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Servitization and Manufacturer Innovation

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ABSTRACT

This paper investigates the influence of servitization on manufacturer innovation. We propose that services act as a window to the market facilitating knowledge transfer and innovation. We investigate this thesis using a panel of 1698 U.S. manufacturing firms over a 17-year period. We find a positive relationship between manufacturer's prior service sales and its number of successful patents. We find that this positive relationship is stronger under higher absorptive capacity and product sales volatility. We also demonstrate that this effect is stronger when services and manufacturing activities co-exist in the same business unit.

Commented [SG(1]: This paper investigates the influence of servitization on manufacturer innovation. We analyze a panel of 1698 U.S. manufacturing firms over a 17-year period. We find robust evidence that the rich customer insight obtained through services enhances manufacturer's patent activity in subsequent years.

KEYWORDS: Servitization, Innovation

INTRODUCTION

Manufacturers have increasingly introduced services to accompany their existing products in order to satisfy a broader array of customer needs and differentiate themselves from the competition (Sawhney, Balasubramanian, & Krishnan, 2003; Lusch, Vargo, & O'Brien, 2007). In their pioneering work, Vandermerwe and Rada (1988) called this phenomenon servitization. Despite widespread industry adoption and some emerging academic research about servitization, there is not sufficient nor unambiguous empirical evidence addressing how servitization impacts manufacturers' business (Bolton, Grewal, & Levy, 2007; Fang, Palmatier, & Steenkamp, 2008; Kastalli & Van Looy, 2013). Scholars have recently begun to empirically investigate the impact of servitization on firms' financial performance (Fang et al., 2008; Neely, 2008; Kastalli & Van Looy, 2013). Yet, more nuanced implications of servitization and different aspects of the role of services in a manufacturing context remain largely unexplored.

Anecdotal evidence suggests that some companies have successfully used their service interactions to obtain market intelligence and improve their products. Boston Scientific, a manufacturer of medical devices, sends its IT professionals to customers at healthcare facilities in order to acquire knowledge and improvement ideas. As these professionals interact with customers they spot unmet demands and new ways for helping customers better use the company's devices. Using this knowledge, the company has developed products with enhanced function and new features (Nash, 2015).

This examples suggest that servitization may have a significant spillover effect on product development and innovation. However, there are also logical reasons why this may not be the case. Companies may not always be able to absorb and utilize knowledge from service interactions. The knowledge gained through services is informal, unstructured, and may not be readily translatable to innovative ideas. It is not clear whether the insights obtained from service interactions can add significant value over and above what formal research and development achieves. Logic alone cannot determine whether servitization may boost or hamper innovation. Thus we pose the following research question: *How does servitization influence manufacturer's innovation output?*

In order to address this question, we combine U.S. patents data with the S&P Capital IQ's Compustat North America database and construct a panel of 1698 publicly held manufacturers for the time period of 1990 to 2006. The data are analyzed using random effects negative binomial regression model. The results indicate that when service sales of a servitized manufacturer increases, its number of awarded patents also increases in subsequent years. We further find that the positive relationship between patents and service sales is greater under higher absorptive capacity, and product sales volatility. We also demonstrate that the patent-service sales relationship is stronger when products and services co-exist in the same business unit within a firm. Our findings imply that services can create increased market intelligence, yielding insights about product performance and helping to identify customer requirements. This enhanced knowledge can, in turn, be used to create new product innovations and associated patents.

LITERATURE REVIEW

The empirical research in the area of servitization has largely focused on its financial implications. Literature, however, provide clues about the knowledge implications servitization – that it facilitates the acquisition of external knowledge about customer demand and product performance (Gries, Gericke, Blessing, & others, 2005; Gebauer, 2007; Kastalli & Van Looy, 2013; Suarez, Cusumano, & Kahl, 2013). Additionally, the innovation literature recognizes that higher customer contact (a potential result of service transactions) enhances the knowledge creation and innovation processes (Von Hippel, 1998; Gruner & Homburg, 2000; Sawhney, Verona, & Prandelli, 2005; Foss, Laursen, & Pedersen, 2011). Given the stronger customer contact made in performing services compared to manufacturing products, there is a gap in the literature related to whether offering services by a manufacturer can impact its innovation performance.

