Contracting, Directed Parts, and Complexity in Automotive Outsourcing Decisions[1]

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Abstract

In this paper, we examine the outsourcing of interior systems for luxury automobiles. We use insights gleaned from original field interviews and contracts obtained from both buyers and suppliers to construct a theoretical framework and to empirically evaluate the interaction of product complexity, contract structure and buyer involvement in supplier product development in determining program pricing and performance. This is the first such attempt in the literature. We find that directed parts and complexity serve as strongly negative substitutes in the determination of the equilibrium bid price, and that this effect is so strong that it can even counter the individual effects on pricing.

(Product Development; Outsourcing, Complexity, Contracts, Directed Parts)

1. Introduction

There is very little theoretical and empirical work establishing how product complexity shapes contract practices. In this paper, we examine the outsourcing of interior systems for luxury automobiles. This segment has undergone major changes in product complexity and in contract structure over the past twenty years. We use insights gleaned from field interviews and contracts obtained from both buyers and suppliers to construct a theoretical framework and to empirically evaluate the interaction of product

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complexity, contract structure and buyer involvement in supplier product development in determining program pricing and performance.

Auto firms “direct” or pre-select and require use of certain components to be integrated into systems provided by a supplier. These activities have increased in the last few years. Now this activity is commonplace in the industry. Yet, there has been little investigation of the impact of these practices on program cost and supplier incentives. Using newly obtained contract data, we find that although separately, complexity and directed parts increase cost to the buyer, together they may actually reduce costs. One goal of this paper is to understand why this might be true.

Using key assumptions based on our fieldwork, we develop a stylized model of the contracting environment. Our model predicts that directing parts significantly raises bid price for non-complex contracts and that higher complexity significantly increases bid price for non-directed contracts. Our model suggests that the effect when both complexity and directed parts are present depends on the relative importance of the higher cost for a given quality and the lower quality level induced.

We test these relationships using an exclusive data set covering interior development in luxury performance vehicles from 1990-2000. This database covers product complexity, future contracting opportunities, initial supplier compensation and directed parts. We establish three key empirical findings. First, an increase in complexity, evaluated at mean values, drives bids up by about 43%. Second, we find that the presence of directed parts, evaluated in means, increases the bid price by approximately 31%. Finally, and perhaps most importantly, we find that directed parts and complexity serve as strongly negative substitutes in the determination of the equilibrium bid price, and that this effect is so strong that it can even counter the individual effects on pricing.

This result means that increasing complexity without adopting directed parts raises upfront costs to the buyer more than joint adoption. To the extent that complexity and directing parts are substitutes, effective management of complexity cannot be isolated from the choice of contract structure. In an extreme case, the impact of directing parts in complex systems may be to shift the cost of upfront quality control to resulting higher failure rates (a lower acceptable quality level in our model).

We further explore these tradeoffs under alternate contract structures, and identify the conditions under which product characteristics favor one structure over another.

The article begins by describing the recent trend toward directed parts and interior complete contracting in the auto industry. Section 3 presents a model to motivate our empirical analysis, Section 4 discusses the data and Section 5 presents the results and discussion of our empirical analysis. We compare performance of alternative contract structure in Section 6. We conclude in Section 7.

2. Institutional Background

2.1 The Industry

In the "core competencies" push of the early to mid 1980's (Fine and Whitney, 1996), many companies began focusing on outsourcing "non-core" activities to external suppliers as a way to reduce overhead as well as to gain access to the superior capabilities of the suppliers. In the auto industry, this trend coincided with the rise to prominence of Japanese automakers – a rise partially attributed to heavy reliance on outsourcing to a strong supplier network (Clark and Fujimoto, 1991). These developments led many automakers in the late 1980's (initially Chrysler in particular) to begin outsourcing complete subsystems (or "modules") as opposed to sourcing on a part-by-part basis as they had previously done. Seats were one of the systems seen as well suited for outsourcing as a complete module. Seat manufacture was extremely labor-intensive, involving cutting, sewing and stuffing of material – all low-tech, low-rent activities. Seat suppliers, with their lower overhead and more flexible labor contracts, were able to do this work more cheaply than the auto-makers (OEMs). As a result, by the mid-90s, nearly all OEMs had outsourced seat modules to seat suppliers. The contracting structure for implementing this outsourcing is what we call "sequential." Sequential contracts, as the name suggests, award system development to suppliers one system at a time. For example, an instrument panel development contract for a particular auto might be awarded ahead of the seat contract for the same auto. The same supplier might end up being awarded both contracts but need not be.

By the 1990s, the composition of the seat systems themselves underwent a change. In particular, increased electronic content (for lumbar support, airbag controllers, anti-whiplash protection, and automatic comfort adjustments) was transforming the historically low-tech interior systems (including seats) into much more complex and value-laden components. This also greatly increased the interaction or "integrality" of interior systems, requiring far more coordination in development across these systems (e.g., across seats and instrument panels).[2]

[2] For further discussion of integrality in product development, see Ulrich (1995).

The seat suppliers responded to this trend by aggressively expanding their capabilities, primarily through acquisition of suppliers of related interior systems such as headliners, instruments panels and door panels. By 2000, a few OEMs were outsourcing (and many were and are considering outsourcing) the "interior complete" (includes seats, instrument panel, door panels and headliner) to the seat suppliers. Thus, interior development has gone from contracting components separately to modules separately and seems to be heading towards awarding the interior complete contract at once. However, to the best of our knowledge, the impact of this recent change in structure has never been formally examined. Moreover, the financial stakes are extremely large: among the hundreds to thousands of suppliers doing business with any given OEM, interior suppliers are now in the top five in dollar volume, with individual seat suppliers responsible for $3.6 billion in business with OEMs such as GM and Ford.[3]

2.2 The Contracting Process

What do these contracts consist of/look like? Typically, there will be around five to seven suppliers asked to bid on a given contract, such as seats for a luxury sedan. The manufacturer will state the expected annual volume required, the expected length of the contract, and rough technical requirements for the system to be developed. These requirements include: carryover parts from previous models, required or "directed" parts (parts, often made by others, that must be included in the design), and cost and performance milestones.

Suppliers bidding on the contract provide the buyer with a quotation package that includes the detailed design, estimated engineering hours required to fulfill the contract,

[3] Crain's Detroit Business 11(5): January 30, 1995.

and the piece part price. Preparing the quotation can cost the supplier anywhere from $2 million to $20 million depending on the technical complexity of the design and how hard they work on the quotation and can take about eight months. Once all the quotations are received, the buyer chooses the least expensive contract that successfully meets the requirements. If the system is being developed for a new generation of an existing auto, the incumbent supplier will exercise right of last refusal if they are willing to meet the contract terms, otherwise the originator of the chosen proposal is awarded the contract. Right of last refusal (ROLR) means that after the bidding is over, if the incumbent was not the low bidder, the buyer will offer the incumbent the contract under the terms of the low bid. Only if the incumbent refuses these terms will the actual low bidder be awarded the contract.

