Supplier Innovation Strategy: Transactional Hazards and Innovation in the Automotive Supply Chain

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Abstract:

Over the last few decades, innovation has doubled automobile performance at a time when outsourcing has increased. But outsourcing is subject to well-known contracting hazards that would also afflict outsourcing for innovation. In this paper, we examine how supplier firms generate innovation in the presence of such hazards, using a recent survey of the US automotive supply chain that contains new measures of innovative activity. Taking the supplier perspective on the traditionally buyer-framed make-or-buy problem pays surprising dividends. First, we identify three supplier innovation strategies—distinct combinations of various innovative activities. Next, we find evidence that each strategy represents a response to the transactional hazards associated with innovating in this environment. Finally, the coexistence of heterogeneous supplier strategies enhances our understanding of the buyer's make-or-buy problem, providing a more complex picture of the various approaches to transactional hazards that buyers employ simultaneously.

I. Introduction

The importance of innovation for firm performance is by now well understood. Whereas once, innovation strategy might have been regarded as a concern for a rather narrow set of high-tech industries, now firms from a wide swath of the economy find that technology is central to their regular strategic considerations. Yet amidst this burgeoning interest, measures of innovation remain limited primarily to R&D spending and patents, because those data are readily available. However, reliance on such measures restricts attention to publicly traded firms and those that generate patentable inventions, leaving out smaller firms and innovations that are not, or cannot be, patented. This innovative activity is thus largely invisible to the literature, what Martin calls "dark" innovation (2013), and its invisibility can have consequences for how we conceptualize innovation and innovation strategy.

This paper seeks to address the measurement gap through fieldwork and surveys of manufacturers in the U.S. automotive supply chain, which run the full gamut in terms of size. We thus contribute to a small literature addressing this measurement problem, including work by Acs and Audretsch (1988, 1990), who look at product introductions by small- to medium-sized firms, and European innovation surveys that inquire about a variety of innovation types (Hall and Jaffe, 2012). We observe innovation that involves know-how rather than formal engineering, and that reduce costs through energy savings or higher quality, at firms that consider "innovation" too highfalutin to describe what they do. Armed with qualitative data about innovation, we survey firms about product development, turnover, and "innovation broadly defined to include product or process improvements." A lack of correlation among these variables and R&D spending suggests that our survey captures distinct innovative activities that are not already measured in the literature—and that are notable because they involve innovations *in use*, rather than patented or announced.

Because the respondents are all automotive suppliers, we can explore strategy implications, especially make-or-buy questions. We begin by observing that our firms, as suppliers, innovate within the constraints of an outsourcing relationship with their automotive customer. A transaction cost logic is therefore a useful guide in analyzing the data. First, a cluster analysis identifies three clusters, each utilizing very different combinations of innovative activities. We then consider additional variables suggested by theory, such as the value of the part being produced, the asset specificity of investments, and whether multiple customers are served. Each cluster seems to exhibit behavior consistent with transaction cost predictions. For example, the "high R&D" cluster spends intensively on R&D and sells high value products to multiple customers, suggesting a strategy that avoids hold-up by generating technologically advanced products that are not customer-specific. By contrast, the "high design" cluster spends considerably less on R&D, instead investing in specific assets, and selling to a single customer, suggesting a relational commitment that mitigates hazards. Finally, the "high variety" cluster performs less innovative activity and specific asset investment, producing lower value products and somewhat avoiding investment altogether.

This transaction-cost-inspired analysis addresses a second understudied topic in the literature, that of outsourcing innovation. An extensive literature discusses transactional hazards associated with production outsourcing (Macher and Richman, 2008), and a separate literature examines the importance and capabilities involved with outsourcing innovation (Chesbrough, 2003; Gulati and Singh, 1998; Ahuja, 2000; Benson and Ziedonis). But relatively little attention has been paid to the transaction costs of innovation outsourcing. Studies set in innovative industries show that learning (Mayer and Argyeres, 2004) and intellectual property rights (Oxley, 1999) can mitigate hazards, but our setting illustrates interesting additional problems. The auto industry's extreme asymmetry in bargaining power, with few large buyers and many small suppliers, presents a problem for suppliers even for non-customer-specific innovation with strong intellectual property rights. One respondent had a patent infringed by a customer that threatened to take away future business if the supplier sued. This problem is of particular concern in settings where innovation by suppliers and producers of complements is important, and such diverse areas as platform industries and venture-backed start-ups (Katila et al, 2008).

Finally, we take a slightly different perspective on the make-or-buy problem, taking the supplier's perspective rather than the more typical buyer's perspective, and considering the entire supply chain rather than focusing on a single type of hazard. This seemingly minor shift pays some surprising dividends in our conceptualization of the outsourcing problem. The three clusters we find suggest that buyers use multiple strategies simultaneously, by itself not a particularly novel insight. But in the context of innovation strategy, the make-or-buy problem takes on an additional complexity as "buy" options multiply, so that in our study, which is but a first foray into this problem, buyers have three "buy" possibilities. We discuss the practical implications below.

The remainder of the paper is organized as follows. In the second section, we describe the literature on the measurement of innovative activity and on innovation outsourcing. In Section 3 we describe our survey and fieldwork. Section 4 provides descriptive data and Section 5 presents the cluster analysis and regression analysis. Section 6 discusses implications and concludes.

II. Measurement of innovation and its relationship to theory

There are two main streams of literature that our study brings together. First, a literature on measuring innovation has largely been driven by tests of the Schumpeterian hypothesis that large firms are more innovative than small firms (or the reverse). The literature discusses the many problems of measurement have have surfaced in trying to test this hypothesis. Second, a separate literature examines innovation outsourcing.

Over the past three decades, the auto industry has seen two stark trends: de-integration and innovation. From 1980 to 2004, average horsepower nearly doubled (Knittel, 2012) at a time when supplier firms increasingly took on the production of automobile components. While 30 years ago, American automakers made most of their components in-house, now 70% are made by suppliers. Moreover, 70% of suppliers now contribute design effort compared with 48% in 1989.[1] Thus, innovation and outsourcing are important, linked phenomena that can be studied in the automotive setting.

[1] For methods behind these calculations, see http://drivingworkforcechange.org/reports/supplychain.pdf. Von Corswant and Fredriksson (2002) also document trends in outsourcing of innovation and increased speed of innovation throughout the 1990s. This is not to imply that automakers are not also innovating; Lee and Veloso (2008) show that both automakers and suppliers increase component-level innovation, especially throughout the 1980s and 1990s, but suppliers do more.