Servitization

Since the introduction of servitization to literature (Vandermerwe & Rada, 1988) research has been steadily growing in this area (Baines, Lightfoot, Benedettini, & Kay, 2009). Academic research initially emphasized servitization's marketing-related benefits (Lele & Karmarkar, 1983; DeBruicker & Summe, 1985; Hull & Cox, 1994), but soon after, operations issues also attracted attention (Armistead & Clark, 1991; Loomba, 1996; Goffin & New, 2001). More broadly, researchers have consistently advocated that manufacturers should integrate services into their core products (Wise & Baumgartner, 1999; Oliva & Kallenberg, 2003; Baines, Lightfoot, Benedettini, et al., 2009; Baines, Lightfoot, Peppard, Johnson, Tiwari, Shehab, & Swink, 2009). Research in this area predominantly used conceptual and case-based studies (C. Voss, 1992; Robinson, Clarke-Hill, & Clarkson, 2002). More recently, empirical studies have appeared (Fang et al., 2008; Kastalli & Van Looy, 2013; Suarez et al., 2013) indicating the next phase of servitization research. Prestigious practice-oriented publications have also devoted attention to benefits of servitization and how firms can utilize this strategy to enhance their competitive advantage (Quinn, Doorley, & Paquette, 1989; Anderson & Narus, 1995; Wise & Baumgartner, 1999; Brady, Davies, & Hobday, 2006; M. A. Cohen, Agrawal, & Agrawal, 2006).

Researchers have identified three categories of servitization – product-oriented, use-oriented, or result-oriented (Mathieu, 2001; Cook, 2004; Tukker, 2004; Van Ostaeyen, Van Horenbeek, Pintelon, & Duflou, 2013; Gaiardelli, Resta, Martinez, Pinto, & Albores, 2014). In product-oriented servitization, products are accompanied by additional services that support the functioning of the product, e.g., repair, installation, warranty, and product take-back services. This type of servitization typically does not involve a radical change in manufacturer's business model. Use-oriented servitization involves a shift in product ownership, where a manufacturer retains legal ownership of the product and leases its uses to a customer. Result-oriented servitization involves the manufacturer taking responsibility for the operation of the product while in use by the customer. An example is the Rolls Royce's Power-by-the-Hour program, where the company completely undertakes the provisioning, maintenance and repair of jet engines and customers only pay for the engine uptime. Following prior empirical work (Fang et al., 2008; Kastalli & Van Looy, 2013; Suarez et al., 2013) we study servitization at the organization level and focus on all services sold by manufacturers. This conceptualization encompasses all of the three types of servitization.

Implications of Servitization. In the recent years, researchers have investigated the impact of servitization on manufacturer's financial performance (Fang et al., 2008; Neely, 2008; Guajardo, Cohen, Kim, & Netessine, 2012; Kastalli & Van Looy, 2013; Suarez et al., 2013). Considering the complexity and challenges of servitization (Gebauer, Fleisch, & Friedli, 2005) it is not surprising that mixed results have been found (Kastalli & Van Looy, 2013). Neely (2008) finds that larger servitized firms have lower profitability than their pure manufacturing counterparts and go bankrupt at a higher rate. The extent of servitization was found to have a negative relationship with net profit as a percentage of sales. Other studies have suggested nonlinear effects. Fang et al. (2008) and Suarez et al. (2013) find that only at high levels of servitization firms can recoup its benefits while at the lower levels the relationship between servitization and firm performance is nearly flat or even negative. Kastalli and Van Looy (2013) find that servitization and margin are strongly and positively associated when servitization is relatively low or high, but are negatively associated when servitization is relatively moderate. These findings point towards the need for a deeper investigation of contingencies (Fang et al., 2008) and the mechanisms by which servitization affects firms.

Scholars have noted that services and products can play a complementary role and influence each other. Fang et al. (2008) state that the main benefit of servitization is due to the synergy realized between products and services. In many cases, firms offer services, such as repair and maintenance, to support their product business. Kastalli & Van Looy (2013) show that offering services increases the demand for products.

