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PROJECT SCOPE AND PROJECT PERFORMANCE: THE EFFECT OF PARTS STRATEGY AND SUPPLIER INVOLVEMENT ON PRODUCT DEVELOPMENT*

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This paper examines the effect on product development of project scope: the extent to which a new product is based on unique parts developed in-house. Using data from a larger study of product development in the world auto industry, the paper presents evidence on the impact of scope on lead time and engineering productivity. Studies of the automotive supplier industry suggest that very different structures and relationships exist in Japan, the U.S., and Europe. Yet there has been little study of the impact of these differences on development performance. Further, little is known about the effects of different parts strategies (i.e. unique versus common or carryover parts) on development. The evidence presented here suggests that project scope differs significantly in the industry, even for comparable products. These differences in strategy, in turn, explain an important part of differences in performance. In particular, it appears that a distinctive approach to scope among Japanese firms—high levels of unique parts, intensive supplier involvement in engineering—accounts for a significant fraction of their advantage in lead time and cost.

(PROJECT MANAGEMENT; PRODUCT DEVELOPMENT; SUPPLIER MANAGEMENT)

1. Introduction

The introduction of new products has been an important activity in manufacturing businesses since at least the mid-19th century. But spurred by new technologies and the emergence of global markets in recent years, product development has become a focal point of international competition in many industries.[1] The importance of product development has motivated significant attention to the determinants of performance by both practitioners and academics.[2] A great deal of interest has centered around comparison of Japanese, U.S., and European firms. Yet most work in international comparisons has focused on a small number of cases, or "before/after" situations. Few of these examples involve analysis of data, and few achieve comparability between projects or products.[3] Moreover, the focus of discussion has been different approaches to project management, with less attention given to the strategy of the project.

This paper examines one aspect of project strategy, what I shall call project scope: the extent to which a new product is based on unique parts developed in-house. Using data and evidence from a larger study of product development in the world auto industry, I look at the impact of using off-the-shelf parts and of involving suppliers in development.[4] Studies of the automotive supplier industry suggest that very different structures and relationships exist in Japan, the U.S., and Europe. Yet there has been little study of the impact of these differences on development performance. Further, little is known about

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[1] Recent international surveys of executives have shown that product development is at the top of the competitive agenda in manufacturing industries. See Miller et al. (1984) and Sasser and Wheelwright (1986).

[2] In addition to articles in the popular press like Uttal (1987), there is a growing academic literature [see, for example, Imai et al. 1985; Cooper and Kleinschmidt 1986; and Maidique and Zirger 1984] on product development and even a journal devoted to the subject (*Journal of Product Innovation Management*).

[3] A good example of this is the paper by Imai et al. (1985). The authors describe four development projects in Japan and contrast them with general approaches in the U.S. They make no attempt to put the examples on comparable grounds, and provide no direct data for comparison with U.S. or European experience.

[4] For a description of the project see Clark et al. (1987).

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the effects of different parts strategies (i.e. unique versus common or carryover parts) on development. The evidence presented in §3 suggests that project scope differs significantly in the industry, even for comparable products. These differences in strategy, in turn, explain an important part of differences in performance.[5] In particular, I find that a distinctive approach to scope among Japanese firms accounts for a significant fraction of their advantage in lead time and cost.

The remainder of the paper is divided into four sections. I first lay out a framework for analyzing the impact of project scope on lead time and cost. I then present summary data on both performance and scope. The data include measures of supplier involvement, and the use of unique parts, as well as management practices in managing supplier relationships in the design and development process. §§4 and 5 of the paper contain the statistical evidence linking choices about scope to lead time and engineering manhours. The paper concludes with a brief discussion of implications for practice and further research.

2. Scope and Performance: A Framework

The development of a product like the automobile is a complex set of activities involving many people over long periods of time. The time and cost required to complete a development project (the two dimensions I examine here) depend on the number of activities, their duration, and the way that different activities interact.[6] These dimensions of a project are determined by the content of the product (features, performance, degree of innovation), and the scope of the project. Product content affects the number of parts to be developed, the extent of testing required, and the degree of difficulty in integrating the parts into a coherent whole. Project scope determines what part of the development effort will be done by the internal project team.[7]

Scope has two elements. The first is the choice of unique versus off-the-shelf parts. Using unique parts adds activities (and cost) to the project and may affect the time required to complete it. The second element is the choice of supplier involvement. Once unique parts have been selected, the firm may rely on a supplier for engineering work, thus reducing, to some extent, internal engineering efforts in the project. The extent to which project scope affects engineering hours and lead time depends on the capability of suppliers and the nature of the parts involved. I first examine scope and engineering manhours and then consider the impact on lead time.

Scope and Manhours

Decisions about scope have a direct impact on observed manhours in the project. If one uses off-the-shelf parts, for example, it is likely that the hours observed in the project (assuming no change in the content of the product) will be less than if one were to engineer a new part in-house. This conclusion has to be tempered with the realization that coordination costs may limit the savings from using old parts or farming work out.

Without direct measures of the engineering manhours in suppliers, or the manhours embodied in off-the-shelf parts, one must estimate the impact of scope using available

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[5] An exception is Helper (1987), which provides a theoretical and an historical analysis of the U.S. automotive supplier industry. Work on the supplier industry in Japan has provided descriptions of supplier involvement in development—see, for example the study by Mitsubishi Research, Inc. (1987)—but no evaluation of performance.

[6] How the interaction of activities affects performance depends on information processing capability. An information processing approach to modeling development has been developed in Clark and Fujimoto (1989a); Clark et al. (1987); and Fujimoto (1986). All of these models draw on work by Simon (1969).