After the contract is accepted, the typical timeline is that the supplier is paid largely based on the estimated engineering hours and develops the system. System development consists of first building a prototype model, then crash-testing the prototype and finally making any needed changes to the original design necessary to assure meeting performance and safety goals.[4]

It is important that these contracts take place in the context of ongoing interactions. It is particularly important to recognize that good performance by a supplier on a given contract tends to open up more favorable opportunities for that supplier in the

[4] If the hours exceed the estimate, all resulting changes are reviewed by the buyer engineer and/or purchasing agent responsible for the system. In such an event, compensation for the changes is a subject of negotiation. However, it is widely assumed (by all parties) that such "late stage" changes will be more costly for the buyer. The supplier has to draw upon additional engineering services that have already been allocated to other programs. There is a higher markup for such changes compared to initial contract items. One reason for this is to provide incentive for the buyer to be diligent in specifying the initial technical requirements. The model developed in the next section does not formally incorporate "late stage" changes

future. Specifically, this happens through both a formal and a more informal channel. Formally, the supplier gains right of last refusal on the next generation of the same contract through providing satisfactory performance on the current contract. Informally, buyers tend to award more lucrative contracts to suppliers who have performed well on previous contracts. Thus, satisfactory performance may lead to more and better contracts in the future. Below, we model this benefit as an expected future surplus to the supplier. It is noteworthy that the informal channel provides the supplier with quality incentives no matter which of the two contracting structures are used, while the formal channel only applies under the sequential contracting structure. We exploit this observation in our model.

2.3 Related Contracting Literature

Buyer-supplier contracting has been the subject of a large theoretical literature in economics in recent years (for a survey see e.g., Hart and Holmström, 1987; Tirole, 1999). Much of this literature is set in an institution-free environment and focuses on the choice of an optimal contract within a large set of theoretically possible contracts (e.g. Grossman and Hart, 1986; Baker, Gibbons and Murphy, 1992). Another strand of this literature focuses more on specific institutions and compares a small number (typically two) of contract options within that institutional context. Our model falls within this second category. The only paper of this type that we know of that is explicitly set in a buyer-supplier automotive contracting setting is by Taylor and Wiggins (1997). Our model differs from this work in a number of distinct ways: First, the contracting

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because we are primarily concerned with supplier incentives and buyer's choice of contracting structure structures compared in the two papers are different. Our model treats the comparison between sequential and interior complete contracts, where their model is concerned with the comparison of two configurations, "American", i.e. competitive bidding, large orders and inspections, and "Japanese," i.e. long-term relationships, small orders and no inspections. Second, the main tradeoff in Taylor and Wiggins is between setup and inspection costs. Our main tradeoff relates incentives for quality provision and directing parts. Third, product characteristics are not parts of the Taylor and Wiggins model and an important focus of our paper is the interaction of directing parts and product complexity in determining contract pricing. Although both papers consider intertemporal incentives, Taylor and Wiggins model these through a repeated game, while we use a reduced form three period model where the payoff in the last period proxies for the continuation value from unmodeled future contracting.

3. The Model

In this section we develop a model of a buyer and supplier contracting over a system specified by the buyer. Both the particular contracting institutions and product characteristics are our main focus. Using this model we are able address several questions. First, in sequential contracts, how does the buyer's equilibrium cost (i.e., supplier's price) vary with changes in system complexity and directed parts? Second, how does the choice of contract form affect the buyer's equilibrium cost? Specifically, we compare sequential contracts with interior complete contracts. This analysis allows us to make predictions about the relative merits of the two contractual forms given varying choices of directed parts and system complexity, as well as to generate

rather than buyer diligence in providing specifications.

comparative statics results for equilibrium bidding in the (observed) sequential contracts. This model will also be used in a subsequent section to inform our empirical analysis of pricing under sequential contracts.

Contracts are awarded through first price auctions where the suppliers submit bids representing the payment to them for fulfilling the contract. The goal of the buyer in awarding the contract is to minimize costs given the product specifications. The supplier's objective is to maximize discounted expected profit.

First consider the case of an interior complete contract. Since such a contract awards all business at once, no bidder is an incumbent. Timing is as follows (as is depicted in Figure 1):

There are three time periods: 0, 1, and 2. At date 0, the buyer specifies the product characteristics, chooses a supplier through competitive bidding, the contract is signed and the upfront payment is made to the supplier. Between dates 0 and 2, the supplier expends unobservable effort which determines the quality of the product that is being produced. At date 2, prototype development is complete and crash-testing takes place, revealing product quality and any necessary changes to be made to ensure performance. We assume that if the supplier successfully fulfills the contract, she can expect surpluses in the future. These are discounted back, using per-period discount factor, δ, to date 2 and represented by the value v. This future value serves to model the informal incentive for quality provision mentioned above, and represents the expected benefits from (unmodeled) more lucrative contracts awarded in the future.

Consider a supplier who bids b and is awarded the contract. The discounted expected profit the supplier expects to receive is:

$b-c(q(\theta, D), \theta, I=0, D, M=1, \tau) + \delta^2 v$, if quality generated is the required level, *q*;

and by

$b-c(\underline{q}, \theta, I=0, D, M=1, \tau) + 0$, if the supplier chooses to shirk on quality and provides the lowest legally enforceable quality level, $\underline{q}$.

Here *c(.)* is the supplier's cost function, which depends on quality *q*, product complexity *θ*, incumbency status *I*, directed parts *D*, the contracting structure *M*, and contract volume *τ*.[5] A summary of notation is presented in Table 1.

If the supplier is not awarded the contract, the discounted expected profit is normalized to 0. For now, we assume $\delta^2 v > c(q(\theta, D), \theta, I=0, D, M=1) - c(\underline{q}, \theta, I=0, D, M=1)$, so that it is always in the supplier's interest to provide quality $q(\theta, D)$ if awarded the contract. We will investigate this assumption further later in the paper. We also assume that there are at least three competitors in the bidding stage and that all are identical in terms of cost.[6]

Under these assumptions, each supplier will bid $b = c(q(\theta, D), \theta, I=0, D, M=1) - \delta^2 v$ and has a 1/3 chance of being awarded the contract and will end up with zero profit.

Now consider the case of a sequential contract. There are now two interior contracts that are awarded separately, in sequence, e.g. seats and instrument panel. In this structure, an important difference from the interior complete is that at date one, a second contract is awarded and there will be an incumbent firm, i.e., the firm that won

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[5] As we do not examine the effects of variation of volume τ in our model, hereafter we omit τ as an argument in the cost function c.