Services can also act as a medium for knowledge transfer in manufacturing firms. Suarez et al. (2013) point out that services can facilitate the transfer of product-related knowledge to customers and new product developers. Moreover, service provision involves significant acquisition of new knowledge and resources, which can spill over from the service area to the product area. Kastalli & Van Looy (2013) assert that services in product firms can generate market and product knowledge, which can be utilized to enhance new product development. Gries et al. (2005) surveyed 173 German manufacturers in order to identify the sources through which manufacturers discover design flaws. The study indicates that a significant portion of the design flaws in product firms are discovered during service activities. The authors report that processing warranty claims and performing maintenance and repair services accounted for 43 percent of discoveries of design flaws, together, compared to only 25 percent being discovered during manufacturing and assembly processes (25 percent). The study also highlights the role of customers in design improvement. Unsolicited customer feedback accounted for 36 percent of flaw discoveries, while customer surveys only revealed 5 percent of the flaws. Gebauer (2007) finds that the manufacturers who center their business strategy around customer support services also create a culture of innovation. These findings indicate that services and the resulting customer interaction can be particularly useful for acquiring knowledge and enhancing innovation; however, empirical evidence of such a proposition is needed.

Innovation

Innovation has been called the “engine of economic growth” (Nagaoka, Motohashi, & Goto, 2010). The literature uniformly considers innovation a fundamental component of competitive advantage and an essential factor for survival (Damanpour & Evan, 1984; Han, Kim, & Srivastava, 1998; Hurley & Hult, 1998; Christensen, Anthony, & Roth, 2004)(Damanpour & Evan, 1984; Han et al., 1998; Hurley & Hult, 1998; Christensen et al., 2004)(Christensen et al., 2004; Damanpour & Evan, 1984; Han et al., 1998; Hurley & Hult, 1998). Innovation can be studied at the individual, organizational, or country levels. The focus of this study is on the organizational innovation, defined as the adoption of an idea or practice that is new to the adopting organization (Daft, 1978; Damanpour, 1991; Walker, 2006).

Innovation Antecedents. The organizational antecedents of innovation encompass culture, strategy, structure, and resources (Damanpour, 1991). A culture that values developing new ways of doing things, a strategy that emphasizes competing through superior new product development, a flexible and decentralized organizational structure, specialized human resources with broad knowledge base, and the availability of slack resources have all been found to drive innovation (Damanpour, 1991). Formal R&D activity has often been cited as the direct driving force of innovation (W. M. Cohen & Levinthal, 1990). Although, the subsequent literature demonstrated that daily business activities and customer interaction can also lead to innovations especially in smaller firms (De Jong & Marsili, 2006; Hirsch-Kreinsen, 2008). Collaboration among firms, units and individuals is also recognized as an important catalyst of innovation (Forsman, 2011).

Knowledge and Innovation. Central to our discussion in this paper is the knowledge component of innovation. Scholars have identified that the existing knowledge plays a key role in the subsequent innovation. In fact, a certain level of accumulated knowledge is shown to be necessary for identifying, understanding and implementing new knowledge (Smith, Collins, & Clark, 2005). Organizations can build an internal capability to identify and acquire new knowledge from their environment, known as the *absorptive capacity* (W. M. Cohen & Levinthal, 1990). Customer and market knowledge are also crucial for the effectiveness of innovation. Han, Kim, & Srivastava (1998) found that market-oriented organizations are better innovators due to their deeper understanding of customers.

Organizational innovation relies on the ability to acquire knowledge from external sources and mobilize and integrate it throughout the organization. Literature indicates that the interaction of firms in alliance networks enhances knowledge transfer and innovation capability (Mowery, Oxley, & Silverman, 1996; Ahuja, 2000; Owen-Smith & Powell, 2004; Gomes-Casseres, Hagedoorn, & Jaffe, 2006). Scholars have also linked innovation to inter-unit knowledge transfer (Kogut & Zander, 1992; Tsai & Ghoshal, 1998). Tsai (2001) finds that organizational units that have more knowledge-exchange links to other units enjoy higher innovation and business performance. This effect is further strengthened by the unit's higher absorptive capacity. Zirger and Maidique (1990) also demonstrate that cross-functional coordination, specifically among R&D, marketing and production units, enhances the success of new product development.