[7] Project performance is also affected by the way the project is organized and managed. For further analysis of the managerial issues see Clark and Fujimoto (1989a) and Clark et al. (1987).

data on internal manhours, the use of off-the-shelf parts, and the involvement of suppliers. The measure of scope I use is the "new-in-house ratio" (NH)—the fraction of total engineering work (measured in manhours) done in-house by the project team. I estimate NH using the following expression (see the appendix for a derivation):

$$\mathrm{NH} = 1 - b[C + S(1 - C)], \tag{1}$$

where C is the fraction of parts that are off-the-shelf, S is the fraction of engineering effort for unique parts done by suppliers, and b is the fraction of total engineering effort that is parts specific. The expression for NH in equation (1) has a direct interpretation. It says that NH is equal to one minus the fraction of the total project effort that is specific to off-the-shelf parts ($b \cdot C$), and that is specific to unique parts but done by suppliers $[b \cdot S(1 - C)]$. Note that b is included to adjust for the fact that the measures of supplier involvement and off-the-shelf parts are parts specific, while NH refers to total engineering effort, including coordination.

Since NH may be defined as the ratio of observed project hours (H_p) to total engineering hours (H), I use the estimate of NH given by equation (1) to adjust observed manhours for differences in scope. In addition, I use statistical methods to estimate the impact of scope on observed hours.

Scope and Lead Time

Scope has a direct impact on manhours, but the impact on lead time is not straightforward. In order to make the connection between lead time and scope concrete, I use the simple network model of a development project shown in Figure 1.[8]

As diagrammed, the project has four classes of activities: design (D), parts engineering (E), prototype build (B), and testing (T). In this project, there are three parts, two of which are engineered in parallel (E1, E2). The diagram indicates the length of time required for each activity, and how activities connect with one another. Lead time depends on the length of activities, but is not simply the sum of activity durations. Lead time is determined by the critical path in the network.[9]

Figure 1 illustrates the potential impact of scope on lead time. For example, if the project were to use an old part for E3, overall lead time could be cut dramatically. However, using an old part for E2 would have no effect, because E2 is not on the critical path. Moreover, if the old E3 imposed constraints on the design that increased coordination time, or added to task time for E1, using the old part may not have the desired effect.

Supplier involvement may also reduce lead time if a supplier were more capable in executing E3, for example, or if supplier involvement would permit development of E3 to occur in parallel with the development of E1.[10] But simply "farming out" work will

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[8] The diagrams used here and the notion of a critical path are developed in detail in Wiest and Levy (1969).

[9] Using the common forward pass method, one can determine the shortest path through the network. The first step is to obtain all earliest start times (ES) and earliest finish times (EF) by passing from left to right in the network, where:

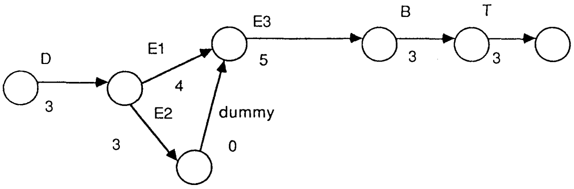
$$\mathrm{ES}(a) = \max\,[\mathrm{EF}(\text{all predecessors of } a)].$$

For activity w,

$$\mathrm{EF}(w) = \mathrm{ES}(w) + t(w),$$

where $t(w)$ is the time required to complete w. See Wiest and Levy (1969) for more detail on the common forward pass algorithm.

[10] The impact of suppliers on lead time has not been examined directly in the literature on supplier relations, vertical integration, or product development. The literature on transaction costs, however, has direct implications. It suggests that activities like part design and engineering that may involve unique assets and uncertainty about outcomes are likely to be done in-house. (See Monteverde and Teece 1982 for a study along these lines.) Since



Note: Numbers along the arrows are weeks.

FIGURE 1. Lead Time in a Representative Project.

not reduce lead time unless the parts are on the critical path, and unless suppliers bring additional capability to the project.[11] Further, additional coordination time may offset the gains from supplier involvement, if relationships with suppliers are difficult to manage. Thus, the effect of scope on lead time depends on supplier relationships, on supplier capability and the particular parts they develop in the product.

3. Scope in the World Auto Industry: Summary of the Basic Data

The analysis in this paper is based on data developed in a study of product development in the world auto industry. The unit of analysis is the project; the data cover 29 major new vehicle development projects in 20 companies. The companies in the sample (8 in Japan, 3 in the U.S., and 9 in Europe) accounted for about 75 percent of automobile production in the world in 1987. The sample includes products that range from micromini cars to large luxury sedans.[12]

Table 1 summarizes data on lead time, engineering manhours, product content, and project scope; variable definitions are presented in the footnote to the table. The data show sizeable differences in performance, product content, and project scope across regions. In terms of performance, the Japanese projects have a sizeable advantage in both manhours and lead time. On average, the unadjusted data show that the Japanese use one-third the manhours and complete a vehicle about 18 months faster than their competitors in Europe and the U.S.

Our primary interest in this paper is the impact of scope on project performance. Table 1 documents the significant differences in parts strategies and supplier involvement. In terms of supplier involvement, the U.S. firms do most engineering work in-house (rely on detail control parts with suppliers) while the Japanese firms emphasize black box designs. The Europeans fall between the Japanese and the Americans in both categories. However, the Japanese projects use a much *lower* fraction of common or carryover parts than either the American or European projects. On balance, the supplier effect dominates, leaving the Japanese projects with a *lower* project scope than either the U.S.

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the theory assumes that organization form (i.e. vertical integration) is based on efficiency considerations, the implication is that moving engineering of parts in a product development project outside the firm would lead to higher transaction costs and may increase lead time. But as Helper (1987) has shown, the transaction cost literature tends to downplay problems associated with internal administration of vertical relationships.