[6] In reality, the number of bidders varies, but there are typically 3-5 serious bidders, who are essentially identical in capabilities. Theoretically, the advantage we get from assuming three rather than two bidders is that, later on, when one bidder is the incumbent, there are still at least two symmetric non-incumbents bidding, which simplifies the equilibrium bidding outcome.

the first contract. Timing for the sequential structure is as follows (as depicted in Figure 2):

There are three time periods: 0, 1, and 2. At date 0, the buyer specifies the product characteristics for an interior system module, chooses a supplier through competitive bidding, the contract is signed and the upfront payment is made to the supplier. Between dates 0 and 1, the supplier expends unobservable effort, which determines the quality of the module that is being produced. At date 1, prototype development for this module is complete and testing takes place, revealing module quality and any necessary changes to be made to ensure performance. The buyer then specifies the product characteristics for the remaining system module(s) and chooses a supplier through possibly asymmetric competitive bidding. A contract is signed and the upfront payment is made to the supplier. Between dates 1 and 2, the supplier expends unobservable effort, which determines the quality of the module(s) that is being produced. At date 2, prototype development is complete and crash-testing takes place, revealing product quality and any necessary changes to be made to ensure performance. We assume that if the supplier of the second module(s) successfully fulfills the contract, she can expect surpluses in the future. These are discounted back to date 2 and represented by the value v.

The winner of the contract for the first module awarded (i.e. the incumbent at date 1) is treated as follows: if the desired quality level, $q(\theta, D)$, is provided successfully in the first contract, then the incumbent is not only allowed to bid on the second contract, but is also granted right of last refusal (ROLR) in the bidding for the second contract. Additionally, we assume that the incumbent has a cost advantage over potential entrants derived from her experience with the initial contract.[7] If, instead, the incumbent does not meet the desired quality level in the first contract, then the buyer does not allow the incumbent to win the second contract. This is known by all potential entrants ahead of the second contract bidding process.[8] We assume that the future value, v, of being awarded *both* contracts in a sequential award is the same as the future value derived from being awarded a single interior complete contract. We now derive the supplier's expected profits and bidding behavior for the sequential contracting structure.

To find the equilibrium behavior, we solve backwards, beginning with bidding for the second contract. Consider a successful incumbent from period 1, i.e., an incumbent who has met the quality requirements. We assume that there is a probability *p* that no other viable bidders will decide to compete against the incumbent for the second contract.[9] With probability *1-p*, at least two potential identical entrants will enter the bidding against the incumbent. In this competitive environment, with ROLR, it is optimal for the incumbent to submit a bid of $\overline{c}$, defined as the buyer's upper bound on reasonable expected cost for the contract. Thus, in the event that competing bidders do appear, the incumbent will obtain the contract through ROLR at a bid $b^c < \overline{c}$, where b^c is the amount of the lowest competitor's bid. If no competing bidders appear, then the incumbent will

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[7] Our interviews suggest that having an early piece of a contract reduces the cost of adapting the second contract product design to meet the constraints posed by the product resulting from the first contract. There are also some economies of scope in engineering design across sequential contracts.

[8] For example, close competitors will hear that a buyer is "unhappy" with product performance of supplier X in a contract before the second contract is sent out to bid. Such statements, even when casually made, signal the opportunity to bid for contracts without the incumbent's right of last refusal and cost advantage as a barrier.

[9] Again, this is because preparing a bid is extremely expensive, and, given the barrier of ROLR, may not pay off for a non-incumbent, and non-incumbents may not have available capacity for the job. In practice, non-incumbents will signal this by submitting extremely high bids (above $\overline{c}$). On the other hand, sometimes the incumbent may be overcapacitated and would be willing to pass on a "sure thing", providing the non-incumbent with a valuable opportunity to "get a foot in the door."

obtain the contract at bid $\bar{c}$. So, at whatever price the incumbent wins the contract (call it b), his expected profit from that point on is

b- c(q(θ, D), θ, I=1, D, M=0) + δv, if quality generated is the required q(θ, D);

and is

b- c($\underline{q}$, θ, I=1, D, M=0) + 0, if the incumbent chooses to shirk on quality and provides the lowest legally enforceable quality level.

Notice that the future value v is only discounted 1 period here because this is already the second stage contract, and so is awarded in period 2, rather than period 1. If the incumbent is not awarded the contract, he gets 0.

Now let us consider a non-incumbent bidding for the second contract. [10] If she is awarded the contract, her payoff will be:

b^c-c(q(θ, D), θ, I=0, D, M=0) + δv, if quality is q(θ, D);

and is

b^c-c($\underline{q}$, θ, I=0, D, M=0) + 0, if the supplier chooses to shirk on quality and provides quality $\underline{q}$.

If the non-incumbent does not win the contract her payoff is zero. At this point assume that δv > Max [c(q(θ, D), θ, I=0, D, M=0) - c($\underline{q}$, θ, I=0, D, M=0), c(q(θ, D), θ, I=1, D, M=0) - c($\underline{q}$, θ, I=1, D, M=0)] so that both the incumbent and non-incumbents will choose to provide quality if awarded the contract. So, any non-incumbent will bid b^c = c(q, θ, I=0, D, M=0) - δv.

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[10] We assume that a non-incumbent who replaces an incumbent in period 2 and performs acceptably can reasonably expect to get the same future benefits as would the incumbent. This assumption roughly agrees with industry practice regarding new suppliers who have "saved" programs from failure.

Therefore, from the second period on, a successful first period incumbent expects profits of $p(\bar{c}$ - $c(q(\theta, D), \theta, I=1, D, M=0) + \delta v) + (1-p)(c(q(\theta, D), \theta, I=0, D, M=0)- c(q(\theta, D), \theta, I=1, D, M=0))$ whereas a non-incumbent expects profits of zero.

Now, from the perspective of the first period, a supplier winning the first period contract with bid *b* will expect:

$b - c(q(\theta, D), \theta, I=0, D, M=0)+ \delta[p(\bar{c} - c(q(\theta, D), \theta, I=1, D, M=0) + \delta v)+ (1-p) (c(q(\theta, D), \theta, I=0, D, M=0)- c(q(\theta, D), \theta, I=1, D, M=0))]$.

For the winning first period supplier to choose to provide $q(\theta, D)$ rather than $\underline{q}$, we assume that $-c(\underline{q}, \theta, I=0, D, M=0) + c(q(\theta, D), \theta, I=0, D, M=0)- \delta[p (\bar{c} - c(q(\theta, D), \theta, I=1, D, M=0))+ (1-p) (c(q(\theta, D), \theta, I=0, D, M=0)- c(q(\theta, D), \theta, I=1, D, M=0))] < p\delta^2 v$.

Again, assuming three identical potential suppliers at the beginning of the first stage, we see that each will bid $b= c(q(\theta, D), \theta, I=0, D, M=0)- \delta[p (\bar{c} - c(q(\theta, D), \theta, I=1, D, M=0) + \delta v)+ (1-p) (c(q(\theta, D), \theta, I=0, D, M=0)- c(q(\theta, D), \theta, I=1, D, M=0))]$.

So, under interior complete contracting, the buyer pays an expected price of $c(q(\theta, D), \theta, I=0, D, M=1) - \delta^2 v$ and under sequential contracting, the buyer pays an expected price of $c(q(\theta, D), \theta, I=0, D, M=0) + \delta\ c(q(\theta, D), \theta, I=1, D, M=0) - \delta^2 v$. So, the difference in buyer costs between the two contractual methods thus far comes down to the difference between $c(q(\theta, D), \theta, I=0, D, M=1)$ and $[c(q(\theta, D), \theta, I=0, D, M=0) + \delta\ c(q(\theta, D),\theta, I=1, D, M=0)]$.