On the other hand, knowledge transfer skills are only as beneficial as the sources of knowledge available to the firm. External knowledge acquisition complements internal knowledge management capabilities (Caloghirou, Kastelli, & Tsakanikas, 2004). Access to rich and diverse sources of knowledge is essential for the innovation process. Interaction with customers has been found to be a significant driver of innovation and new knowledge absorption (Gruner & Homburg, 2000; Sawhney et al., 2005; Foss et al., 2011). Day (1994, 2002) demonstrates that organizations continuously acquire information about the customers' implicit and explicit needs (market sensing) and then interpret and exploit this information (sensemaking). Foss et al. (2011) maintain that organizations can manage these processes to improve innovation performance and create coditions that foster learning from customer interaction. They demonstrate that the link between innovation and customer interaction is mediated by delegation of responsibility, knowledge incentives and internal communication.

Von Hippel (1998) explains that customer interaction contributes to the innovation process because customers, have incentive to share knowldege with the firm in order to benefit from the resulting innovations, and have sticky knowledge that can only be transfered through close interaction. Sticky knowledge is difficult to transfer because it is tacit or disaggregated among many entities (Foss et al., 2011). The stickiness of customer knowledge requires that strong interaction take place between customers and the firm in order to mobilize this knowledge.

Cavusgil et al. (2003) find that a stronger relationship between two parties enhances the transfer of tacit knowledge, ultimately leading to a higher innovation capability. This line of research establishes a firm link between acquiring customer knowledge and better innovation performance. The current paper extends this literature by showing that services of a manufacturer can be a means for interacting with the customers and absorbing external knowledge.

Service transactions are ideal opportunities for customer interaction. The intangibility of service necessitates stronger interaction between the provider and the receiver (Araujo & Spring, 2006). Hill (1977) conceptualizes services as a previously agreed-upon change in the condition of the service receiver or their belonging. From this perspective, services often involve significant customer input and reciprocal transfer of information between the customer and the provider. Therefore, offering services could be a means for product manufacturers to strengthen contact with customers and tap into their sticky knowledge. In sum, the prior literature offers valuable clues pointing towards the link between services and innovation in manufacturing firms. However, this linkage has not been formally investigated yet.

HYPOTHESES

Services and Innovation

In this section we examine the effect of a manufacturer's services on their product innovation. Services act as an efficient market listening mechanism and necessitate significant interaction with the customers (Skaggs & Youndt, 2004). They provide insights into the customers' mindset and preferences, unmet demands, and opportunities for new value proposition (Rothwell, Freeman, Horlsey, Jervis, Robertson, & Townsend, 1974). Literature has long recognized the value of working closely with customers for innovation (Rosenberg, 1982; Urban & Von Hippel, 1988; Lilien, Morrison, Searls, Sonnack, & Hippel, 2002; Chesbrough, 2003). Often times the users of a technology possess deep experience and insight about it, which makes them key sources of feedback. Customers are also the most relevant evaluators, since they are the ones who ultimately pay for the technology. Through services, firms can get closely in touch with their customers, engage them in the dialogue, and utilize their ideas and feedback for developing new product ideas (Foss, Laursen, & Pedersen, 2011; Mills, 1986).

In a competitive market, satisfying customers and meeting their explicit requirements are not enough for retaining market share. Customers are not always aware of what they want, and it is the firm's job to tap into their unconscious desires and offer innovative solutions that exceed the explicit requirements (Jones, Sasser, & others, 1995; Schneider & Bowen, 1999). Kastalli and Van Looy (2013) argue that offering services significantly improves manufacturer's understanding of the customer's broader needs, which can be leveraged for designing new products. Customer interaction, achieved through services, facilitates the learning process and generation of ideas for filling the gaps between the products and market needs.

Through these interactions firms gain a better understanding of how their products are performing under real-world conditions, to what extent their products meet customer requirements, and what improvements could be made to them (Rothwell et al., 1974; Zirger & Maidique, 1990). Services performed on products have a strong potential for uncovering design flaws and incompatibilities. Each used product is one that is tested by customers free of charge under real conditions. Product-related services, such as repair and maintenance, are an effective channel for obtaining used products and examining their performance. Sundin et al.

(2009) support this argument contending that offering product services teaches the manufacturer how its products perform throughout their life-cycle.