A. Measuring Innovation

An empirical literature is motivated by theories about how to generate innovation. Cohen (2010) provides a recent review of this theoretical and empirical literature, starting with Schumpeter (1942) who posits that larger, monopolistic firms innovate more than smaller, competing firms. The empirical literature testing this theory employs measures of firm size and R&D spending (Cohen and Klepper, 1996) and shows spending rising with firm size but no clear economies accruing to larger firms and significant differences across industries (Cohen, Levin, and Mowery, 1987). This might be because R&D spending is an input to the innovation process rather than a measure of innovation itself, and may even be uncorrelated with innovation. Korn (2011) cites a Booz & Company study that finds that "few of the biggest R&D spenders crack the top 10 in terms of being considered 'innovative' by their peers." Indeed, as we discuss below, our survey results show that R&D intensity is but one measure, and is not highly correlated with our other measures.

Instead of using R&D spending as a measure of innovation, other studies have used patents as a measure of innovative output. Henderson and Cockburn (1996) and Cockburn and Henderson (2001) look at patents by pharmaceutical firms to try to discern economies of scale or scope in generating innovation. Their studies find firm effects but, again, no Schumpeterian economies. One explanation might be that the effectiveness of patent protection varies by industry and type of innovation (Gans, Hsu and Stern 2002), but also that higher patent counts do not imply more invention, particularly when comparing across industries (Cohen, 2010; Boldrin et al, 2011). Indeed, a survey of publicly traded firms conducted by Levin, et al. (1987) suggests that firms rely more on rapid innovation and other appropriability strategies than on patenting.

Thus, publicly available data on R&D spending and patenting have several demonstrated limitations. First, the data represent only large, publicly-traded firms, and may therefore be inappropriate for testing the Schumpeterian hypothesis, since differences in firm size are arguably minor. Second, both measures might be considered measures of inputs to the innovation process rather than outputs. And finally, the measures are but components of broader innovation strategies (Levin et al, 1987). Our interviews at smaller firms illustrate some of these points. Not only did a small minority of firms—just 40 out of a total 1400 respondents—hold any patents, but many firms did not measure R&D spending explicitly and employees performing R&D often had other responsibilities, including management or sales.

Exceptions to the large-firm, publicly-available data problem exist. McDermott and Corredoira (2010) is the most similar to our study in the sense that it also examines an automotive supply chain, in Argentina, which is made up primarily of SMEs. They find that firms with more linkages to outside institutions generate greater process upgrading. Cohen and Malerba (2001) take an interest, similar to ours, in different innovative activities. Mining the Yale survey, they use a set of 11 activities, which span process innovations, material improvements, miniaturization, and design, and find that firms that pursue a variety of activities have the best technological change. Bartel et. al. (2007) is another survey-based study, of the valve industry, identifies how information technology could improve productivity, the subject of Bailey et, al's (2012) case study. European studies make use of more extensive innovation surveys (Hall and Jaffee, 2012) in such countries as Finland (Leiponen, 2005), Denmark (Leiponen and Drejer, 2007), and Holland (Van Dijk et al, 1997). And finally, hand-collected data of SMEs by Acs and Audretsch (1988, 1990) look at product announcements to measure innovation by smaller firms, while Pavitt et al (1987) compile British data on “significant” new products or processes, many of which are produced by small firms.**But none of these studies look at the issues firms have when they supply a relatively small number of customers with monopsony power (eg, B to B instead of B to C).**

B. Outsourcing Innovation

While the Schumpeterian literature focuses on how firms generate innovation, a separate literature has examined the importance of accessing outside ideas from diverse sources. Much of this literature focuses on horizontal, intra-industry alliances (Eisenhardt and Schoonhoven, 1996; Rothaermel, 2001; Sampson 2007; Stuart 2000; Walker, Kogut, and Shan, 1997) or a variety of outside sources including firms and universities (Chesbrough, 2003). However, suppliers are also studied as an important source of innovation and ideas in a variety of industrial settings (Azadegan et al, 2008, Dyer and Singh, 1998; Rothaermel et al, 2006; Wagner 2012). Indeed, Harhoff et al (2014) find that only supplier collaborations generate productivity gains, and not collaborations with customers or competitors.

In addition to informational benefits, firms can also gain engineering-oriented advantages through outsourcing. By collaborating with suppliers, firms can improve quality and product development time. Clark (1989) found that Japanese automakers engaged suppliers more than U.S. automakers and produced better products more quickly. Cusumano and Takeishi (1991) show that Japanese methods worked in the US as well. However, the technology environment can affect the value of involving suppliers in product development. Kapoor and Adner (2012) find that vertically integration is associated with shorter product development cycles when faced with architectural innovation (which affects how components fit together) in the dynamic random access memory industry. Similarly, Bozdogan et al (1998) find that aerospace firms doing architectural innovation involve their suppliers earlier than when they do component innovation. . An outsourcing failure illustrates the problem as well. MacDuffie (2013) describes attempts by automakers to modularize subsystems in order to outsource design and manufacture but found problems related to the complexity of interaction among modules. The paper does not use the notion of architecture, but the fitting together of modules proved difficult. Finally, Novak and Stern (2008) suggest that vertical integration is better for quality in the long-run.

Indeed, of the many difficulties firms encounter in accessing outside resources, certain contracting hazards have been especially well studied: a) hold-up, which hinders customer-specific investment and b) free-rider problems, which hinder general investment. Hold-up is of particular concern when a supplier makes a customer-specific investment. The customer can refuse to pay or meet his contractual obligations, knowing that the supplier has weak alternative uses for the investment (Williamson, 1985; Klein et al, 1978). Ulset (1996) shows that technological novelty and uncertainty affect the decision to outsource and, conditional on outsourcing, management oversight and intellectual property rights, which address hold-up and free-riding, respectively.

Ahmadjian and Oxley (2011) find evidence of hostage mechanisms at work in Japanese auto manufacturing, while other work shows that good buyer-supplier relationships, or a more relational style of contracting, are important for successful outsourcing (Mudambi and Helper, 1998; Dyer and Chu, 2000; MacDuffie and Helper, 2006).

While the hold-up problem has been studied extensively as a barrier to the outsourcing of production, its role in innovation has received less attention. Williamson (1975) discusses innovation outsourcing but focuses on moral hazard on the supplier side and ex ante oligopsony on the buyer side as obstacles, rather than hold-up. And studies of hold-up in innovative settings, such as software development (Kalnins and Mayer, 2004), focus on production rather than innovation. Helper (1991) comes closest to our study by examining the effects of outsourcing on innovation, arguing that before the rise of foreign competition, US automakers' desire to maintain market power led them to adopt purchasing and operations practices that reduced most suppliers' ability to appropriate a return on investment in innovation.

An extensive empirical literature suggests at least one important avenue for managing innovation outsourcing in the presence of hold-up. Consistent with Helper (1991), much of this literature focuses on the importance of collaborative supplier relations (Ragatz et al, 2002; Bozdogan et al, 1998; Croom, 2001; Bonacorsi and Lipparini, 1994) and inter-firm communications (Hoegl and Wagner, 2005; Macduffie, 2013). Specific aspects of the relationship have also been explored, including length of the relationship (Stump et al, 2002), benchmarking and monitoring (Helper, MacDuffie, and Sabel 2000), and "lean" manufacturing techniques. (e.g. Cole, 1998; Helper and Kiehl, 2004; MacDuffie and Helper, 1997; Womack et al, 1990). Taken together, these studies suggest that buyer investment in its supplier relationship can mitigate contracting hazards. However, the incentive to do this is affected by other factors including regulation and competition (Helper and Levine, 1992).

