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Electronic Companion—"How Does Outsourcing Affect Performance Dynamics? Evidence from the Automobile Industry" by Sharon Novak and Scott Stern, *Management Science*, DOI 10.1287/mnsc.1080.0922.

Online Appendix A

Contracting in Automobile Product Development

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

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

Though the governance mode is relatively fixed over the product lifecycle, manufacturers devote considerable internal and external resources and attention to improving products as the lifecycle evolves. While establishing a perception of high quality in the initial introduction year is quite important (the reputational effect will spill over to future model-years), companies attempt to address the myriad technical issues arise as the result of large-scale use and respond to detailed (and often voluminous) customer feedback over the life of the major. Many consumers (particularly in the luxury segment) seek out models that are known to have resolved any engineering issues, and this important customer segment will be particularly sensitive to reports of improvement and changes over the product lifecycle. A key difference between internal development and external sourcing is the availability of personnel who had been assigned to product development efforts prior to product launch. While internal governance usually allows for reassignment to initiate improvements after the initial model-year, it is difficult to maintain the integrity of external teams (from the perspective of a downstream procurer). Indeed, many contracts are specified to limit the extent to which employees can be pulled from current projects to return to an earlier one (these provisions reflect trade secrecy concerns).

More generally, contracts contain detailed provisions governing initial contract performance requirements for external contracts, including the ability to pass key safety and production thresholds, commitments to satisfy specific technical requirements, etc. Although the contract language includes requirements for continued involvement and updating in response to customer feedback, and incremental model improvement, there are very few mechanisms to enforce these contract provisions. In large part, the inability to enforce performance-oriented contracts is a consequence of the underlying production structure: the relationship between observed performance and individual contracts is very noisy and dependent on the actions of other contractors and internal development teams. While procurement takes place at the level of components, overall performance is the level of systems (and overall vehicle performance and vehicles sales depends on the interaction among these systems, combined with other factors such as marketing, distribution issues, etc). Because of the problem of assigning responsibility for failure (or success), the only “contractual” approach would involve outsourcing large segments of the automobile (e.g., an entire system, or even a combination of systems). Indeed, after our sample period, manufacturers began to use such arrangements (e.g., an “interior complete” contract with a Tier I supplier).

Online Appendix B

Data Collection

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

The unit of analysis is an automotive system for a specific “major” for a given automobile model. “Major” model changes,” which are typically implemented at approximately five-year intervals, provide an opportunity to significantly alter product positioning, technologies, and contracting choices for an automobile model. Overall, the dataset includes comprehensive information about seven systems for 19 automobile “major” model versions between 1980 and 1995 (see Novak and Eppinger (2001) for further details). The data were collected through on-site interviews with over 1000 people, including CEOs, chief engineers, project managers and system engineers involved in development for each model-year.

The unit of analysis is the model-year-system. The original sample consists of 133

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

model-year systems, drawn from nineteen distinct "major" model changes (associated with seven different automobile models) and across seven distinct systems for each model: engine, transmission, body, electrical, suspension, steering, and brakes. From this initial dataset of 19 models, each of which includes seven distinct systems, 2 overall models and five individual model-systems were excluded due to inadequate data. While governance choices are at the component level, the performance measures and the contracting environment measures are at the model-system level. Consequently, we are unable to exploit the (limited) information we have about the nature of individual bilateral contracts (e.g., the duration of individual relationships, or the scope of activity covered by an individual contract). The final dataset consists of 112 observations at the model-system-year level of system-specific contracting choice, the contracting environment, and performance.

Appendix C

System-specific Contracting and Performance Drivers

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

Sunk Cost is a dummy variable indicating whether there is pre-existing in-house sunk investments for each system (mean = 0.14). Specifically, managers were asked whether or not existing plant equipment directly affected their design choices for the system, as systems are often designed around plant-specific process equipment investments. On the one hand, the existence of pre-existing in-house capital investment will tend to favor a positive relationship between *Vertical Integration* and *Sunk Cost* at the system level; as such, we employ $Sunk\ Cost_{-I}$ as an instrumental variable for *Vertical Integration* in the IV analysis. When *Sunk Cost* = 1, this likely indicates that a company has significant experience and capabilities in a given system, which may be associated with a higher level of performance over the product lifecycle.[2] Moreover, we expect that the short-term performance penalty associated with vertical integration will be muted when *Sunk Cost* = 1, and also that there may be fewer opportunities for new learning and performance improvement within an individual product lifecycle.