[11] For example, suppliers may allow the firm to avoid the "mythical man-month phenomenon." This occurs when adding an additional person to a project team lengthens the time to completion because of indivisibilities in tasks (10 people working for 1 hour may not be able to do the same work as two people working for five hours) and coordination costs. The phenomenon has been discussed by Brooks (1982).

[12] The data were developed through a variety of methods, including detailed interviews with project managers and other key informants; structured and unstructured interviews with personnel in marketing, engineering, manufacturing and purchasing; and a questionnaire that sought specific information on the details of the project. Repeat visits to the companies were used to review the questionnaire responses and resolve any questions and inconsistencies. For a more detailed description of the project and the methods used, see Clark et al. (1987).

TABLE 1

Summary Data on Performance and Content by Region

Variables	Total	Japan	U.S.	Europe
Number of Projects	29	12	6	11
Range of Introduction Dates[1]	1980–87	1981–85	1984–87	1980–87
Project Performance				
Engineering Hours[2] (Thousands)				
Average	2577	1155	3478	3636
Lead Time[3] (Months)				
Average	54.3	42.6	61.9	62.8
Product Content				
Price[4] (Thousands of 1987 U.S. dollars)				
Average	14032	9238	13193	19720
Body Size[5] (% in number of projects)				
Micro-mini	10%	25%	0%	0%
Small	56%	67%	17%	64%
Medium-Large	34%	8%	83%	36%
Number of Body Types[6] (Average)	2.1	2.3	1.7	2.2
Supplier Involvement in Engineering (Share of Procurement Costs)				
Supplier proprietary parts[7]	0.07	0.08	0.03	0.07
Black box parts[8]	0.44	0.62	0.16	0.39
Detail-controlled parts[9]	0.49	0.30	0.81	0.54
Use of Off-the-Shelf Parts				
Common parts ratio[10]	0.18	0.12	0.29	0.19
Carried-over parts ratio[11]	0.09	0.07	0.09	0.12
Scope (NH)[12]	0.61	0.57	0.66	0.62

[1] Calendar year when the first version of the model in question was introduced to the market.

[2] Engineering hours spent directly on the project in question by the engineers, technicians, and other employees at the car company. Suppliers' engineering hours are excluded, except when total vehicle development was subcontracted out under a consignment arrangement. Engineering overhead hours are excluded. The hours include time spent in concept generation, product planning, and product engineering, while process engineering is excluded. The figures include neither engine nor transmission development except modification required to match them with the total vehicle.

[3] Time elapsed between start of the development project and market introduction. Start of the project is defined as beginning of organizational activities for product concept generation.

[4] Average suggested retail price of major versions for each model. 1987 U.S. retail prices are used wherever possible. The prices of the models not sold in the U.S. were estimated by applying relative price to a global model to the global model's U.S. price.

[5] Micro-mini models are vehicles with 0.55 liter engines, sold in the Japanese market. Medium-large models typically have a wheelbase of around 105 inches or over. Small models, often called compact and sub-compact, are in between the above two. Other than the above criteria, industry practices in size segmentations were also applied.

[6] Number of body types which are significantly different from each other in terms of doors, side silhouette, and so on.

[7] Those parts which are developed entirely by parts suppliers as standard products.

[8] Those parts whose functional specification is done by assemblers, while detailed engineering is done by parts suppliers.

[9] Those parts which are developed entirely by assemblers from functional specification to detailed engineering.

[10] Fraction of parts which are common with other models in the company (defined by number of parts drawings).

[11] Fraction of parts which are carried over from the predecessor model (defined by number of parts drawings).

[12] Calculated according to equation (1).

or the Europeans. About two-thirds of the engineering work involved in the American products in the sample was unique to the project and done in-house. The balance was either done in suppliers or in other projects. The comparable figures for Japan and Europe are 57 and 61 percent, respectively.

The narrow gap in the scope measure reflects a positive relationship in the data between the extent of supplier involvement and the fraction of unique parts in the project. For example, five out of the six American projects pursued a "low-supplier/low-unique parts" strategy, while nine out of twelve Japanese projects adopted a "high-supplier/high-unique parts" strategy.[13]

The contrast between the Japanese and the Americans is intriguing. The American projects make only modest use of suppliers in design and engineering, but they rely relatively heavily on common parts. The engineers in the American projects thus spend more time making a larger set of common parts fit into a new design. To the extent that common and carryover parts pose constraints for product design and engineering, the greater use of unique parts in the Japanese projects suggests a possible advantage in product performance. This comes from the ability to more appropriately tailor a part to the specific requirements of a product. Thus, most of the Japanese firms use suppliers to sustain development of more uniquely designed products without substantially increasing their internal engineering workforce.

This interpretation is consistent with evidence in the literature on the supplier system in the Japanese auto industry.[14] While existing evidence on long-term relationships, the network of direct and indirect suppliers and extensive involvement of suppliers in operations in the Japanese auto industry primarily has come from studies on parts manufacturing, the information developed in this study suggests that differences in supplier manufacturing relationships also carry over into the design and development of the product. Although supplier management has been in transition in the U.S. companies, the projects in our sample were heavily influenced by the traditional system in which suppliers produced parts under short-term, arm's-length contracts and had little role in design and engineering. In the Japanese system, in contrast, suppliers are an integral part of the development process: they are involved early, assume significant responsibility, and communicate extensively and directly with product and process engineers.

In Europe, supplier involvement in development is closer to the Japanese than the U.S. model. Suppliers are involved earlier in the process, and, for sophisticated components, play a critical role in innovation. This pattern of involvement, and the existence of longer term relationships in Europe, is consistent with the fact that many of the major innovations in the European auto industry have come from suppliers—e.g. ABS, traction control, turbo-charging, to name a few.[15]

This brief summary suggests that the supplier systems in Europe and Japan may help to explain the degree of reliance on black box parts in the Japanese and European projects in the sample, and may play a role in explaining regional differences in development performance. But the issue is complex. There are important firm-to-firm differences in

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[13] These strategies were defined by dividing the sample using the mean values of the supplier participation ratio (S) and the unique parts ratio ($1 - C$).