A second obstacle to outsourcing innovation is the free-rider problem, which makes it difficult for a firm to appropriate returns from investment in innovation (or other generally applicable investment, such training. While this is a general problem (e.g. Argyres and Zenger, 2012; Barney, 1986; Demsetz, 1988; 2012; Teece, 1988; Wernerfeldt, 1984;), in the automotive context, automakers have concerns about knowledge spillovers. If a supplier works on a project with one automaker, it can apply what it has learned to another, competing, automaker. This spillover through shared suppliers could make automakers reluctant to outsource innovation (MacDuffie and Helper find that investments by Honda in teaching suppliers “continuous improvement” methods did spillover to their other customers).

Empirical research shows how related these two problems are. Hold-up is a hazard that arises with asset specificity, but relationship-specific investment can mitigate spillovers somewhat. Takeishi (2001) finds that despite shared suppliers, outcomes vary among Japanese automakers in Japan. One mechanism might be relationship-specific investment, i.e., asset specificity. Dyer and Hatch (2006) find very little spillover effects when Toyota transferred knowledge to improve a supplier’s processes. They attribute this outcome to customer-specific investments in processes that are not readily transferable to other customers. And Veloso and Fixson (2001) show that automakers outsource when a supplier’s product becomes less customer-specific; as antilock brake systems and airbags became more standardized across all vehicles, automakers increasingly outsourced these.

III. Data

Our data was collected in three phases. (1) First, we conducted dozens of detailed interviews at all levels of the supply chain throughout July and August of 2010 in the Midwest, the traditional center of the auto industry, and the Southeast, an up and coming center of auto manufacturing. The interviews and plant visits were instrumental in conceptualizing innovation in manufacturing firms. They informed our survey design by helping us understand what issues were important to suppliers, identify barriers to gathering information about innovation, and suggest ways to ask about innovation. (2) Second, after the pre-survey interviews, we conducted a nationwide survey with responses from hundreds of supplier firms. (3) Third, about 30 post-survey interviews followed the collection of survey data. Our interviewees were mostly company presidents and sales managers, and most interviews included a comprehensive tour of production facilities.

We also consulted existing innovation surveys, including the Oslo Manual (OECD, 2010), Berkeley Patent Survey (2008), Survey of Innovation and Business Strategy (Statistics Canada, 2009) and the Frascati Manual (OECD, 2002). The resulting variables are consistent with Hall and Jaffe's (2012) analysis of information that would be valuable for measuring innovation, including the use of new or improved goods, services and production methods. We improve upon similar questions in European surveys by going beyond yes or no responses, to measure the economic value of cost reductions, and by inquiring about process innovation and design input. Also, our measures of innovation pertain to goods actually being produced and sold, unlike existing measures in the literature, such as patents or product announcements whose value is difficult to estimate.

To reach as many auto suppliers as possible, we combined 11 different data sources and conducted Internet-based research to identify likely automotive suppliers. After manual and automated de-duplicating procedures, the remaining firms were phoned by a survey-consulting firm and asked if they currently supply the auto industry (over half said, no). Appendix 1 describes our process for determining which firms might be auto suppliers. The remaining firms were sent our survey.

Below, we describe insights from interviews about the types of innovative activity being performed in mostly small- to medium-sized firms. We then discuss some of the variables from the survey and how we worded innovation questions.

A. Survey findings

What does innovation look like in the SMEs of the auto supply chain?[2] On our many plant tours, we observed a wide variety of activities that (1) reduced cost, (2) improved quality, and (3) created new processes that enabled the production of goods that are new-to-the-world. However, many of our interview subjects did not consider their activities to be sophisticated enough to be called "innovation". However, our observations are highly supportive of Hall and Jaffe's (2012) idea of measuring non-R&D investments, as we see firms investing in machinery, training and performing design work.

A variety of tactics allowed firms to innovate. Lower-tier suppliers especially

[2] We also visit large, technologically advanced tier one suppliers that develop next-generation products proactively. We do not describe these firms here because they resemble other publicly traded firms, about which much more is known descriptively and statistically from readily available data.

focused on innovations that were cheap, quick, and un-codified. This form of innovation had two benefits: being cheap, it did not require raising large capital or maintaining high overhead – difficult to do in the purchasing environment these small suppliers faced, and being uncodified, it was harder to copy by competitors.

1. Cost Reduction

One supplier, a metal stamping firm, purchased a used press capable of stamping inch-thick material, much thicker than the sheet metal that their current machinery was capable of punching through. This press allowed the firm to to produce a part that had previously been produced by casting, a much more costly and energy-intensive process that involves pouring molten metal into a mold. Another, similar, case involved expanding the firm's capability to include welding. The supplier then welded together two stamped parts to supplant a cast part that had been imported from a low-wage country, saving money and energy in production and transportation, as well as lead-time.

2. Quality Improvement

Quality improvements also create value for customers. For example, at a wire company, engineers created a new machine out of parts from two disused machines. The new machine was used to produce an item that had been produced by a Chinese competitor but at higher quality and faster delivery than the Chinese competitor. Thus, the supplier firm was able to compete with production at lower-cost overseas firms.

3. New Manufacturing Capabilities

Not all innovative efforts were directed at improving the production of existing parts. Some process refinements enabled the production of new goods. A metalworking firm adapted its generations of experience with metal tooling to stamp very thin material including plastic. This enabled the firm to serve an East Coast customer producing electric generators, a customer outside the firm's immediate geographical region and auto industry.

4. New Products

Even scientific firms utilized low-tech ingenuity to create new products. One rubber industry firm generated patents for chemical additives and had been hiring chemists with doctoral degrees from the local university. Yet by observing its customers, managers noticed that pre-mixing its chemicals would make it easier for customers to produce more consistent results. The result was a "cake mix" product line, easy-to-use, pre-mixed packages of chemicals, which were more profitable than selling in bulk.

5. Innovation that did not occur

Our interviews also revealed instances when transaction hazards were not mitigated. For example:

1) Even when innovations could be patented, a powerful customer could demand a

second source or threaten to deny business to a supplier that defended its patent. This situation was illustrated vividly during a visit to an engine component company. The firm had patented a part that was key to its customer's ability to meet environmental regulations. However, after a few years the customer helped another supplier reverse engineer the technology. Our interviewee, the inventor and company owner, considered suing, but realized he would likely never win business from the automaker again if he did so. Thus, upstream market power can reduce the value of even strong claims to intellectual property.