Next, we examine the way that this cost depends on the product and contract characteristics. In doing so, we will be able to make predictions about the crucial cost comparison identified above as a function of the environment, as well as the comparative statics of bids in the (observed) category of sequential contracts.

We make the following assumptions on the cost function motivated by industry knowledge gathered through extensive fieldwork.

1. $c(q(\theta, D), \theta, I, D = 1, M) > c(q(\theta, D), \theta, I, D = 0, M)$, i.e., all else equal (including q), mandating the use of directed parts increases the supplier's cost.

2. $c(q(\theta, D), \theta = 1, I, D, M) > c(q(\theta, D), \theta = 0, I, D, M)$, i.e., all else equal (including q), increased complexity raises the supplier's cost.

3. $c(q_1, \theta, I, D, M) > c(q_2, \theta, I, D, M)$ if $q_1 > q_2$, i.e., all else equal, providing higher quality costs the supplier more.

Next, we make assumptions on the way in which quality varies with complexity and directed parts. Recall the role that quality plays in the contracting process: the supplier must attain a given level of quality in order to reap the future benefits, *v*, from a continuing relationship with the buyer on related lines of business. This benchmark quality level is a proxy for the manufacturer's expectations of product performance/quality. Why might these expectations vary with complexity and directed parts? As pointed out by Novak and Tayur (2002), the presence of directed parts potentially shifts responsibility for system performance from the supplier to the buyer since the supplier may be able to claim ex-post that any performance failure was due to parts that the buyer chose. In non-complex systems, this effect is likely to be very small, for in such systems it is relatively easy to determine the cause of a given failure. In more complex systems, however, it is much more difficult to separate sources of failure within the system. As a result, the buyer is less able to hold the supplier to high levels of performance and system quality. Naturally, knowing this, suppliers will put less effort into quality provision for these systems. We capture this effect in our model by assuming that acceptable quality for complex systems with directed parts ($q(\theta = 1, D = 1)$) is lower than acceptable quality for other complexity, directed parts combinations. Specifically, this will mean that the supplier for a complex, directed system will need to attain less quality to be rewarded with future benefits (v). To keep things simple, we further assume that this is the only variation in acceptable quality, $q(\theta, D)$, i.e., we assume $q(0, 1) = q(1, 0) = q(0, 0) > q(1,1)$.

Given these assumptions, we are in a position to examine some comparative statics. For sequential contracts, how does the buyer's cost change as complexity and directed parts change? As we derived above, the buyer's expected cost is $c(q(\theta, D), \theta, I=0, D, M=0) + \delta\, c(q(\theta, D), \theta, I=1, D, M=0) - \delta^2 v$. Taking a non-complex, non-directed parts system as the baseline, we see that (a) both a complex, non-directed system and a directed, non-complex system cost the buyer more; and (b) a system that is both complex and has directed parts ***may cost either more or less*** than either the baseline or any of the other choices. This occurs when both are present, because it is true that for a given quality, supplier's cost (and thus buyer's cost) is higher, but the quality level itself will be lower, which lowers cost.

Thus, we see that whether system complexity raises price is ambiguous and depends on both the interaction between directed parts and complexity and the extent to which directing parts shifts assignment of responsibility for product performance from the supplier to the buyer. One of the things we will investigate empirically is the cumulative impact of complexity and directed parts on price.

4. Data

The unique dataset used in this paper is composed of: procurement cost, initial piece rate, engineering hours in product development, product complexity and directed parts contained in contracts between buyers and interior system parts suppliers for the period 1990-2000. We also have the total product volume and contract length for each contract.

Contract-level data was obtained primarily through contract documents and on-site interviews at auto manufacturers and supplier facilities worldwide. Over 200 people were interviewed on the supplier side, including project managers and system engineers involved in development of each vehicle for each time period in the study. The interviews were conducted on-site at each company, over periods ranging from three days to one month. All subjects were given a list of questions pertaining to the terms of the contracts for their respective systems. The questions focused on principally objective information (i.e., how many variations of seats are offered in the contract), so as to minimize the likelihood of response bias. All participants were assured that only aggregate data would be presented, and confidentiality agreements were signed with each company.

We observe 26 interior product development projects, which resulted in a contract with a winning supplier as well as the piece price and engineering estimates of the losing bidders. Summary Statistics are presented in Table 2. CPI corrected average piece part price for our sample is \$484 with a maximum value of \$2051. [11] The average length of

[11] The results of econometric estimation do not change significantly if PPI for motor vehicles and passenger car bodies or PPI for motor vehicle parts and accessories are used for deflation instead of CPI.

contracts is 4.8 years, and average annual contract volume is 111,448. For each product, we know how many hours the winning supplier estimated product development would require (engineering effort) and their estimate of piece part price. The key explanatory variables in our study are product complexity and directed parts, the measurement of which we detail below.

Product Complexity

We estimate product complexity as in Novak and Eppinger (2001), on a spectrum from 0 to 1 (no complex interactions to high system complexity), using detailed design and manufacturing data contained in each contract, as well as through interviews with supplier and manufacturer engineers. We detail the measures used on a system level (seats, headliners, door panels, instrument panels) in Appendix A. For headliners and door panels, there has been little change in product complexity over the time period of our study. For seats and instrument panels, there has been a dramatic increase in product complexity.

Directed Parts

The dummy variable for directed parts indicates whether or not the module contained OEM-assigned critical components, such as the airbag and airbag controller in the seat. This variable was calculated by identifying key components, defined as involving major interactions with more than one part. The dummy for directed parts was set to be equal to 1 if at least one critical component was contractually specified and 0 if the supplier was allowed to choose the combination of components in the module.[12] Mean value for the directed parts dummy is 0.385 among the 26 contracts in the sample.

5. Empirical Results

In this section we describe our empirical analysis of determination of supplier bid price as a function of directed parts and product complexity. The principal empirical challenge associated with such a study is that the sample size is limited by availability of comparable contracts. In a segment such as luxury performance cars there may only be 5-10 observations every five years for interior system contracts. Rather than expanding the dataset and thus confounding incomparable projects, our focus is on a very specific segment where both the challenges faced by the parties in development and the data available are comparable across a set of observations.

Given these limitations, we interpret our results cautiously. However, a number of important regularities emerge which are both consistent with the qualitative phenomena as well as our economic model regarding bid price, product complexity and directed parts. We begin by describing the overall relationship between these factors, discuss the key issues for specification and then turn to the principal empirical findings of this research.