[14] See Ikeda (1987b, c); Nishiguchi (1987); Lamming (1987); and Imai et al. (1985) for further examples on the Japanese supplier industry. Studies have shown that the Japanese auto companies deal directly with 200–300 "first-tier" suppliers who possess significant engineering and manufacturing capability. Direct suppliers take responsibility for a subsystem and work with a network of subcontractors and lower-tier suppliers in development and manufacturing. Some of the first-tier suppliers deal exclusively with one auto company and are part of the auto company's group. However, it is common for first-tier suppliers to deal with more than one auto company, even when the supplier's equity is partially owned by a competitor. See Nishiguchi (1987) for more detail.

[15] For more detail on the European supplier industry, see Shapiro (1985) and Lamming (1987).

scope *within* regions, and the regional distributions on the variables underlying scope (supplier involvement, off-the-shelf parts) overlap: some European firms rely more heavily on suppliers for engineering work than some Japanese firms, and they too manage that work through a collaborative relationship. The question is how such variations in scope affect engineering hours and lead time, taking into account regional and product content differences.

4. Scope and Engineering Manhours

I use two methods to assess the impact of decisions about scope on engineering manhours. The first relies on direct adjustment of the observed hours data based on estimates of project scope (NH); the second uses statistical analysis to identify how observed hours vary with changes in project scope. Direct adjustment is based on the definition of NH given in equation (1), with $b = 0.7$.[16] Table 2 presents data on observed hours in the project (H_p), estimates of the hours associated with off-the-shelf parts and suppliers (H_{sc}), and total vehicle hours (H), where

$$H = H_{sc} + H_p, \qquad \text{and} \tag{2}$$

$$H_{sc} = \left(\frac{1 - \mathrm{NH}}{\mathrm{NH}}\right) \cdot H_p. \tag{3}$$

Direct adjustment suggests that scope accounts for an important part of the differences in observed project hours. For example, the ratio of U.S. hours to Japanese hours falls from 3.0 to 2.36 while the Europe-Japan ratio falls from 3.15 to 2.81. However, the calculation is based on assumptions that may understate (or overstate) the impact of suppliers and the use of off-the-shelf parts. For example, direct adjustment takes place in the "equal productivity model": the estimates assume that work by suppliers and work on off-the shelf parts is done with the same level of productivity we observe in the project (indicated by H_p).[17] If suppliers are more (less) efficient than the auto companies, the calculation understates (overstates) the role of scope in explaining variations in observed engineering hours.

An alternative to direct adjustment is to use statistical analysis of variation in scope (NH) and in-house manhours to estimate how scope affects observed hours in practice. To do this, I use a simple model in which manhours in the project are a function of product content, project scope and regional characteristics. Thus,

$$H_p = f(P, \mathrm{NH}, R), \tag{4}$$

where P is a vector of product characteristics, R is a vector of regional dummy variables, and NH and H_p are defined as before.

Statistical results based on a linear specification of equation (4) are presented in Table 3. The regression in column 1, which excludes any measure of scope but includes variables measuring product content and a dummy variable for the Japanese projects, provides a base of comparison.[18] The content variables—MICRO, PRICE, BODY TYPE—have

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[16] Firms in the industry do not break down engineering hours into parts-related and nonparts-related. After discussions with engineering managers in Japan, the U.S. and Europe, it appeared that a value for b of 0.7 was a reasonable estimate of the industry average. Experiments with other values of b, and with different values of b for the different regions, showed little qualitative effect on the impact of NH on manhours or lead time.

[17] The estimates of H_{sc}, for example, can be interpreted in two ways. One can interpret H_{sc} as an estimate of the number of additional hours that would result if the common and carryover parts were newly designed and the supplier work were brought in-house. Or, one could interpret H_{sc} as an estimate of the number of hours embodied in the off-the-shelf parts actually used plus the hours expended by suppliers. Under either interpretation I assume that the firms do not systematically choose high or low engineering hour parts to farm out to suppliers, or to carryover from previous models. This assumption allows one to use mean values in the analysis.

[18] I include the dummy variable MICRO to reflect the notion that very small cars (in this case smaller than

TABLE 2

Direct Adjustment of Project Hours to Reflect Differences in Project Scope means and (std. deviations)

	Variable (000s)		
	Observed Project Hours (H_p)	Estimated Hours Associated with Scope (H_{sc})[a]	Estimated Total Hours (H)[b]
Total	2577 (1830)	1497 (913)	4074 (2480)
Japan	1155 (521)	914 (535)	2069 (1035)
U.S.	3478 (2256)	1414 (678)	4892 (2645)
Europe	3636 (1408)	2179 (891)	5815 (1856)

[a] Estimated using equation (3).

[b] Estimated using equation (2).

the expected sign (more complex vehicles require more hours), but they contribute little explanatory power to the regression. The Japan dummy picks up a significant fraction of the variance in the data and shows that little of the "Japan effect" is associated with product content differences.

Adding measures of project scope has a dramatic effect on the regression. Entered in linear form, NH has a strong impact on project hours, and explains a sizeable fraction of the variance in the data. It is also apparent that a substantively important part of the "Japan effect" is associated with project scope. When NH is in the regression the coefficient on the Japan dummy falls by about a third (−2280 to −1515). This difference is statistically significant at about the ten percent level on a one-tailed test, and its size suggests that scope is a more important element in explaining the efficiency of the development process in Japan than we estimated through direct adjustment of the manhours data.