2) Another firm was unable finance a $250 k piece of equipment that would have let them enter a new, green market. The customer wanted exclusive access to the equipment, but wouldn't guarantee enough demand to make it pay off.
3) A sole proprietor tried to develop a metal spraying technology initially developed at a national lab. Working on his own with a part time assistant, he eventually succeeded in creating his own molds and spray nozzles for molten metal, but his primary market was manufacturing horseshoes. He was unable to find automotive customers for his technology before going bankrupt.

The incremental innovations that reduce cost and create value for customers constitute a phenomenon of economic importance, when aggregated across thousands of firms that make up an industry as vast as the auto industry. However, because each incremental innovation might seem unimportant, even to the innovator, measuring and valuing this activity can be difficult. Our measures of innovation try to capture more of this activity, in a setting where many firms do not use refer to their on-going efforts to reduce cost and remain competitive as “innovation”. Also, because some of these firms are small, there is no formal accounting of R&D, or even clear delineation of responsibilities between engineers and technicians, so that counting the number of engineers or scientists might underestimate the capacity for innovation.

B. Survey Questions

To get high quality responses, we divided our questionnaire into three separate surveys to be filled out by Plant Manager, Human Resources Manager and Sales Manager. The plant manager survey asks about the allocation of tasks across skilled and unskilled workers, the share of component design performed by the firm, and other operational questions. Human resources managers were asked some overlapping questions with the plant manager about worker relationships with management, but also more detailed questions about the number of workers and their skill levels. Finally, sales managers were asked about their relationship with their customer, as well as questions about how recently products were introduced at the plant, R&D spending, and product development.

Of the approximately 3800 firms that were determined to be automotive suppliers, about 1400, or 37%, sent back some response. Unfortunately, many respondents returned incomplete questionnaires, and most firms did not return multiple surveys. For example, only 98 returned all three surveys. This paper uses responses from the Sales Survey, which received over 500 responses, however, surveys containing responses to questions of interest reduce the N to about 400. Appendix 2 contains a brief table of contents for each survey and the response rates for each.

1. Innovation Variables

We report R&D spending and three additional measures. This allows us to compare our measures with an existing literature that measures only R&D spending. The measures, described below, include new products, product development, and whether their products contain "innovation", broadly defined. The exact wording of the questions is reproduced in Appendix 3.

R&D Intensity. The most common measure of firm innovativeness in the literature is R&D spending or intensity. We ask respondents to tell us their R&D spending as a percentage of sales (i.e., R&D intensity), and give seven ranges of values to choose from, from 0% to more than 5%. There are several points of reference to gauge whether R&D spending is considered "high". Cohen and Klepper (1996) set their threshold for "innovative" firms at an R&D intensity of 1.5%. Cohen, et al (1987) analyze a sample of large R&D intensive firms report a mean of about 2.3% and a range of 0% to 22%. The National Science Foundation Survey (2008) finds a national average of 3% and a national manufacturing average of 4.3%. Our respondents might be expected to underreport R&D spending (since they often do not have full-time staff devoted to this activity), but only 18% claim to spend nothing on R&D, and over 10% spend more than 5% of sales. Still, almost two-thirds spend less than the national average and 80% spend less than the 4.3% manufacturing average.

New Products. Measuring new product introductions can be an interesting indication of dynamism and change, even for a set of firms that sells products specified by their customer, because turning over products frequently requires flexibility and nimbleness. For example, in Bartel et al (2007), investments in information technology greatly improved the flexibility that valve manufacturers had in changing over production lines. While the introduction of new products designed by clever engineers is clearly a useful form of innovation, we do not mean to imply that slow product turnover implies a lack of inventiveness. Rather, the frequent change in product line may be a distinct innovation strategy. We asked, "What percentage of your sales come from products which you did not make 4 years ago?" Seven categories range from 0% to 100%. About a third of respondents introduced a new product at least every year.

Design. In a manufacturing supply industry, engineers often take completed designs from their customers and produce them exactly as specified. Other suppliers design products themselves. Our survey asks, "In the past year, roughly what percent of your plant's sales were from jobs where your firm designed the part or assembly?" A third of respondents fit the traditional model of supplier firm, producing only products designed by their customers. But about 15% produce parts that they design themselves. The rest, a majority of firms, fall somewhere in between these two extremes.

Innovation. Our broadest innovation question asks, "What percentage of your sales come from products where you innovated in some way? By 'innovated', we mean that your business unit designed a product with improved features compared to what the market had seen before, or that you used a novel process to make the product." This is a somewhat catch-all question, but it is meant to encourage respondents to consider process innovations as well as product innovations when assessing their innovative contribution. Even with our liberal definition of innovation, almost 42% of respondents report contributing little or no innovation to the products they make. At the other end of the spectrum, about 15% contributed some innovation to half their products or more.

2. Non-innovation Variables

We are fortunate to have good response rates on some important non-innovation variables that help to characterize the clusters and make sense of the combinations of innovation activities that constitute the innovation strategies. These variables, most of which are suggested by transaction cost theory, are described below; the exact wording of the survey questions is included in Appendix 3.

Piece price. Prices for supplier components ranged from sub-dollar to over $100. In theory, exposure to hazards increases with the cost of the part, so piece prices are an interesting variable to consider when evaluating hazard responses.

Tier 1. This dummy variable is coded as 1 if the supplier sells directly to an automaker. About 30% of respondents reported being Tier 1; the rest of the firms responding to this question supply Tier 1 suppliers or lower-tier suppliers.

Share of sales in autos. Suppliers vary in how dedicated they are to the auto industry. Indeed some firms primarily supply other industries, leaving automakers relatively little bargaining power, while other suppliers are completely dedicated to the auto industry.

Cost reduction. Suppliers are often asked to reduce costs, sometimes according to a schedule specified by their customers. However, actually achieving cost reductions can be difficult, so that price reductions constitute a reduction in the supplier's margin, rather than lower cost. We ask suppliers to report actual cost reductions to learn what kinds of firms are relatively better at achieving lower costs.

Multiple customers. We ask who the firm's customer is. Many firms list several specific customers while others report selling to "many" or "multiple" or sometimes "all" automakers. All firms that report more than one customer are coded as "1" for "multiple customers."

Asset specificity. This variable, suggested by transaction cost theory, measures the share of investment that a supplier cannot re-deploy for another customer. We ask this question explicitly and in keeping with the theoretical formulation of the concept. Proxies for this variable abound in the literature, thus our direct measurement of asset specificity is a methodological contribution along with the innovation variables we introduce.

IV. Descriptive Statistics

Our efforts to reach automotive supply chain firms yield respondents from almost every state in the country and firms of all sizes. We briefly describe this variation, and then present responses to innovation questions.