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

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[2] It is also possible that *Sunk Cost* will be associated with high barriers to adopting frontier technology and production methods, perhaps limiting performance (particularly early in the lifecycle). Table 6 explores the interaction between *Vertical Integration* and *Sunk Costs*.

the earliest parts of the product lifecycle).

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

The degree of system-specific complexity may also impact realized performance (as well as be correlated with *Vertical Integration*). The degree of system-level complexity will impact the need for coordination across component elements of the system, encouraging in-house contracting. Our measure of system complexity draws on several measures, based on detailed system design and manufacturing data. For each system, we estimate product complexity on a scale from 0 to 1 (no complex system interactions to high product complexity) based on an unweighted average of characteristics of design complexity. For some systems, measures include characteristics such as "newness" - the degree to which a design configuration has been used in the company and in the vehicle. For example, product complexity in the suspension system is 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. *Complexity* (mean = .39), is the result of applying this procedure for each component within each system.

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

Model-Year Measures

Japan OEM (mean = .366) is a dummy variable equal to 1 if the model originates from a firm with company headquarters in Japan. This measure is useful in several ways: First, Japanese companies in this sample were new entrants to the luxury automobile market, and this measure allows us to isolate those firms with less ex-ante model-specific skills, and thus with more opportunities to learn over the product lifecycle. Additionally, Japanese firms are well known to invest heavily in continuous product improvement, and are able to achieve a much higher level of internal flexibility due to the absence of union restrictions. Consequently, the interaction between *Japan OEM* and *Vertical Integration* is predicted to have a negative relationship with *Short Term Performance* and a positive relationship with *Performance Change*.

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

System Groupings

Innovative Supplier System (mean = .447) is a dummy = 1 if the system in question varies in performance based on availability (during the sample period) of globally available innovative suppliers. Interviewees were asked whether suppliers varied in their innovative capacity at the system level and to evaluate the extent to which access to such suppliers was thought to be a direct performance determinant. Such systems were identified to be Transmission, Electrical, and Brakes. As discussed in Section II, the availability of an innovative external supplier raises the returns to outsourcing, particularly in terms of *Short Term Performance*. As a result, we expect a negative interaction effect between *Vertical Integration* and *Innovative Supplier System* in the *Short Term Performance* equation.[3]

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[3] We also experimented with a measure of the potential for learning within each system, based on engineering principles. While the results were consistent with the remainder of the analysis, the interaction effects between vertical integration and this measure of *Adaptive System Potential* were imprecisely estimated; in the interest of space constraints, we drop this measure from our main analysis.

Appendix D

Overall Performance Regressions

Dependent Variable : OVERALL PERFORMANCE (N=112)							
	(C-1)	(C-2)			(C-3)		
	Ordinary Least Squares						
VERTICAL INTEGRATION	-0.488* (0.257)	-0.256 (0.321)			-0.248 (0.265)		
SUNK COST					-0.094 (0.275)		
LOW CAPACITY					0.046 (0.259)		
PLATFORM					-0.068 (0.093)		
COMPLEXITY					0.320 (0.337)		
DESIGN GOAL					-0.316 (0.354)		
JAPAN OEM					0.411** (0.151)		
YEAR		0.108** (0.018)			0.092** (0.018)		
CONSTANT	3.813 (0.155)	3.871 (0.269)			3.769 (0.303)		
Parametric Rest.		#Restr	F-stat	p-value	#Restr	F-stat	p-value
SYSTEM DUMMIES		6	70.84	.000	6	21.18	.009
R-Squared	0.032	0.543			0.588		

Notes: (1) Stars denote statistical significance at 5% (**) and 10% (*), respectively.

(2) Standard errors, clustered by company, are presented in parentheses.