Services such as product consultation tap into the customers' complex behavior and mindset, i.e. how they make decisions and value products. Tuli et al. (2007) report that business counseling services accelerate organizational learning by providing a deeper knowledge of customer's operational environment and their specific needs. Similarly, installation and training services provide a better understanding of customers' operating conditions and capabilities related to the product usage. Repair services help shed light on a product's performance in the field and its durability. Likewise offering other types of product-related service can generate knowledge that can be leveraged for improving the product itself. Sundin et al. (2009) provide multiple examples of how the reprocessing of used products, e.g. maintenance, repair and remanufacturing, has generated innovation ideas leading to significant product enhancement. These improvements encompassed product performance, ease of use, safety, ease of repair, maintainability and recyclability.

Hypothesis 1. Within a servitized firm, increases (decreases) in the level of servitization are followed by increases (decreases) in the level of product innovation.

Absorptive Capacity

The improvements that result from services primarily involve acquiring product and market knowledge from new external sources. Firms need to be appropriately equipped in order to exploit the new opportunities made available from offering services. This requires the firm to possess absorptive capacity, i.e., the ability to sense learning opportunities, identify sources of knowledge, absorb that knowledge and apply it to the existing or new markets (W. M. Cohen & Levinthal, 1990). Services expand and enrich an organization's access to external sources of knowledge. This access can only create value though if the organization knows how to exploit it and identify innovation opportunities. Absorptive capacity enables the firm to interact effectively with its external environment and promotes learning within and between subunits (Lane & Lubatkin, 1998; Rosenkopf & Nerkar, 2001; Lavie, Stettner, & Tushman, 2010). It allows the firm to operate proactively and explore new technologies and market opportunities (W. M. Cohen & Levinthal, 1990; Lavie & Rosenkopf, 2006; Rothaermel & Alexandre, 2009). In sum, absorptive capacity enables the organization to better realize the potential innovation benefits made available through services.

Hypothesis 2. The positive association between a servitized firm's change in level of product innovation and its level of servitization increases with increasing manufacturer absorptive capacity.

Human Resource Productivity

Human resource (HR) productivity refers to how efficiently a firm uses its human assets. Ceteris paribus, a higher HR productivity indicates higher education and skills of employees as well as better operations and HR management. Employee performance has a central role in innovation and successful innovation strategies often focus predominantly on human resources (KPMG, 2013). Furthermore, human resource productivity is often used as an indicator of workforce performance and capability (Delery & Shaw, 2001).

Improvements in HR productivity can be achieved, for instance, by employee training and motivation, work design improvement, and hiring more competent employees. Productivity is a strong indicator of skills and knowledge. Drucker (1999) maintains that knowledge is what makes work more productive. More productive employees tend to have a higher level of knowledge and also be better at absorbing new knowledge. Similarly, we expect that manufacturers with higher HR productivity are better at absorbing new knowledge from service activities. For example, a highly qualified maintenance worker can better identify design flaws of a product and can communicate his findings with design engineers more effectively.

Higher HR productivity leads to higher performance, which has been shown to motivate future innovation through increasing resource availability and manager risk tolerance (Staw, Sandelands, & Dutton, 1981; Dutton & Jackson, 1987; Bowen, Rostami, & Steel, 2010). Higher HR productivity also may indicate a relatively more conducive environment to organizational learning, since productivity must typically emerge through multiple cycles of learning and improvement. In such a firm this positive support for learning and experimentation would also likely enable and perhaps even facilitate learning between functions, e.g., between service personnel and product designers. These arguments imply that, under higher human resource productivity, we should observe a stronger relationship between service sales and innovation output.

Hypothesis 3. The positive association between a servitized firm's change in level of product innovation and its level of servitization increases with increasing human resource productivity.

Product-Service Organizational Proximity

External knowledge acquisition effort needs to be complemented by efficient internal knowledge diffusion (W. M. Cohen & Levinthal, 1990; Foss et al., 2011). Presence of shared knowledge throughout an organization is a prerequisite of innovation (Dougherty, 2004). While offering services helps a firm to acquire knowledge about market demand, customer satisfaction and product performance, innovations can only emerge if this knowledge is sufficiently communicated within the firm. Communication among units and sub-units helps to refine the new knowledge and combine it with the existing knowledge in a meaningful way (Haefliger, Von Krogh, & Spaeth, 2008). Activities that are performed within the same unit or highly connected units will have a higher chance of providing constructive feedback to each other because of shared goals and language. Therefore, co-existence of products and services in the same unit should enhance their interaction and complementarity.