A. Firm-Level Descriptive Statistics

The geographical distribution of respondent firms and likely auto suppliers (candidate firms on our list but who did not respond to the survey) are similar. However, we cannot say for certain that our respondents are representative, nor whether our subsample, sales survey respondents, is representative of the supply chain as a whole. We do know that the greatest concentration of auto supply chain firms is in Michigan, Ohio and Indiana, and that nearly two-thirds of our respondents are from this tri-state region.

Most firms that answer firm-size questions are small. About 40% had 50 or fewer workers, and only 6% had more than 500, the Small Business Association's definition of “small” firm. Small firms accounted for a significant amount of employment, as well. Approximately 2/3 of the workers in our survey were employed by the largest 20% of firms. Only about 30% of firms that identify their tier are Tier 1firms, although not every respondent answered each question. About 40% of respondents were single-plant firms, and only 7.8% of respondents are unionized. Value-added per employee was high for small firms. Firms for which we had value-added and size data had a value-added per employee of $123 000 on average for small firms (N=205) compared with $58,000 for firms with more than 500 employees (N=7).

The average age of respondent firms was 32 years, with almost 60% of firms more than 25 years old. . Several firms we visited had very little debt, owned their land and (often decades-old) equipment outright, and slowed down operations during the recession through employee furloughs until business picked up again. One firm took the opportunity to purchase used equipment inexpensively from plants that were downsizing or closing. Ironically, sources of this equipment were often highly innovative firms. They had invested in expensive, innovative new equipment in the few years before found themselves unable to repay their loans when auto sales fell 40% in 2009, and thus were forced to close their doors.

B. Innovation Statistics

The firm-level statistics suggest wide variation among firms in the auto supply chain, from small to large, young to old, specialized to diversified. In this section, we consider firms' innovative activity as measured by our four variables. First, we ask whether the variables do indeed capture heterogeneous innovative activity.

To get a sense for whether our new innovation measures are capturing something that R&D spending does not, we present a correlation matrix of all four measures and find that some are more correlated than others (Table 1). For example, firms whose products incorporate innovation are correlated with firms investing in R&D with a correlation coefficient of 0.33. To a lesser degree, firms incorporating innovation in their products also produce more new products, with a coefficient of 0.21. Firms that perform more product development have higher R&D spending (0.32) and incorporate innovation in their products (0.20).

On the other hand, some of these correlation coefficients might seem lower than expected. For example, we might have expected firms that produce new products to also incorporate innovation in more of their products. A possible explanation is that in this industry, managers do not think that producing goods that are new to the firm, i.e., products that the firm did not make four years ago, necessarily implies innovation. We visited a firm that receives rods from an automaker; their task is to machine both ends and drill a hole. No design effort by the supplier is required, and no process innovation is involved. But specialized test equipment was specified by the automaker and is provided by the supplier. This supplier gets one-year contracts, sometimes getting renewed and sometimes not. Also, during the downturn, when activity declined at the factory, the manager took the opportunity to move machinery around into reconfigured production lines and to re-paint the floor. The ability to respond to customer requests quickly and efficiently might not involve innovative activity, but would represent a certain dynamism.

Figure 1 plots the distribution of firms for each of our four variables, with the x-axis increasing in innovative activity. For example, for R&D spending, an x-axis value of 1 corresponds to "0% R&D spending" while a value of 7 corresponds to "more than 5%", the highest of the seven response categories for the R&D spending question. We see from Figure 1 that firms do not fall neatly into a normal distribution. In the case of "products contain innovation" and "new products", there is a pyramid structure with many firms doing very little innovation and a few firms doing a lot. For the other variables, we see a peak at the low to moderate level of innovation, and a second, smaller peak at higher levels of innovation.

This double peaked character may explain the low correlation coefficients, and suggests real heterogeneity in innovative activity. Also, the variation in the shapes of the distributions suggests that by measuring these new variables, we are doing more than taking a firm's innovation “temperature” with multiple thermometers and instead measuring different types of innovation. This is consistent with McDermott and Cordeira's (2010) finding that different firms pursued different types of “upgrading” or innovation strategy.

V. Cluster Analysis, Regression Analysis

Because of the heterogeneity of the innovation variables described in the previous section, we performed cluster analyses on the four variables to see how they might interact. The best fit with a k-means analysis generated three clusters. Table 2 shows the means of each cluster and the ANOVA p-values. Figure 2 graphs these means to show how each cluster presents a unique innovation “profile” or strategy. We label these “high R&D”, “high design,” and “high variety,” to characterize each cluster according to its relative strength or emphasis. These profiles demonstrate why our innovation variables have such small correlation coefficients and that they measure distinct innovation activities. For example, “high variety” firms produce components that are new to the firm without doing much R&D spending, while the “high design” group produces relatively fewer new products.

Our innovation profiles are similar to the three component types that Clark and Fujimoto (1991) describe in their study of the automotive industryCorresponding to our "high R&D" cluster are "*supplier proprietary parts* … standard products taken from concept to manufacturing by the supplier and sold to assemblers through a catalogue." (Clark and Fujimoto, 1991, p 140) Their second category of parts are "*black box parts*… When developmental work is split between assembler and supplier,.. Typically an assembler generates cost/performance requirements, exterior shapes, interface details, and other basic design information based on the total vehicle planning and layout. (p. 140-142). This characterization of the allocation of engineering input does not quite capture the level of collaboration and relational contracting that we associate with our "high design" cluster, but it does capture the sometimes nearly-equal division of effort. Finally, for the third category of parts, "Most of the component engineering work for *detail-controlled parts,* including parts drawing, is done in-house. This concentrates detailed as well as basic engineering in the hands of the car makers. Suppliers, selected through inquiries and bids, take responsibility for process engineering and production based on blueprints provided by car makers," (p. 143). This last set of parts corresponds to our "high variety" cluster of suppliers, who primarily produce parts designed by their customers.

But do supplier clusters represent responses to hazards associated with innovating for big customers? We perform a discriminate analysis using OLS regressions of cluster dummies on various non-innovation variables (Table 3). We find that firms in the high-R&D and high-design clusters produce higher-value components than high-variety firms, which are more likely to be lower-tier (i.e., they supply suppliers rather than automakers directly). High-design firms are significantly more dedicated to the auto sector than the other clusters, while high R&D firms are more likely to have multiple customers.[3]

<Insert Table 3 about here>

We also regress these non-innovation variables on the four innovation variables. Three of the four variables are the "lead variable" for a cluster; the fourth is the catch-all innovation variable. Table 4 presents results of the OLS regressions. We again find that design effort and R&D intensity are associated with higher-value components, and that high-variety suppliers are in lower-tiers of the supply chain. Design-intensive suppliers, such as those in the high-design cluster, invest more in specific assets than the other two clusters.