We begin in Table 3 by examining how mean bid price varies according to different choices of directed parts and complexity. Two patterns emerge. First, relative to simple, undirected systems, bid price is substantially increasing in both complexity and directed parts. However, the combination of high complexity and directed parts is

[12] We assume that the direction of one critical component creates the same order of magnitude of uncertainty in the likelihood of change as directing more than one critical component. Again, this is

associated with a lower bid price. Each of these differences of the means is statistically significant. While this result accords with our key theoretical predictions, it is necessary to consider alternative (and potentially correlated) drivers of bid price such as volume and/or the presence of outliers driven by idiosyncratic factors.

Indeed, bid price, after controlling for other factors, is strongly increasing in volume. Specifically, Figure 1 reports an "added-variable" plot of bid price versus parts volume in logarithms, which is formed by plotting the residuals from a regression of bid price as a function of directed, complexity and the interaction of directed and complexity, versus the residuals of volume as a function of directed, complexity and the interaction term. As is standard for pricing problems, the relationship between volume and bid price can be monotonic but non-linear. By inspection of Figure 1 (and further semi-parametric exploration using kernel estimation[13]), we determined that after taking log values, a linear approximation of the bid-volume relationship is reasonable. As engineering costs to develop a system do not increase with volume but are fixed over a project, this result is consistent with our expectations.

We now turn to the econometric analysis. Given the limited number of observations in our sample, the choice of control factors for determining the relationship between price, complexity and directed parts is critical. For example, we cannot simultaneously include full sets of dummies for company, year and interior system type, as this specification will not allow us to identify all of our parameters of interest. We were able to reject the significance of time dummies as a group, and therefore focus on a set of specifications which account for company-specific effects and still allow us to

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because such components, by definition, have extremely intricate interactions with the other parts.

exploit contracts over the full sample. Similarly, we were able to reject all but seat dummies, we focus on seat vs other systems rather than including a full set of system dummies.

The results of the estimation of a linear regression with robust (White) standard errors are presented in Table 4.[14] In the first column we consider only completed projects, while the second column includes uncompleted projects as well. We distinguish between these cases in order to account for possible differences driven by the two uncompleted projects, which were highly complex, experimental seat programs by the same automaker. We suspected that supplier estimates of bid price might have been affected by such characteristics. As shown, the results do not differ across specifications. We find that bid price is significantly higher for non-complex contracts with directed parts. Evaluated in means, the presence of directed parts increases the bid price by approximately 31%. Although Novak and Tayur (2002) find that engineering cost decreases with directed parts, the finding that bid price increases suggests that suppliers pass on the cost of working with unfamiliar parts through the piece part price. Another predicted result is that bids are much higher for non-directed contracts with higher complexity. All else being equal, an increase in the dummy for complexity from 0 to 1, evaluated at mean values, drives bids up by about 43%. This result is consistent with our expectation that more complex projects require more work to complete to satisfaction, and are thus more costly. Furthermore, the finding that the impact of system complexity on program cost is much more severe than directing parts is consistent with buyer claims

[13] Available from authors upon request.
[14] It should be noted that even though the company dummies are mainly insignificant, the F-test shows that they are significant as a group.

that they perceive larger benefit in choosing “best in class” parts when systems are complicated.

At the same time, the negative and significant coefficient for the interaction term demonstrates that the presence of the directed parts in the contract and complexity serve as substitutes in the determination of the bid. One possible interpretation of this result is that by directing parts, the buyer has reduced the work needed to complete the project. We disagree with this explanation, as directing parts in complex systems requires recalibrating the interaction of all the parts and reduces the supplier’s ability to rely on prior experience to control cost of changes. Furthermore, we find that bid price increases for simple systems with directed parts, which certainly argues against the reduced work explanation. Instead, our understanding of this process suggests that the lower bid price is driven by the reduction in effort supply on the part of the supplier. In other words, suppliers are less able to apply their previous systems knowledge to ensure product performance and furthermore, as shown in Novak and Tayur (2002), they expect to be held less accountable for any resulting cost of failure. Overall, this means that a lower level of quality will be delivered and accepted for such contracts. This explains why the effects of directed parts and complexity cancel out when both are present.

Although our analysis is limited by the small sample of observations available, our findings pose a number of implications of interest. Perhaps most importantly, the fact that bid price is affected in specific, measurable ways by product characteristics and the nature of the contracting relationship allows us to analyze various outsourcing propositions in terms of their potential effect on economic efficiency. To the extent that complexity and directing parts are substitutes, effective management of complexity cannot be isolated from the choice of contract structure. In an extreme case, the impact of directing parts in complex systems may be to shift the cost of upfront quality control to resulting higher failure rates (a lower acceptable quality level in our model). As a goal of directing parts is to ensure consistent quality across buyer programs, this analysis highlights the challenges associated with achieving such objectives.

6. Section on Interior Complete vs Sequential

We now turn to a comparison between interior complete and sequential contracting structures. As was previously shown, in Section 3, the buyer's expected price under interior complete contracting is $c(q(\theta, D), \theta, I=0, D, M=1) - \delta^2 v$. Similarly, under sequential contracting, the buyer pays an expected price of $c(q(\theta, D), \theta, I=0, D, M=0) + \delta\, c(q(\theta, D), \theta, I=1, D, M=0) - \delta^2 v$. Under the assumption that quality is provided under both structures, the cost comparison is then $c(q(\theta, D), \theta, I=0, D, M=1)$ vs. $c(q(\theta, D), \theta, I=0, D, M=0) + \delta\, c(q(\theta, D), \theta, I=1, D, M=0)$. For purposes of comparison, we begin by assuming that these two expressions are equal. In this case, the key drivers of the comparison will be the extent to which quality is provided along with any incumbency effects. Clearly, if quality is likely to be provided under one contracting structure but not the other then the buyer should adopt the structure that induces quality.

We first consider quality provision under the two structures. For convenience and to highlight the relevant considerations, we separately analyze two competitive environments for the sequential structure: one without second period competition for incumbents (i.e., $p=1$) and one with some expected second period competition (i.e., $p<1$). Within each environment, we examine incentives for quality provision as well as the interaction of quality provision with directing parts and product complexity. We also compare sequential with interior complete contracting in terms of quality provision and the relevant interactions.

Throughout this analysis, we assume that there are no interactions between either M (the contracting structure) or I (incumbency) with q (quality) in the cost function.[15] Assuming there is no competition for the incumbent in the second period (i.e., p=1), the relevant conditions that ensure that acceptable quality is provided under interior complete and in each period of sequential contracting are given by equations (1), (2), and (3) in Appendix B.

Proposition 1: Whenever acceptable quality ($q(\theta, D)$) is provided under interior complete, it will also be provided in both periods of sequential contracting. If there is discounting between periods (i.e., $\delta<1$), then quality will be provided for a strictly larger region of values of v (the expected future surplus) under sequential contracting.

Proof: By inspection of equations (1), (2), and (3) in Appendix B and by assumption of no interaction between either M or I with quality .

Proposition 1 tells us that, all else equal, the sequential structure with no competition provides the buyer with a better instrument to induce quality (that is, through making the second part of the contract contingent on performance in the first part) than interior complete.