The results in column 2 also suggest that there is an interaction between NH and the content of the product. The coefficients on body types and vehicle price increase sharply when NH is introduced into the regression. In order to explore that interaction more carefully, I have included two interaction terms in the regression in column 3. The results indicate a significant interaction between price and NH. The estimates imply that the impact of scope on manhours depends on the complexity of the product; the more complex the product, the more impact changes in scope have. The coefficient on the price interaction term, for example, implies that increasing NH from 0.57 to 0.62 (the equivalent of switching from the Japanese to the European average) would add 0.510 million hours to a $12,000 vehicle project, but 40 percent more (0.713 million hours) to an $18,000 project.

The results are intuitively appealing; given what is known about coordination costs, it seems reasonable that adding a given increment of engineering work to a complex project would have a greater impact on hours (through additional coordination costs)

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anything sold in the U.S. market) contain fewer parts and have lower levels of performance. The number of body types in a program (BODY TYPES) affects the overall work load, although the different bodies share a large fraction of the total parts. Finally, the price of the vehicle (PRICE) should capture the level of performance in the vehicle, the complexity and sophistication of components, and the amount of testing and attention to detail.

TABLE 3

Scope and Manhours: Statistical Results (std. errors are in parentheses)

Independent Variables[a]	Specification (1)	(2)	(3)	(4)
CONS	2899	−4875	3833	5244
	(1097)	(1953)	(4526)	(939)
PRICE	0.007	0.040	−0.365	0.020
	(0.036)	(0.028)	(0.203)	(0.030)
MICRO	−570	−359.1	−469.0	−218.4
	(1025)	(773.8)	(736.0)	(752.2)
BODY TYPES	247.2	677.4	−1271	514.4
	(286.9)	(234.7)	(1341)	(247.7)
JAPAN	−2280	−1515	−1565	−2512
	(647)	(517)	(490)	(789)
NH	—	9997	−4752	—
		(2275)	(7373)	
NH*PRICE	—	—	0.676	—
			(0.337)	
NH*BODY	—	—	3427	—
			(2387)	
C	—	—	—	−7259
				(1546)
$(1 - C)*S$	—	—	—	−3607
				(2585)
R^2	0.46	0.71	0.76	0.74
SEE	1510	1138	1053	1075
d.f.	23	22	21	22

[a] All variables are entered linearly. CONS is the constant term. For definitions of variables, see Table 1 and text.

than adding the same increment to a simpler project. The fact that the data capture this effect, and the size of the estimated impact, implies that decisions about scope may have a bigger impact on performance than one would estimate from simple accounting adjustments.

One can get some feel for the validity of this notion by comparing the effect of a change in NH under alternative assumptions. For example, evaluated at the sample mean, the equal productivity model implies that an increase in NH from 0.61 (the sample mean) to 0.71 would add 0.422 million internal engineering hours to the project (total hours would be unchanged). However, the parameter estimates in Table 3 (which relax the equal productivity assumption) imply that such a change in NH would add almost 1.0 million hours to the internal engineering effort. The implication is that engineering work outside the firm is more efficient, less difficult, or both.[19]

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[19] The large effect of NH may reflect a relationship between the degree of difficulty in the project and the use of unique parts. Suppose, for example, that projects that use a lot of common parts are intrinsically easier, perhaps because difficult problems are held constant. Then one would expect to find that switching from low to high NH would have a bigger effect on manhours than the shift in the unique parts ratio would imply. If

Evidence from interviews and further statistical analysis suggests that both differences in efficiency and degree of difficulty may be at work in the sample. To see the possible impact of the two effects, I decomposed NH into the common/carryover ratio (C), and the fraction of unique parts engineered by suppliers $[(1 - C)*S]$. The results are presented in column 4.[20] The results show that the common/carryover parts ratio has a strong impact on manhours, suggesting that a substantial fraction of the estimated effect of scope on manhours reflects intrinsic difficulty in projects with a high fraction of unique parts. This finding is consistent with interview evidence. Although small changes in the fraction of unique parts (e.g. from 70 to 75%) are not generally associated with big jumps in difficulty, there was a sentiment among some product planners and engineers in the industry that the relationship between the degree of difficulty and the fraction of unique parts is not proportional. Thus, for example, entirely or almost entirely new vehicles with a high fraction of unique parts (e.g. 90 to 100%) were viewed as more than twice as difficult as vehicles with half the unique parts ratio (e.g. 45 to 50%).

While the estimated impact of supplier involvement is not statistically different from what one would expect under the equal productivity model, the evidence suggests that supplier relationships are an important element in an efficient engineering system. One piece of evidence is the strong relationship between the supplier variable and the Japanese dummy. When one excludes the Japanese dummy from the regression in column 4, for example, the coefficient on the supplier variable increases by a factor of 2.7, while its standard error declines slightly (i.e. the coefficient is −9772 with a standard of 2025). Thus the supplier effect on manhours is closely related to the complex of organizational and managerial factors captured in the Japanese dummy. These include early involvement in design, strong communication links, and joint engineering problem solving. The implication is that it is not only the extent of supplier involvement (i.e. $[(1 - C)*S]$) that is important, but the quality of the relationship and the way that it is managed that matters.

These results confirm the importance of suppliers in the Japanese manhour advantage, but they also suggest that attempts to decompose development efficiency into an in-house piece and a supplier piece may miss the importance of the total development system linking assemblers and suppliers. If, as is the case in the Japanese auto industry, suppliers and assemblers have integrated their engineering activities, efficiency in one group depends on efficiency in the other. Further, it is the efficiency of the whole, not the parts, that matters, and the data suggest that the integrated system in Japan is highly efficient. Furthermore, it is an efficient system that employs a high fraction of unique parts, thus obtaining benefits in product performance as well. The ability of the Japanese firms to operate efficiently while using a larger fraction of unique parts is due in significant part to the capability of the supplier network.