<Insert Table 4 about here>

Taken together, these regressions suggest that each cluster approaches hazards to innovation outsourcing differently. High R&D firms supply multiple customers without asset specificity and less dependence on the auto industry over all. An electronic components manufacturer that we interviewed exemplifies this cluster. They perform high levels of R&D activity to produce goods for their main customers, which are in the technologically demanding electronics industry. Another firm in this cluster is focused on the auto industry but is diversified in its customer base, selling to almost every automaker. They manufacture state of the art components and prospectively design the

[3] The multiple-customers regression uses a reduced data set, looking only at tier-1 suppliers.

next generation of components. While each car model has specific interface requirements that involve some customization, the relationship with buyers is largely arms-length. Thus intensive R&D seems to be one way for supplier firms to respond to hold-up and appropriability hazards.

High-design firms employ a different response to hazards. Committed to the auto industry, these firms also invest in specific assets, suggesting a closer, more cooperative relationship with buyers. To the extent that these suppliers contract with multiple customers, it may be because their work is customer-specific and therefore less transferable to other customers.

Finally, high-variety suppliers could also be described as low-innovation suppliers. By investing less in innovation and specific assets, these suppliers avoid hazards altogether. We observed innovations that were cheap, tacit, or not easily imitated. This type of innovation also eliminates any need for formal intellectual property rights, which ill-serve small, competitive suppliers; even when innovations could be patented, a powerful customer could demand a second source or threaten to deny future business to a supplier that defended its patent. Interestingly, we found that peer firms sometimes even exchange know-how informally. For example, in Cleveland, a group of metal-working firms whose families socialize and share knowledge are known as the “German mafia” because they are similar in size, age, and founding by German immigrants.

VI. Discussion and Conclusion

In October 2015, Toyota shocked observers by dropping its long-standing supplier, Denso, a Japanese firm and member of Toyota's *keiretsu,* in favor of Continental, a German firm (Kubota and Pfanner, 2015). Toyota felt that Continental was the better supplier for its crash-prevention components because it provided a complete system and would incorporate state-of-the-art technology. This change in supplier highlights the role of technology in formulating strategy, and exemplifies how the nuances from our analysis inform the make-or-buy problem for innovation. Denso is typical of the relational approach in our high-design cluster, while Continental resembles a typical high-R&D firm. Rather than choosing between making and buying, firms actually face a more complex decision about which innovation-type to source from.

Without good measures of heterogeneous innovative activities, it has been difficult to quantify the nature of this more-complex make-or-buy problem. In this paper, we offer a start towards clarifying this important strategic question conceptually. It is important to stress that this is but a beginning, as our study raises new questions for future work. For example, what are the strategic trade-offs among innovation types? In the Toyota-Denso case, the long-term working relationship between the two firms was undoubtedly valuable and change would not have been undertaken lightly, so why did they do it? Second, what other clusters or innovation types might there be? We identified three, but in other settings, perhaps in service industries, there might be others. And finally, what constraints and conditions affect the use of innovation types?

Our hazards approach to analyzing data suggests that there may be policy implications to the latter two questions. While we find three different supplier responses to transactional hazards, another interpretation is to regard such hazards as constraints within which suppliers must act. That is, with hazards in place, suppliers may invest and innovate only in such a way as to avoid the hazards. Put another way, without hazards, high-variety suppliers might innovate more and high-R&D firms might be able to spend less if their investments were not at risk of expropriation by their customers. Thus, transactional hazards are a sort of black hole on whose periphery firms may innovate. Are there policy interventions that could reduce the size of the black hole?

There is suggestive evidence that the Manufacturing Extension Program, which is modeled after agricultural extension programs (Ezell and Atkinson, 2011), pays for itself in increased tax revenue generated from increased firm productivity (Helper and Stanley, 2009). Studying other industries and other countries could surface other approaches to hazards. Katila et al (2008) describe how venture capitalists serve to reduce expropriation risks for the high-tech start-ups they fund, while Arora et al (2015) find large industry variation in how firms use outside inventions. Also, a large literature compares US and Japanese outsourcing in the automotive industry (e.g. Clark, Chew and Fujimoto, 1987; Dyer and Chu, 2000; Helper, MacDuffie and Sabel, 2000; Helper, 2011; MacDuffie, 1997; MacDuffie and Helper, 1997; MacDuffie and Helper 2006; MacDuffie 2013).

We initially motivated this paper as an attempt to expose innovative activity at small supplier firms and we return to that perspective in concluding. In measuring "invisible" innovation, we also uncover the innovation strategies of supplier firms, with managers consciously investing in activities such as diversification away from the auto industry, pursuing better clients, outsourcing straightforward tasks to lower-tier suppliers, etc. These decisions and choices form a strategy that promotes productivity and survival (Bresnahan and Raff, 1991). Looking forward, an additional question is how diversification by supplier firms would affect innovation and buyer strategies. One-third of our respondents reported trying to grow their non-automotive business, and if successful, these suppliers might bring new knowledge and capabilities to automotive customers, while gaining bargaining power.

The types of innovative activity captured in our interviews and surveys reduce cost and create value for customers, and constitute a phenomenon of economic importance when aggregated across thousands of supplier firms. However, because each of these innovations might seem unimportant, even to the innovator, measuring and valuing this activity can be difficult. Our survey gathers information on this incredibly varied activity, going beyond patents and R&D spending, to measure innovations that are actually in use, to contrast with patents and product announcements, which are pre-commercial. Moreover, the innovation measures exhibit dual-peaked and skewed frequencies that may shed light on why existing empirical studies have been unsupportive of the Schumpeterian hypothesis.

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Table 1: Correlation Matrix of Innovation Measures

	R&D intensity	Design	New products	Innovation
R&D spending	1.00			
Design	0.32*** (0.00)	1.00		
New products	0.06 (0.18)	-0.14*** (0.01)	1.00	
Innovation	0.33*** (0.00)	0.20*** (0.00)	0.21*** (0.00)	1.00

Table 2: K-means Three-Cluster Analysis—Innovation Variables (means, standard dev.)

	High R&D Cluster	High Design Cluster	High Variety Cluster	ANOVA (t test)	ANOVA (p value)
R&D spending	5.89 (1.71)	2.71 (1.11)	2.13 (0.99)	65.80***	0.00
Design	2.50 (1.28)	3.02 (0.79)	0.60 (0.61)	46.16***	0.00
New product	3.02 (1.71)	1.68 (0.99)	2.63 (1.70)	1.80***	0.01
Innovation	3.34 (1.86)	1.90 (1.00)	1.56 (0.86)	7.84***	0.00
N	93	126	175	394	394

Table 3: Comparison of Clusters –estimates of firm behaviors (OLS)

	Piece Price	Tier 1 (y=1)	% of sales in automotive	Cost reduction	Multiple customers* (y=1)
High R&D Cluster (omitted)	----	----	----	----	----
High Design Cluster	-0.23 (0.20)	-0.01 (0.07)	0.53* (0.29)	-0.33** (0.14)	-0.10 (0.10)
High Variety Cluster	-0.95*** (0.19)	-0.12* (0.06)	0.16 (0.27)	-0.36*** (0.13)	-0.20** (0.10)
N	384	372	390	381	143
R2	0.08	0.01	0.01	0.02	0.03

