003	.097	-.010	.090	.095
	(.125)	(.114)	(.131)	(.093)	(.201)	(.105)	(.110)
Constant	.225	.132	-.080	-.451***	.050	.266***	.202**
	(.314)	(.135)	(.278)	(.131)	(.447)	(.082)	(.078)

Notes: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**) and 10% (*) significance level.

* The instruments for VI_X for model *j* are the value of SUNK COST, LOW CAPACITY, PLATFORM, and COMPLEXITY for system X in model *j*.

TABLE 7
IV Regressions:
Interaction Terms

Dependent Variable : VERTICAL INTEGRATION (N=133)

	(7-1)			**(7-2)**		
VERTICAL INTEGRATION$_{-i}$	1.336*** (.316)			1.214*** (.266)		
VI$_{-i}$ *PERFORMANCE	-.649 (.426)					
VI$_{-i}$ *SKILL SHORTAGE				-.375** (.172)		
SUNK COST	.110 (.074)			.164** (.074)		
LOW CAPACITY	-.173** (.070)			-.186** (.080)		
PLATFORM	.048 (.045)			.016 (.043)		
COMPLEXITY	.103 (.082)			.096* (.082)		
PERFORMANCE	. 086 (.195)					
SKILL SHORTAGE				.206* (.107)		
UNION	-.086 (.082)			-.063 (.082)		
Ln (VOLUME)	-.004 (.037)			-.017 (.040)		
Parametric Restrictions	#Restr	F-stat	p-value	#Restr	F-stat	p-value
SYSTEM DUMMIES	6	13.08	.000	6	9.76	.000
YEAR CONTROLS	2	.19	.826	2	.11	.899
Constant	-.002 (.476)			.116 (.494)		

Notes: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**) and 10% (*) significance level.

The instruments for VI$_{-i}$, and VI$_{-i}$*X are M_SUNK COST$_{-i}$, M_CAPACITY$_{-i}$, M_PLATFORM$_{-i}$, M_COMPLEXITY$_{-i}$, and M_X$_{-i}$, and their interactions with X.

APPENDIX B
Pairwise Correlations

	VERT INT.	SUNK COST	LOW CAP	PLAT	COMPL	UNION	VOL	PERF	SKILL SHORT
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			
VOLUME	.73*	.08	-.16	.01	-.23*	.78*	1.00		
PERFORMANCE	-.13	-.14	-.17	-.10	.24*	-.23*	-.13	1.00	
SKILL SHORTAGE	-.26*	.47*	.59*	.10	-.06	-.02	-.10	-.14	1.00

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

APPENDIX C
OLS System-to-System Interactions

	DEPENDENT VARIABLE						
	VI_SUSP.	**VI_BRAKE**	**VI_TRAN.**	**VI_ENG.**	**VI_ST.**	**VI_BODY**	**VI_ELEC.**
VI_SUSPENSION		.723***	.510*	.381*	-.063	.120	-.464
		(.217)	(.271)	(.182)	(.470)	(.284)	(.261)
VI_BRAKES	.536**		.122	.021	-.124	-.549***	.392**
	(.203)		(.215)	(.158)	(.322)	(.172)	(.132)
VI_TRANSMISSION	.335	.108		-.230	-.062	.265	.364***
	(.197)	(.178)		(.157)	(.336)	(.182)	(.181)
VI_ENGINE	.813**	.061	-.748*		1.074	.359	.426
	(.315)	(.438)	(.379)		(.802)	(.417)	(.454)
VI_STEERING	-.021	-.056	-.032	.167		-.050	.157
	(.152)	(.141)	(.171)	(.108)		(.150)	(.133)
VI_BODY	.125	-.773**	.421	.176	-.158		.472**
	(.282)	(.274)	(.257)	(.261)	(.502)		(.175)
VI_ELECTRICAL	-.533***	.609*	.637***	.229	.543	.519*	
	(.167)	(.282)	(.202)	(.199)	(.559)	(.241)	
Constant	.002	-.246**	.274	.234***	-.158	-.165	-.093
	(.116)	(.110)	(.169)	(.067)	(.231)	(.117)	(.121)
R^2	.888	.879	.857	.888	.745	.855	.924
N	19	19	19	19	19	19	19

Note: Robust standard errors are given in parentheses. Stars denote statistical significance at 1 (***), 5 (**) and 10% (*) significance level.

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