Next, we examine the effect of directing parts on incentives for quality provision. We first consider non-complex systems ($\theta = 0$). Since quality standards are the same, whether

[15] If we assume that M (contracting structure) did make quality provision easier or harder directly through the cost function then we would be assuming the direction of the comparison. Our interviews do not give us any reason to think that such a interaction is reasonable.

parts are directed or not in this case (recall our assumption that q(0,0) = q(0,1)), if there is no interaction between quality and directing parts in the supplier's cost function, the only impact on quality provision of directing parts would be to reduce the second period monopolistic rents under sequential contracting, and thus reduce quality provision in the first period of the sequential contract. However, it is still true, whether parts are directed or not, that quality will be provided more often under sequential, although this effect is diminished when parts are directed.[16]

Now consider complex systems (θ = 1). Recall that directing parts lowers the acceptable quality level in this case (i.e. q(1,1) <q(1,0)). If we again assume no interaction between quality and directed parts in the cost function, directing parts will shrink the incremental cost of providing acceptable quality (c(q(θ, D), θ, I, D, M) - c($\underline{q}$, θ, I, D, M)). This will lead to quality (at a lower standard) provision more often under both interior complete and each period of sequential. Under which structure will the impact of directing parts on quality provision be greater?

Proposition 2: If quality would not be provided under either structure without directing parts, then directing parts helps at least as much under sequential as under interior complete.

Proposition 2 says if quality provision is unlikely under either structure, directing parts can be a more powerful tool for inducing quality in sequential contracts.

[16] Note that this claim relies on the assumption that $\overline{c}$ (the highest reasonable cost that can be submitted as part of the supplier's bid) is not a function of directing parts, or at least, increases less than the supplier's cost function when D moves from 0 to 1.

Proposition 3: If quality would have been provided in both periods of sequential contracting, but not under interior complete without directing parts, then directing parts may lead to quality provision under interior complete and will lower quality under sequential since provision will continue, but at a diminished level of quality.

Proposition 3 says that once quality be provided under sequential without directing parts, then directing parts can only hurt quality under sequential while it may help quality provision under interior complete.

Proof: Both Propositions 2 and 3 can be seen by inspection of equations (1), (2) and (3) in Appendix B.

All of the above results have assumed that the incumbent faces no second period competition. We now consider the quality provision comparison between sequential and interior complete in the presence of second period competition (i.e. $p<1$).

$P < 1$ CASE

In the model, the only relevant change in this case is that equation (3) of Appendix B (relating to quality provision in the first period of sequential contracting) is replaced by equation (4) of Appendix B. Under the realistic assumption that the incumbency cost advantage ($c(q(\theta, D), \theta, I=0, D, M=0)- c(q(\theta, D), \theta, I=1, D, M=0)$) is no larger than the cost savings to a non-incumbent from shirking on quality in the first contract of a sequential contracting structure ($c(q(\theta, D), \theta, I=0, D, M=0) - c(\underline{q}, \theta, I=0, D, M=0)$), the following results are true:

Proposition 4: Incentives for quality provision in the first period of sequential contracting decrease compared to the case without second period competition.

Proposition 5: There is a p* such that for all $p < p^*$, quality provision occurs more often under interior complete than under sequential contracting.

Proof: Follows from Equations (1), (2), (3), (4) and the assumption that incumbency cost advantage is no larger than the cost savings to a non-incumbent from shirking in the first contract of a sequential contracting structure.

Propositions 4 and 5 tell us that increased second period competition diminishes and may ultimately overturn the quality provision advantage of the sequential contracting structure. It is worth noting that these results together with the observation that the buyer's cost under sequential contracting does not depend on the probability of second period competition p, imply that the buyer prefers less second period competition when using a sequential structure. This occurs because the competition in the first period along with the quality review between the two periods is sufficient to allow both strong incentives for quality provision and to extract the anticipated monopoly rents from the supplier. It is worth noting that this structure bears a strong resemblance to the highly successful Toyota-supplier relationship structure in which suppliers compete fiercely to win a relationship and are subject to quality reviews between contracts, but with little or no competition once the relationship is established (Whitney, 1993; Taylor and Wiggins, 1997).[17]

We now examine a separate effect of directing parts from those considered above. We now incorporate coordination effects by assuming that under interior complete contracting (M=1), the partial (i.e., direct) increase in cost c when parts are directed (i.e., D moves from 0 to 1) is larger than the corresponding increase in c for sequential contracts (M = 0). The reason for this is that the supplier under interior complete contracting is responsible for coordinating the entire interior development, and directing parts makes this harder for the supplier. In contrast, under sequential contracting, the supplier(s) are not responsible for coordinating across systems and therefore there is no interior-level supplier coordination affected by directing parts. This coordination effect directly delivers the following result:

Proposition 6: Ignoring quality provision incentives, all else equal, directing parts makes interior complete less attractive.

Why do we model this coordination effect as increasing the marginal cost of directing parts under interior complete as compared to sequential rather than simply raising costs under interior complete? One might think that because interior complete contracting involves an additional task (cross-system coordination) on the supplier's part, that interior complete contracts should, all else equal, cost more than sequential contracts. However, we note that if we were to consider this, we would also want to explicitly model the fact that the buyer has to perform the cross-system coordination under sequential contracting and so bears the cost for it directly. Thus, this coordination cost is essentially just a matter of a transfer between the buyer and supplier and washes out. If, realistically, the supplier has a different cost of coordination than the buyer, this would of course impact the desirability of one structure compared to the other. Notice, though, that this is just a straightforward "outsourcing to the most capable" story and is separable from our focus.

[17] It is crucial, however, that the buyer has a credible outside source, should the supplier-partner ever fail to deliver quality. In this sense, even when p=1, there is some implicit competition to retain the contract. This “shadow sourcing” is described as well by Whitney (1993).

It could always be added on, but would not change our results nor add insights to the model.

In sum, a comparison of the net benefit under sequential contracting versus interior complete contracts yields the following insights:

Abstracting from coordination and assuming no second period competition for incumbents:

(1) Quality provision is always at least as likely under sequential contracting as under interior complete.

(2) If quality provision is unlikely under either structure, directing parts for a complex system can be a more powerful tool for inducing quality in sequential contracts.

(3) Directing parts for a complex system is at least as valuable under interior complete as it is under sequential contracting when, in the absence of directing parts, the incentives for quality are sufficient under sequential but insufficient under interior complete.

Abstracting from coordination and assuming some second period competition for incumbents ($p<1$):

(4) Increased second period competition diminishes and may ultimately overturn the quality provision advantage of the sequential contracting structure.

Taking into account the additional coordination activity under interior complete contracting:

(5) Ignoring quality provision incentives, all else equal, directing parts makes interior complete less attractive.

In sum, we see that quality provision and directing parts can lead to notable differences in the relative performance of sequential and interior complete contracts. Our findings suggest important directions for future research, discussed below.