* Multiple customers variable uses reduced data set including only tier 1 suppliers

Table 4: Comparison of innovation activities—estimates of firm behaviors (OLS)

	R&D intensity (High R&D cluster)	Design (High design cluster)	New products (High variety cluster)	Innovation
Piece price	0.26*** (0.06)	0.31*** (0.05)	-0.05 (0.05)	0.13*** (0.05)
Tier 1 (y=1)	0.09 (0.19)	0.18 (0.15)	-0.42** (0.16)	0.24* (0.15)
Asset specificity	0.01 (0.07)	0.10* (0.06)	0.01 (0.06)	0.10** (0.06)
Constant	2.44*** (0.24)	0.73*** (0.19)	2.62*** (0.21)	1.50*** (0.19)
N	405	381	423	421
R2	0.044	0.118	0.019	0.034

Figure 1: Do different innovation variables measure different innovative activities?

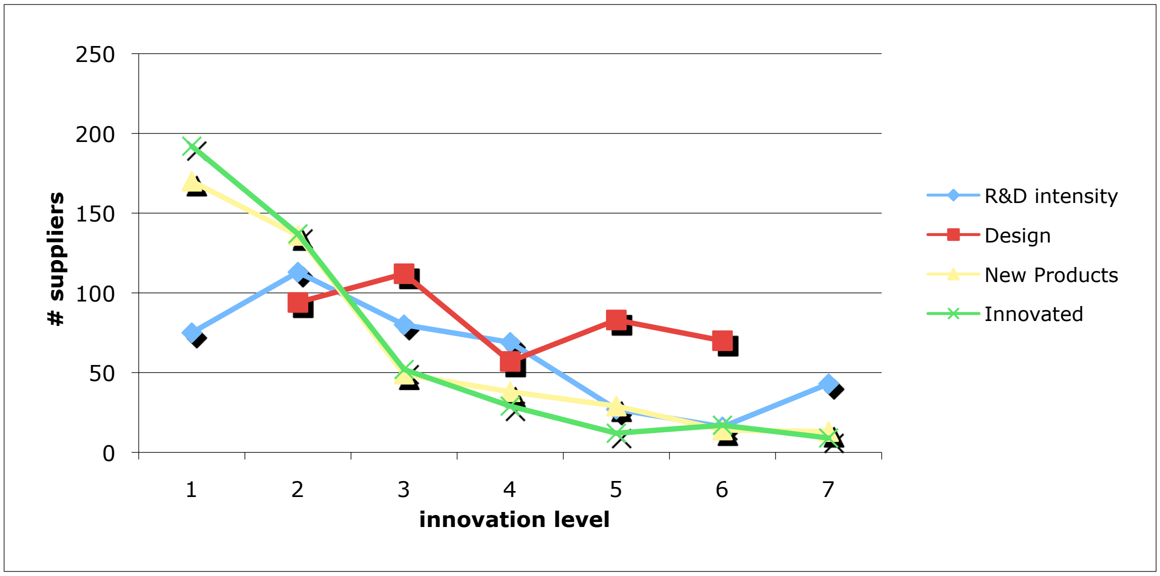
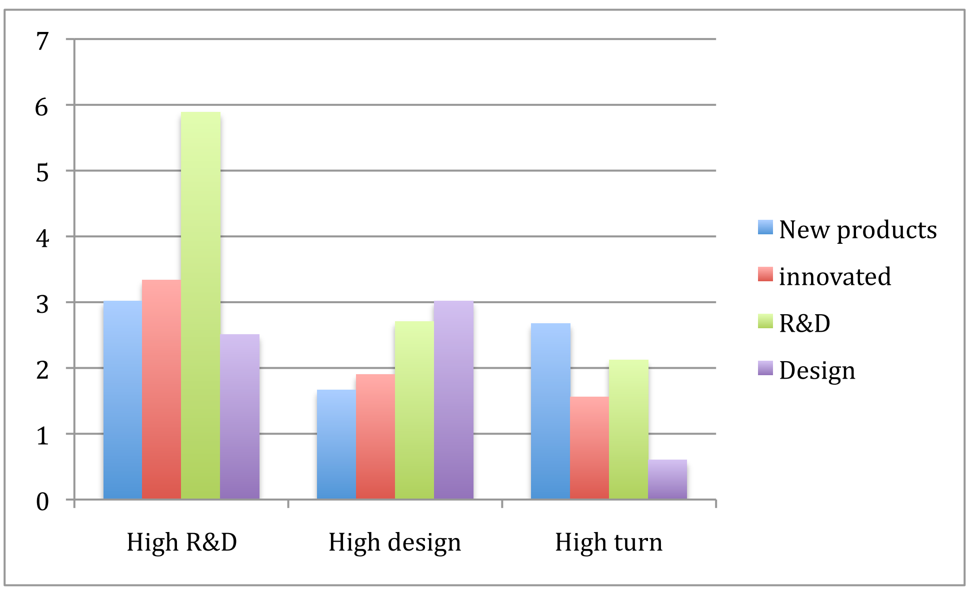


Figure 2: Means for selected innovation variables by cluster (3-cluster)



APPENDIX 1: DATA COMPILATION FOR SURVEY

The task of identifying firms in the supply chain is considerable. The supply chain comprises many tiers and firms are difficult to identify using publicly available data. Many firms that supply the auto industry are not classified as auto parts manufacturers (3363, in the North American Industry Classification System, or NAICS), often because they supply other industries and so do not self-identify as auto suppliers. At the same time, many firms that are in NAICS 3363 no longer supply the auto industry; managers of establishments self-report their NAICS classification and typically do not update these codes.

We assembled a list of candidate firms and establishments from 11 sources. Our two primary lists of firms came from ELM International and the Analyst Resource Center (ARC), but we augmented these with smaller lists from regional industry associations, Michigan Manufacturing Technology Center (MMTC) and Ohio's Manufacturing Advocacy and Growth Network (MAGNET), and trade associations, Original Equipment Suppliers Association (OESA), Precision Metalforming Association (PMA), Industrial Fasteners Institute (IFI), Polymer Ohio. We also used Automotive News Top 150 Suppliers list and National Establishment Time Series (NETS) data supplied information for some of the firms once they were identified as being in the supply chain.

The Michigan Automotive Research and Development Facilities Directory was particularly useful in identifying firms that specialize in automotive research and development (R&D) because establishments performing R&D are classified in NAICS 54171, which at the most detailed category includes "R&D in the physical, engineering, and life sciences." Thus, it would be very difficult to extract from such a large class of firms those whose output is used primarily by the auto industry. A conservative count of establishments from this directory yields 25,000 employees in Michigan alone. A strictly NAICS-based analysis of the auto supply chain would fail to capture these highly skilled workers, and underestimate the employment, wages, and skill level of automotive production.