The field interviews conducted in this study underscore the importance of the supplier network. Especially among the U.S. firms, but also in Europe, one finds a move in the last few years toward greater use of suppliers for engineering work, and a significant change in the nature of supplier relationships.[21] While this move may reflect several pressures on the auto companies, there was a consistent view among executives that involvement of suppliers in a "black-box" format, with closer relationships and more intensive involvement, was a more efficient way to design and develop parts.[22]

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suppliers are more efficient in engineering than assemblers, then increasing the share of internally engineered parts would yield a bigger than expected increase in manhours, even if the degree of difficulty were unchanged.

[20] Note that the scale factor b has been dropped from the variables measuring scope in column 4. Since b is constant across observations, dropping it has the effect of reducing the estimated coefficient and its standard error by a factor of 0.07. Thus, none of the qualitative results are affected.

[21] Evidence on this point is presented in Helper (1985), Shapiro (1985), and Lamming (1987).

[22] This sentiment was not limited to firms in Japan. Executives throughout the industry expressed a desire

5. Scope and Lead Time

The model developed in §2 suggests that the effect of scope on the time required to complete a project depends on two things: (1) the relative speed of suppliers, and (2) the impact of scope on the complexity of coordination in the project. The empirical work in this section is designed to establish the direction and magnitude of the scope-time relationship, and may shed some light on the relative importance of coordination costs and supplier capability. In this regard, it will be useful to take advantage of the fact that the various phases of a development program have different implications for the links between scope and lead time.

In the early stages of a program, for example, much of the work involves concept development and product planning. While some of the early exterior design work may be done by outside design firms, and while suppliers may have some involvement in planning, most of the early stage work is done in-house. Moreover, in relative terms, only a very small fraction of the parts engineering effort occurs in this stage of the project. Thus, any observed relationship between scope and planning time is likely to reflect coordination costs rather than the speed of the suppliers. Supplier capability may play a more important role in the engineering phase of the project where the bulk of the parts-related effort occurs.

Table 4 presents regression analysis of the impact of scope on lead time. The first set of results in column 1 highlights the lack of correlation between the variables measuring product content—price, body types, size—and overall lead time. This may occur because certain tasks are common to all projects, are on the critical path, and have relatively fixed length independent of overall content.[23] It may also indicate that some firms have the ability to pursue more complex activities in parallel, thus undercutting the connection between complexity and lead time. The results also suggest, however, that a modest part of the Japanese advantage in lead time comes from differences in product content; without the product content variables in the equation, the Japanese dummy has a coefficient of −18.6, with a standard error of 3.00.

Adding the NH variable in column 2 shows a strong positive impact of scope on lead time. To put the estimate in perspective, the coefficient on NH (43.3) implies that an increase in scope from the Japanese level of 0.57 to the U.S. level of 0.66 would increase lead time by 3.9 months, or about 21 percent of the gap between the Japanese and the U.S. projects. This impact appears to be quite similar among different kinds of cars. Entering an interaction term between price and NH has little impact. The interaction term is insignificant and other estimates are not affected. It appears that the effect of scope on lead time does not depend on the complexity of the product.

The estimates in columns 3 and 4 attempt to generate more insight into the sources of scope's impact by breaking NH into the common/carryover ratio (C) and the fraction of unique parts engineered by suppliers $[(1 - C)*S]$. These results present a picture quite similar to the one developed for engineering manhours. It appears that much of

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to move toward more supplier involvement. However, as noted above, the Japanese firms stand out in the extent of reliance on supplier involvement. In light of this difference, I examined the possibility of a different effect of scope in Japan on engineering manhours. Close inspection of the Japanese data revealed two distinct patterns of effect. Among small and medium cars, I found the expected effect: the more involvement of suppliers, the lower project manhours. The record for very small cars was mixed. Project hours varied somewhat within this small sample, but the range of variation in NH was quite limited. Thus, it appears that something other than NH was driving project hours in the very small car sample in Japan.

[23] A good example may be body panels. The time required to design and develop body panels and associated dies may not be very sensitive to size of vehicle or vehicle performance. In the projects examined here, for example, the variance of lead time for body dies is much smaller than the variance in product content. In the Japanese projects, for example, lead time for body dies ranges from 13 to 16 months; vehicle price ranges from $4,000 to $20,000.

TABLE 4

Scope and Lead Time: Basic Results

	Specification			
Variables[a]	(1)	(2)	(3)	(4)
CONS	61.14 (6.02)	27.44 (12.30)	69.82 (5.92)	71.28 (6.11)
PRICE[b]	0.13 (0.20)	0.27 (0.18)	0.10 (0.17)	0.19 (0.19)
BODY TYPES	−1.05 (1.58)	0.70 (1.48)	−0.81 (1.36)	0.03 (1.61)
MICRO	−3.44 (5.63)	−2.52 (4.87)	−1.68 (4.89)	−1.94 (4.90)
JAPAN	−16.52 (3.55)	−13.20 (3.26)	−21.05 (3.40)	−17.30 (5.14)
NH	—	43.33 (14.33)	—	—
C	—	—	−26.43 (8.66)	−31.41 (10.07)
$(1-C)*S$	—	—	—	−16.38 (16.84)
R^2	0.62	0.73	0.73	0.74
SEE	8.1	7.0	7.0	7.0
d.f.	24	23	23	22

[a] All variables are entered linearly. CONS is the constant term. For definitions of variables, see Table 1 and text.

[b] Coefficient and standard error have been multiplied by 10^3.

the effect of scope within regions is driven by choices about off-the-shelf parts. The supplier variable, on the other hand, appears to explain at least some part of the Japanese advantage. Compared to results with only C included (column 4), adding $(1-C)*S$ to the equation (column 5) cuts the Japanese dummy by almost four months. Adding the interaction between C and S in the NH variable (and constraining the variables to have the same coefficient) cuts another 3.5 months off the Japanese advantage (see column 2). These results are consistent with the notion that the Japanese firms derive real advantages from their supply base. However, the size of the standard errors, and the sensitivity of the results to functional form, suggest caution about the size of the impact.