Mansfield (1969) argues that successful innovation involves tight connection between different innovating entities. Clarka and Fujimoto (1987) found that successful internal communication significantly increases the speed of product development process. Foss et al. (2011) highlight the importance of internal organization for successful use of external knowledge. They show that internal communication mediates the relationship between customer contact and innovation. Newly generated knowledge may be fragmented and dispersed among different organizational members. This, in turn, necessitates collaboration among these entities in order to aggregate pieces of knowledge into meaningful, cohesive and refined ideas. The newly created knowledge might also include a large tacit component, which further highlights the need for close collaboration (Foss et al., 2011). Communication between activities is facilitated when they belong to the same unit. Similarly, the services that are executed by manufacturing departments, rather than by standalone service departments, will be more likely to produce new knowledge that is usable for improving products, technologies and operations. The knowledge that is created through services in manufacturing departments is more likely to be well aligned with the firm's core manufacturing business and, therefore, has more relevance and higher fit to the firm's prior knowledge. When service and production personnel work closely with each other they will share a common language and their ideas tend to converge. This will increase the likelihood of cross-fertilization of ideas that yield subsequent innovation.

In general, knowledge transfer is easier within a single organizational business unit versus between multiple units, and the personnel and processes within the unit are likely to have richer and stronger communication with each other (Tortoriello, Reagans, & McEvily, 2011). Consequently, we expect the services offered by product units to have a richer knowledge transfer with manufacturing activities and, ultimately, a stronger impact on innovation output.

Hypothesis 4. The positive relationship between services and innovation will be stronger when services and products are produced by the same organizational unit.

Product Sales Growth and Volatility

Finally we consider how the performance of the product business influences may moderate the linkage between service sales and innovation. In sum, we expect that the success of current product business influence the effort for innovation based on service knowledge. Consider two aspects of product business performance, sales growth and volatility. Path dependence theories suggest that an organization's future behavior is to some extent constrained and determined by their past behavior (Teece, Rumelt, Dosi, & Winter, 1994; Lavie & Rosenkopf, 2006; Sydow, Schreyögg, & Koch, 2009; Vergne & Durand, 2010). According to this viewpoint, firms tend to stay within their areas of competency and retain existing strategies until proven to not be working. Similarly, a manufacturer with successful and growing product business is more likely to further exploit their current capabilities and emphasize product manufacturing and sales rather than expand to provide new services. It will also be less likely to engage in exploration and radical innovations. Therefore, growth in product business is likely to limit the incentives and resource allocation for generating new knowledge from service activities and turning them into innovative offerings.

Product sales volatility should have the opposite effect. Sales volatility indicates higher market uncertainty and risk in product sales and revenue. This volatility could be due to competitive dynamics and exchange of market share between competitors. The unstable business and perceived competitive threats highlight the need for change of strategy and encourage firms to utilize their available resources for exploration (G. B. Voss, Sirdeshmukh, & Voss, 2008). Additionally, Jansen et al. (2005) found that exploratory innovation is especially effective in dynamic environments. Constant change in the market necessitates continuous adaptation and exploration of strategies. Accordingly, we hypothesize the following:

Hypothesis 5a. The positive association between a servitized manufacturer's change in level of product innovation and its level of servitization decreases with increasing product sales growth.

Hypothesis 5b. The positive association between a servitized manufacturer's change in level of product innovation and its level of servitization increases with increasing product sales volatility.

METHODS

Data

To test our hypotheses we combine financial and patent data for US publicly-traded manufacturers. Financial data are obtained from the Standard & Poor's (2015) Compustat. Our analysis is limited to the manufacturing firms, i.e. the firms with the one-digit NAICS code of 3.

We obtained patent data from the National Bureau of Economic Research (NBER). The Patent Data Project (PDP) conducted by the NBER provides a dataset of more than three million US Patents for 1976-2006 (National Bureau of Economic Research, 2015).