7. Discussion and Concluding Remarks

7.1 Limitations and Areas for Future Research

There are several limitations to this research. First, our data relies on upfront supplier bid price. Ideally we would like to have total resulting program cost, including cost of changes. Unfortunately, ex post program cost is highly confidential and not available (often, not even within companies). Subject to this limitation, our data are the best available measure of effort and cost. Furthermore, upfront bid price alone is of economic interest as it determines the supply of effort by supplier and buyer during the initial stages of product development and has the advantage that it is comparable across company and program. A second limitation is the size of the dataset. We would prefer to have enough data to correct for possible correlation between intercompany, multiyear observations. However, we would need to expand beyond the luxury performance segment in order to obtain enough such contracts, and the risk of confounding the data by using incomparable projects may exceed the benefit of larger sample size. A third limitation is in the choice of measurement of complexity and directed parts. Specifically, while both of these constructs are subjective a priori, we have tried to use the simplest possible measures, as well as multiple industry expert evaluations, in order to reduce any possible biases arising from definition or sample selection.

In summary, this research provides empirical evidence that the common practice of including buyer-specified components, or "directed parts" in complex systems can have economically significant, measurable unintended consequences for program quality and cost.

7.2 Conclusion

This paper provides the first theoretical model and empirical test of the relationship between bid price, directed parts and product complexity. We establish three key empirical findings. First, an increase in complexity, evaluated at mean values, drives bids up by about 43%. Second, we find that the presence of directed parts, evaluated in means, increases the bid price by approximately 31%. Finally, and most importantly, we find that directed parts and complexity serve as strongly negative substitutes in the determination of the equilibrium bid price, and that this effect is so strong that it can even counter the individual effects on pricing.

This finding, that directing parts and product complexity are substitutes, has important implications for economic analysis of outsourcing: the fact that optimal contract structure is affected by product characteristics poses challenges for designing buyer-supplier relationship across programs with different product characteristics. For example, in projects where parts are directed in order to capture benefits of simplifying buyer coordination across multiple programs, if some of those projects are more complex, the cost savings due to directing parts may be less than the drawbacks resulting from a resulting quality shortfall. Given that current practice has been focused on sequential contracts, the implications of our analysis for managers are that highly complex, directed systems should be analyzed in terms of overall program cost/performance rather than upfront bid, as this figure does not incorporate the changed quality incentives identified in this paper.

There has been some recent movement toward interior complete contracting, and our results suggest an opportunity to expand the empirical analysis as the products of such contracts are completed.[18] Specifically, our analysis in Section 6 suggests that the benefits of directing parts for highly complex products may depend on the contractual form. We provide conditions under which directing parts is more valuable for sequential than for interior complete. This suggests that maintaining a directed parts policy based on sequential contracting may not be sensible for a buyer using an interior complete contract.

Our findings also have implications for the organization of purchasing in auto companies. The traditional arrangement of outsourcing decision-making is at the component level, and is based on earlier product development in which the buyer was responsible for design of interfaces of the vehicle. That is, the buyer performed the integration activity over all outsourced parts. The trend toward "full service supplier" outsourcing creates, at a minimum, the need for coordination of system-to-system interfaces. However, it is not clear that the buyer is performing this function, as it supercedes component-level purchasing. Our results on the role of coordination in such contracts indicate that moving to interior complete can be successful when the supplier is allowed to perform the system-to-system coordination activity; that is, when the interior complete is not directed by the buyer.

[18] For more on the trend toward interior complete development, see websites of Lear Corporation, Magna and Johnson Controls, Inc. (www.lear.com, www.magna.com; www.jci.com).

As data on interior complete contracts become available, we would like to empirically evaluate these predictions. A comparison between the two forms, given that such contracting represents a major shift for the industry and involves a large volume of trade, is of value not only in better understanding these effects, but also will help to guide managers in choosing an appropriate contract form given their product characteristics.

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Variable	Description
θ	product complexity; = 0 if low complexity; 1 if high complexity
I	incumbent; = 0 if firm is not incumbent on contract; 1 if firm is incumbent
D	directed parts; = 0 if no critical components directed; 1 if any critical components directed
M	interior complete; = 0 if contracting is sequential; 1 if entire interior is awarded in a single contract
v	future value contingent on incumbency and successful performance on current contract
$q(\theta, D)$	product quality as a function of product complexity and directed parts, a positive number
b	supplier bid for contract; includes both engineering/design fee and compensation for manufactured product
τ	contract volume, i.e., number of units contracted
$c(q, \theta, I, D, M, \tau)$ – supplier's actual cost as a function of product and contract characteristics	

Table 1. Outline of modeling assumptions.

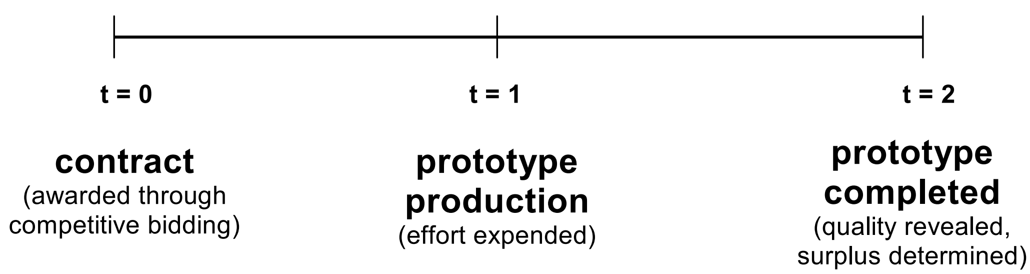

Figure 1. Timeline for Interior Complete Contracting.

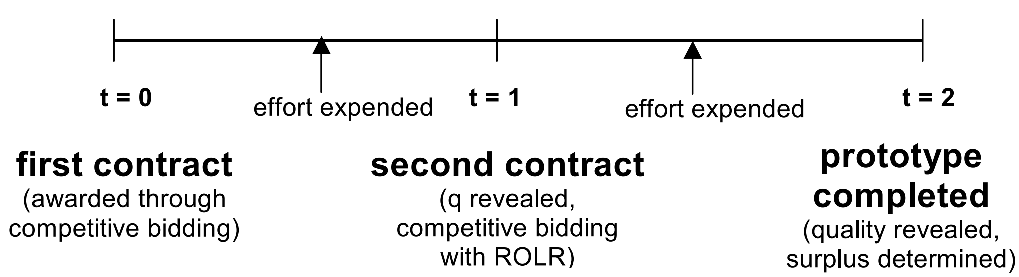

Figure 2. Timeline for Sequential Contracting.