Dividing overall lead time into a planning stage and an engineering stage provides additional insight into the effects of scope. Planning begins with concept study and ends with top management approval of the project; the post-approval stage begins with program approval, includes the bulk of the engineering work on the product and process, and ends with market introduction. Table 5 presents estimates of the impact of scope on the length of each of these stages.

The evidence shows that scope has dramatically different effects on planning and engineering. While scope has a strong positive effect on the length of the planning stage, its effect on post-approval time is small and not statistically significant. Furthermore, once scope is added to the planning regression, the Japanese advantage in planning disappears. The Japanese advantage in post-approval time, however, is unaffected by scope. Thus, it appears that one can decompose the overall Japanese advantage in lead time into two parts. The first, a planning effect, is determined by product content and

TABLE 5

The Effect of Scope on the Length of the Planning and Post Approval Stages
(std. errors in parentheses)

	Dependent Variables			
	Planning Stage Length		Post Approval Stage Length	
Independent Variables[a]	(a)	(b)	(a)	(b)
Controls[b]	yes	yes	yes	yes
JAPAN	−7.74 (3.59)	−3.45 (2.84)	−8.78 (2.21)	−9.76 (2.32)
NH	—	56.12 (12.48)	—	−12.79 (10.19)
R^2	0.20	0.57	0.63	0.66
SEE	8.20	6.11	5.04	4.99
d.f.	24	23	24	23

[a] All variables are entered linearly. For definitions of variables, see Table 1 and text.
[b] Control variables are PRICE, MICRO, and BODY TYPES.

project scope. The second, largely an engineering and implementation effect, appears to reflect differences in organization and management.[24]

These results suggest that the combination of a high fraction of unique parts and significant engineering work done in-house creates a complex planning process that requires more time to complete.[25] Indeed, since variables controlling the price of the vehicle, its size, and the number of body types have been included, it appears that doing the work in-house with more unique parts would increase complexity of the planning process even if the content of the product were unchanged. This conclusion holds even when one controls for the degree of product innovation and market uncertainty.[26] The implication is that who does the work, and how the content gets implemented (off-the-shelf versus unique parts), makes a difference in the length of the planning process.

As far as unique parts are concerned, the evidence on planning time is consistent with earlier findings on manhours. If greater use of unique parts means that the design problems are intrinsically harder and involve more people, it makes sense that the planning process would be more complex. In the first place, the implication is that there are more difficult issues that have to be resolved in planning. Secondly, those issues are likely to extend beyond engineering problems to include additional questions of manufacturing investment and perhaps product policy. Coupled with the fact that the number of people increases, the broader set of issues means that more organizations need to be involved (and involved more intensively) in the planning process. Both of these effects could lead to the need for more, and more intense, communication linkages and thus more time to complete planning.

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[24] For further analysis of the Japanese lead time advantage, see Clark and Fujimoto (1989b).

[25] Breaking NH into C and $(1 - C)*S$ in the planning regression produces significant negative coefficients for both variables. Thus, the scope effect in planning appears to involve both parts strategy and supplier involvement.

[26] Adding a variable measuring product innovation—the number of major systems in the product requiring a significant amount of advanced engineering—and adding engineering lead time to measure market uncertainty (the further from the market the more uncertain is customer response) leaves the estimated effect of scope in the planning regression unchanged.

It also appears that the planning process is affected by long-term supplier relationships. Where supplier reputations have been established and procedures worked out for establishing requirements and evaluating work, planning may proceed more quickly. Further, there is some evidence from the interviews that project managers and engineers found external suppliers easier to work with than their internal parts dividions. In several cases, managers suggested that working with the internal parts divisions gave the project less control over the engineering work and involved them in a more bureaucratic process than working with outside suppliers. The evidence on scope may thus reflect a planning and administrative structure within the auto companies that is slower and less efficient than the network established between the auto companies and their suppliers.

6. Implications

The evidence presented in this paper underscores the notion that decisions about the scope of a project have real effects on project performance. The effect of scope on manhours, for example, is not just an accounting adjustment. Bringing parts engineering in-house and adding work by doing more unique parts design adds more engineering hours than one would expect from the amount of the increased workload. The implication is that decisions about scope not only may change the mix of hours (e.g. the ratio of inside to outside hours), but the total engineering effort to develop the product. To the extent that engineering efficiency influences the number and quality of product development projects that a firm undertakes, decisions about scope have strategic significance.

These real effects on engineering hours are accompanied in this study by real effects on lead time. The estimates suggest that modest changes in scope (i.e. on the order of 10 percentage points) may change overall lead time by four to five months. All of that difference occurs in the planning stage of the project, suggesting that the impact of scope on lead time works through changes in the difficulty of coordination in the planning process. The implication is that by shifting the scope of the project (and making supporting changes in relationships) a firm will be able to develop a product with the same content four to five months faster. The firm may start the project later, gain additional knowledge about future customer demands and bring a better targeted product into the market at the same time as slower competitors. Alternatively, it may forego the added market intelligence and enter the market earlier.

A difference of 4–5 months in the timing of market introduction will have important strategic and financial implications in a market like automobiles where product introductions are associated with gains in market share. For example, in the case of a car that sells for $10,000, previous research indicates that each day of delay in market introduction costs an automobile firm over $1 million in lost profits.[27] Thus, without taking into account the impact of lost market share on costs or future sales, a four- to five-month lead time difference could be worth hundreds of millions of dollars on a single project.