With the resulting combined list of firms, we selected firms that were in the auto supply chain using NAICS codes associated with the auto industry (C.A.R., 2010). In addition to 3363, these include functional specialties involved in auto manufacturing, such as metal stamping, plastics manufacturing, and equipment producers. Table A1 gives the proportion of our sampling frame in each NAICS. Note that NAICS 3363 ("Motor vehicle parts manufacturing") accounts for only 37 % of the sample.[4]

Internet-based research and both manual and automated de-duplicating procedures were used to reduce the list down to likely automotive suppliers. Each of the remaining firms was phoned and asked if they currently supply the auto industry. When called, over half of the establishments listed as NAICS 3363 said that they no longer supply the auto industry.

Table 1 summarizes the outcome of this process. About 20% of our original list, or 3800 firms, were likely automotive suppliers. Three surveys were sent to each firm by e-mail, web link, and mail, each one requiring different expertise: sales, plant

[4] We do not investigate suppliers of glass, fabric, tires, software, and electronic systems (such as entertainment, GPS, and communications devices).

management, and personnel. Unfortunately, while the quality of responses received is likely to be high, because respondents were likely to be knowledgeable about their particular area, the share of firms returning all three surveys was relatively low. Out of 1411 responses (a response rate of 37%), only 98 returned all three surveys.

Table A1: Construction of Survey Sample

NAICS	Candidate Firms by NAICS Code	Percent
3363	Motor vehicle parts manufacturing	37.1%
333514	Special die and tool, die set, jig, and fixture manufacturing	14.3%
326199	All other plastics product manufacturing	12.8%
332116	Metal stamping	1.4%
332710	Machine shops	1.1%
326220	Rubber and plastics hose and belting manufacturing	0.9%
336211	Motor vehicle body manufacturing	0.2%
325	Chemicals manufacturing	1.0%
Other 326	Plastics and rubber manufacturing	2.8%
331	Primary metal manufacturing	3.3%
Other 332	Fabricated metal manufacturing	8.3%
333	Machinery manufacturing	5.9%
334 & 335	Computer and electronic component manufacturing	2.2%
339	Misc. manufacturing	2.6%
324	Durable goods wholesale	1.9%
541	Scientific and technical services	0.9%
Misc.	313, 314, 315, 321, 322, 323, 324, 327, 336, 337, 484, 811	3.3%
	Total	**100.0%**

N	Reason for Elimination from Sample	
3646	Out of business	19.2%
11,363	Not in auto industry	59.9%
130	Duplicates	0.7%
3828	**Total Remaining**	**20.2%**

APPENDIX 2: SURVEY DESCRIPTION AND REPSONSE RATES

We divided survey questions into three (3) separate surveys, with each survey to be filled out on-line or on paper by an expert within the firm: plant manager, human resources manager, and sales manager. Below are the abridged tables of contents for each survey.

Plant Manager Survey—Table of Contents

Response to Crisis: *layoffs, training, and IT investment*
Key Products and Processes: *design effort, names of component and customer*
Operations: *age of machines, energy efficiency*
Management Practices: *use of data, preventive maintenance*
Work Organization: *use of skilled and unskilled workers, management relationship with workers*
Networking and Suppliers: *sources of information, location and inspection of purchased inputs*
Background on the Plant: *age of plant, value of sales and purchased inputs*

Human Resources Manager Survey—Table of Contents

Workforce Characteristics and Work Organization: *number of skilled, unskilled employees, regular and temporary, training, wages, career planning*
Work Organization: *unionization, formal continuous improvement programs, layoffs and turnover*
Background on the Plant: *ownership*

Sales Manager Survey—Table of Contents

Customer Relations: *length of relationship, likelihood of switching suppliers, helpfulness, number of competitors, asset specificity*
Product Engineering and Information Technology: *product development contribution, technical skills*
Handling Information: *use of ERP, value stream mapping*
Background Information about your Business Unit: *profits, R&D, new products, environmentally friendly products, sales of innovated products*

We received responses from 1411 firms, but most firms did not return all three surveys. Also, within each survey, some responses were missing, as is common with survey data. As a result, even though our analysis focuses on Sales Manager survey responses, our N is closer to 300 than 500. Below is a table of response rates and intersections.

Table A2: Response Rates by Survey Type

Survey Response Rates	N	Pair-wise Intersections	N	Response Rate for all 3 surveys	N
Sales	544	Sales *Plant	137		
Plant	528	Plant * HR	170	Sales*Plant*HR	98
Human Resources	663	Sales & HR	166		

APPENDIX 3: SURVEY QUESTIONS

I. Innovation questions

R&D spending
Which range best describes your business unit's R&D as a percentage of sales?
–0
–0.1-1%
–1.1-2%
–2.1-3%
–3.1-4%
– >5%

Design
Please indicate which descriptions apply to your firm's role in product development for your company's current model
–Customer took entire responsibility
–Customer provided majority of engineering hours; your business unit provided the rest
–Customer and your business unit contributed equally to the design
–Your business unit provided majority of engineering hours
–Your business unit took entire responsibility

New Products
Approximately what percent of your business unit's sales come from products which it did not make 4 years ago?
–0-10%
–11-30%
–31-45%
–46-55%
–56-70%
–71-85%
–85-100%

Innovation
What percentage of your sales come from products where you innovated in some way? By 'innovated', we mean that your business unit designed a product with improved features compared to what the market had seen before, or that you used a novel process to make the product.
–0-10%
–11-30%
–31-45%
–46-55%
–56-70%
–71-85%
–85-100%

II. Non-innovation questions

Piece price
Please check the appropriate range for the average piece price of the key product in 2010:
–<$1
–$1-10
–$11-50
–$51-100
–>$100

Tier 1
Please check here if you ship directly to this automaker.

Share of sales in autos
What percent of your business unit's sales end up as *original equipment* for cars or light trucks?
–0-10%
–11-25%
–26-40%
–41-65%
–66-80%
–81-100%

Cost reduction
What has been the average annual percent c*hange in your unit costs* for this *product* for 2009-2010?
–Decreased <10%
–Decreased 3.1-10%
–Little change (+/- 3%)
–Increased 3.1-9%
–Increased >9.1%
–Don't know

Multiple customers *and* ***OEM country of origin***
Name of automaker on which this product ends up: ___________________

We ask who the firm's customer is. Many firms list several specific customers while others report selling to "many" or "multiple" or sometimes "all" automakers. All firms that report more than one customer are coded as "1" for "multiple customers."

Asset specificity
If you were to stop getting these orders from this customer, approximately how much of your investment in plant, equipment, and training would you be unlikely to find alternative uses for and have to write off? (Example: If you could easily re-allocate all of the assets you use to make this product, then check the first box.)
–10% or less

–11-33%
–34-66%
–67-89%
–90-100%