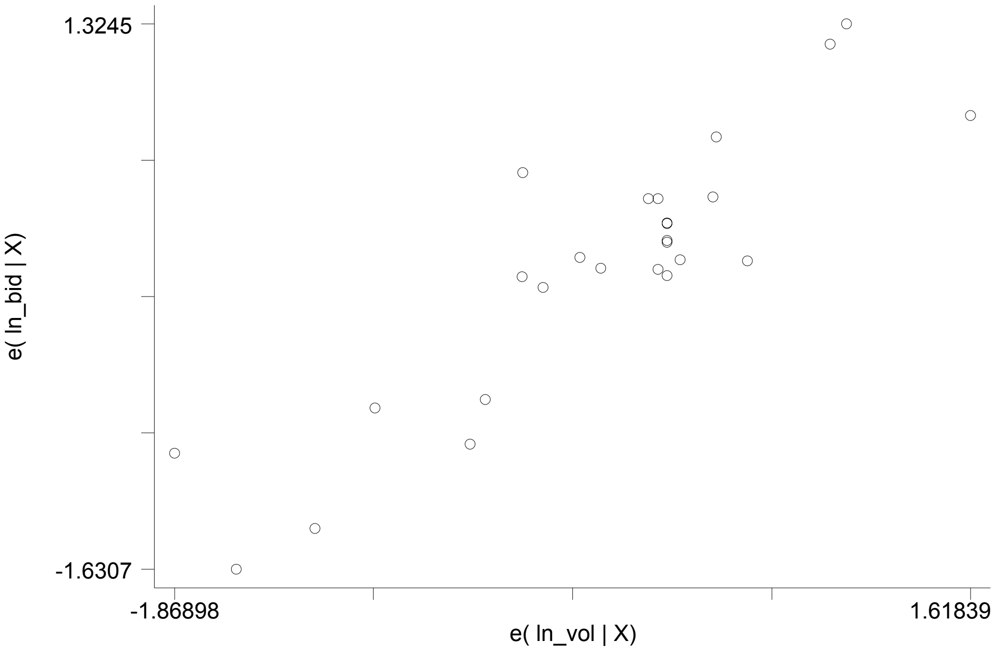

Figure 3. Added variable plot.

Variable	Label	Observations	Mean	Std. Deviation	Minimum	Maximum
seat	Module Type	26	0.769	0.430	0	1
Door_panel	Module Type	26	0.077	0.272	0	1
inst_panel	Module Type	26	0.077	0.272	0	1
_1993	Year	26	0.077	0.272	0	1
_1994	Year	26	0.038	0.196	0	1
_1999	Year	26	0.077	0.272	0	1
_2000	Year	26	0.385	0.496	0	1
_2001	Year	26	0.423	0.504	0	1
Co1	Company 1	26	0.154	0.368	0	1
Co2	Company 2	26	0.462	0.508	0	1
Co3	Company 3	26	0.115	0.326	0	1
Co4	Company 4	26	0.231	0.430	0	1
Co5	Company 5	26	0.038	0.196	0	1
directed	Directed Parts	26	0.385	0.496	0	1
complexity	Complexity Level	26	0.615	0.496	0	1
completed	Project completed	26	0.923	0.272	0	1
eng	Effort Measure	26	5416629	5545904	0	22400000
piece	Piece Part Price	26	484.01	393.35	84.56	2051
vol	Annual Volume	26	111448.1	82289.9	9900	338000
length	Contract Length	26	4.885	1.505	2	8
bid	Bid	26	65317192	99791424	4345379	412954976

Table 2. Summary Statistics.

		Directed	
		0	1
complexity	0	34688128	60942516
	1	69044272	35977356

Table 3. Distribution of Average Bid Price (completed projects).

ln_bid	I (OLS w/robust se)	II (OLS, outliers, robust se)
directed	1.048***	1.049***
	(0.291)	(0.297)
complexity	0.845**	0.854**
	(0.361)	(0.365)
directed*complexity	-1.264***	-1.226***
	(0.414)	(0.419)
ln_vol	0.786***	0.801***
	(0.139)	(0.137)
completed		-0.805*
		(0.341)
seat	0.740	0.722
	(0.427)	(0.423)
company 1	0.034	0.016
	(0.401)	(0.397)
company 2	0.749*	0.746*
	(0.368)	(0.367)
company 3	-0.487	-0.492
	(0.395)	(0.396)
company 4	0.813*	0.800*
	(0.474)	(0.464)
constant	6.827***	7.483***
	(1.583)	(1.736)
Adjusted R^2	0.888	0.915
# of observations	24	26

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

Table 4. Estimation results.

Appendix A: Seat Complexity Measures

This appendix provides a brief overview of the methods used to evaluate product complexity, defined as all interactions affecting the difficulty of coordinating changes during product development. We first compiled a list of the different feature combinations possible for seat, headliners, door panels and instrument panels using a search of supplier and buyer engineering documents, as well as through interviews with buyer and supplier engineers. From this list, we developed a list of "key" features most likely to affect system coordination. Experts from the participating companies were asked to review this list and to add or question any item. These reviews helped to limit potential bias by involving a large number of experts.

For each system in each contract, the configuration of the lead volume system was used to determine product complexity.[19] Using the development contract specifications, systems were scored points for complexity in each "key" feature. For example, as shown in Table 5 below, seats were evaluated on configuration, seat track type, memory, headrest type, lumbar option and heater control options.[20]

	Key Feature					
	seat configuration	seat track type	seat memory	head rest	lumbar	heater
Least complex	bucket	2 way manual	fixed	Manual 2,3,4 way	Cushion only	no
		2 way power	2 way power	2 way power	Cushion and back	
		4 way power	4 way power	4 way power	No of zones	
Most complex	All belts to seats	6 way power			Massaging/cycling Massage return to preset	yes

Table 5. Key Seat Features

[19] A program contract may include 10-15 seat variants, for example, ranging from entry level to fully loaded. Our goal in choosing the variant with highest expected volume was to capture the most frequently experienced product complexity in a development program.

[20] Interested readers may contact the authors for more on the questions asked and the measuring scale used.

Appendix B

Conditions for quality provision when there is no interaction of contract structure (M) or incumbency status (I) with quality q.

Provide $q(\theta, D)$ under interior complete when:

$$\delta^2 v > c(q(\theta, D), \theta, I=0, D, M=1) - c(\underline{q}, \theta, I=0, D, M=1) \qquad (1)$$

Provide $q(\theta, D)$ in both first and second periods of sequential with no second period competition ($p=1$) when:

$$(2^{nd}\text{ period})\ \delta v > c(q(\theta, D), \theta, I, D, M=0) - c(\underline{q}, \theta, I, D, M=0) \qquad (2)$$

and

$$(1^{st}\text{ period})\ \delta^2 v > c(q(\theta, D), \theta, I=0, D, M=0) - c(\underline{q}, \theta, I=0, D, M=0) - \delta[\bar{c} - c(q(\theta, D), \theta, I=1, D, M=0)] \qquad (3)$$

Provide $q(\theta, D)$ in both first and second periods of sequential with some second period competition ($p<1$) when:

(2) and

$$\delta^2 v > [c(q(\theta, D), \theta, I=0, D, M=0) - c(\underline{q}, \theta, I=0, D, M=0)]/p - \delta[\bar{c} - c(q(\theta, D), \theta, I=1, D, M=0) + \frac{1-p}{p}[\, c(q(\theta, D), \theta, I=0, D, M=0) - c(q(\theta, D), \theta, I=1, D, M=0)]\,] \qquad (4)$$