Further evidence for the importance of scope in development performance is found in the advantage of the Japanese producers. The results underscore the role of the supply base in the Japanese auto industry's success. It appears that supplier involvement (and strong supplier relationships) accounts for about one-third of the manhours advantage, and contributes four to five months of the lead time advantage. Even these numbers understate the role of suppliers, since a strong network of suppliers allows many of the Japanese firms to use more unique parts in their designs, thus improving the performance of the product.

The impact of suppliers in Japan is rooted in far more than just a difference in the fraction of parts engineered by suppliers. There are important differences in supplier capability and in the relationship with suppliers that underlie these results. Not only is there a longer term to the relationship, but the quality of the relationship is more one of

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[27] This calculation is conservative, since it includes only the difference in the present value of profits, and does not add the impact of lost sales on costs or future market share. See Clark et al. (1987).

partnership, particularly when compared to traditional U.S. relationships where suppliers have played little role in engineering and where relationships have been defined by arms-length contracts. The evidence presented here and interviews in the Japanese firms suggest that much of the difference we observe has to do with the engineering capabilities in the supplier network, and the ability of the auto firms to both nurture and capitalize on that capability. In effect, the relationship allows the auto firm to benefit from the supplier's know-how and to capture it more effectively in the design of the product, and in the conduct of the development process.

But it is important to note that such benefits are based in a relationship of reciprocity. Not only do suppliers have valuable capability, but the auto firm manages the process so that capability plays an important role. Moreover, the auto firms cultivate capability in their suppliers. This involves investment, sharing of knowledge, providing space and facilities for "guest engineers," and helping suppliers to solve problems. On the supplier's side, there is a commitment to build capability and a willingness to assume a critical role in the development process. Further, among the better suppliers there is a focus on service that results in supplier engineers searching for ways to find and meet the needs of the customer's design and the development process. In effect, the better suppliers look for opportunities to create value for their customers. This is far different than simply meeting specified requirements with minimum effort.

There is a growing recognition in the auto industry (and in other industries as well) that a network of capable suppliers integrated into the engineering process has significant advantages. The implication is that the critical managerial problem in product development is not only securing effective collaboration within the firm, but in managing the supplier network to achieve integration of engineering effort. This recognition and the evidence that project scope—including the firm's parts strategy—has a significant influence on project performance raises a number of questions for practice and further research.

An important issue is the quality of the product. I have presented evidence on lead time and manhours, but there has been no analysis of the impact of scope on the quality of design. Preliminary analysis suggests that a high unique parts ratio is associated with higher design quality, but the possible trade-off between parts commonality and design quality and the role of suppliers merits much closer scrutiny. Likewise, the analysis here makes no distinctions among the different types of parts or systems done by suppliers. Does it matter for development performance (including design quality) what kinds of parts or systems suppliers do? More broadly, the results suggest the need to re-think traditional concepts of vertical integration. There is evidence in this data that integration of capability between upstream and downstream firms without financial ownership (i.e. an integrated supplier network) may be more effective in developing new technology and new products than an enterprise where the upstream firm is a wholly owned subsidiary of the downstream firm. At least in the development process, the implication is that the vertically integrated firm actually is less integrated than the network of independent suppliers. There is a need for more research on the nature of integration, particularly in the development process and its interaction with the nature of the financial and commercial relationships between firms.

Finally, the evidence here suggests the power of choices about scope, but much work remains to be done on the specific strategies for parts development and their connection to product development. Further, we need to know much more about the managerial practices and policies that are effective in creating an integrated network. Managing across firms in a network to achieve collaboration and superior performance in technical development thus seems an important issue for further research.[28]

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Appendix

To estimate the manhours affected by decisions on scope I use data on supplier involvement and the use of off-the-shelf parts, along with a simple model. To begin, I assume that the total hours required to engineer a product are given by: $H = H_i + H_o + H_s + H_c$ where H_i is parts engineering hours internal to the project, H_o is equivalent hours for off-the-shelf parts, H_s is supplier hours, and H_c is hours required for coordination. In this formulation, total project hours are given by $H_p = H_i + H_c$, while hours associated with scope are given by $H_{sc} = H_s + H_o$.

Since H_s and H_o are not observed, the challenge is to estimate H_{sc} on the basis of data on H_p and information about scope decisions. There are two ways to attack this problem. The first is to derive a direct adjustment factor, A, such that:

$$H = \frac{1}{A} \cdot H_p.$$

The second is to use statistical methods to estimate the impact of scope. Both methods measure scope using the "new-in-house-ratio" (NH)—that is, the fraction of total engineering work done in-house by the project team. Thus, NH is given by:

$$\text{NH} = \frac{H_i + H_c}{H}.$$

Estimating NH requires assumptions about off-the-shelf parts and supplier involvement. Let H_t be total parts-related hours. Then, with information on the off-the-shelf ratio ($C = H_o/H_t$), the extent of supplier involvement in the engineering of unique parts ($S = H_s/(H_s + H_i)$), and the fraction of total engineering effort that is parts specific ($b = H_t/H$), I can expand the definition of NH throughout substitution. To begin, I use the fact that $H = H_c + H_t$ to get:

$$\text{NH} = \frac{H_i + H_c}{H_t + H_c},$$

which can be written:

$$\text{NH} = b\left(\frac{H_i + H_c + H_s - H_s}{H_t}\right).$$

Given that $H_i + H_s = H_t(1 - C)$, we have

$$\text{NH} = b\left(\frac{1}{b} - \frac{C \cdot H_t + H_s}{H_t}\right) \quad \text{and} \quad \text{NH} = 1 - b\left(C + \frac{H_s}{H_t}\right).$$

Since (H_s/H_t) is just $S(1 - C)$, this becomes:

$$\text{NH} = 1 - b[C + S(1 - Cl)].^{29}$$

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[29] *Note.* A longer description of the adjustment procedure is available in the appendix to Clark et al. (1987).

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