We merged the Compustat financial dataset with the PDP dataset by the GVKEY code and applied the following data filtering steps in order to construct our final sample. First, all of the observations with negative values on total revenues, assets, and R&D expenditure were dropped. Second, firms with no service revenues were deleted. Third, observations with extreme values (i.e. the 1st and the 99th percentiles) on total revenues, assets, service revenues, research and development expenditure, return on assets, return on sales, and the number of patents were deleted in order to mitigate the effect of outliers or mis-recorded data. Finally, the missing data were list-wise deleted for each model. The final sample includes 10551 firm-year observations from 1698 firms for the period of 1990 to 2006.

Measures

Patents as Innovation Indicators. Many scholars use patent data for analyzing innovation (Griliches, 1990; Hall, Jaffe, & Trajtenberg, 2005; Schilling & Phelps, 2007; Nagaoka et al., 2010; Q. Liu & Wong, 2011). Patents provide an explicit, public trace of firm's knowledge creation. Patents have several advantages over the alternative measures of innovation. Large amounts of patent data that are systematically checked and screened by patetn offices are available on a global scale. Patents are also very rich sources of data.

To account for variation in the value of patents we follow literature (Almeida, 1996; Lanjouw, Pakes, & Putnam, 1998; Almeida & Kogut, 1999; Hall et al., 2005; Thompson & Fox-Kean, 2005; Galasso & Simcoe, 2011) and use the citation-weighted number of patents for measuring innovation.

The dependent variable, $Patents_{it}$ is the citation-weighted number of patents that are granted to firm *i* and applied in year *t*.

Service Revenues. Service revenues (or its transformed versions) have been commonly used as a measure of servitization by the econometric analyses in the literature.

Our approach for measuring service revenue (*Service*) is inspired by Fang et al. (2008). The Compustat Business Segments database provides two NAICS codes (and their corresponding SIC codes) for each segment. We select a subset of NAICS codes as service codes. These codes, listed in Table 1, correspond to the codes under t1he *service* category in the SIC system (i.e. the two-digit codes from 70 to 89). The following rules are used to determine the annual service revenues for a given firm: If both of the segment codes are service codes, then all of that segment's annual revenues will be considered service revenues. If only one of the two codes is a service code, then 50 percent of that segment's revenues are considered service revenues. Our post-hoc analyses indicated that the results are not sensitive to this decision rule. The firm's annual service revenues will be computed as the sum of the annual service revenues across the segments.

Table 1. NAICS Service Codes

Two-digit NAICS Code	Description
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services
62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)

Absorptive Capacity. Absorptive capacity is often conceptualized as a firm's knowledge base – the stock of prior knowledge (W. M. Cohen & Levinthal, 1989; Mowery et al., 1996; Kim, 1998; Ahuja & Katila, 2001; Lane, Koka, & Pathak, 2006). Cohen and Levinthal (1989) argue that R&D investment not only generates new knowledge but also enhances a firm's ability to identify, assimilate, and exploit knowledge from the environment. The authors equate this second face of R&D with absorptive capacity. Consistent with this view many scholars have considered R&D intensity (R&D divided by total sales) as proxies for firm's absorptive capacity (W. M. Cohen & Levinthal, 1990; Mowery et al., 1996; Lane & Lubatkin, 1998; Tsai, 2001). Following this literature we operationalize absorptive capacity using R&D intensity (*RDInt*).

Human Resource Productivity. Consistent with prior research (Huselid, 1995; Koch & McGrath, 1996; Guthrie, 2001; Datta, Guthrie, & Wright, 2005) we operationalize human resource productivity with sales per employee – the ratio of firm sales to number of employees (*SEMP*). This measure is not without limitations. Especially, sales can change without a major shift in employee characteristics. Additionally, this metric is most useful when industry or firm differences are taken into account. We address these limitations by controlling for firm size (assets, sales, number of employees) variations and firm-to-firm differences in our models.

Service Types. We classify services based on the type of segment they are located in. We identify three segment groups: (a) pure-service segments: segments that only have service activities, (b) servitized segments: segments that have both manufacturing and service activities, and (c) all other segments. The total amount of services sold by pure-service segments will be captured in the variable *Service_Pure*. The total amount of service sold by servitized segments will be captured in the variable *Service_Servt*. The remainder of service sales will be captured in *Service_Other*. The following equation describes the relationship between service types:

$$\text{Service}_{it} = \text{Service\_Pure}_{it} + \text{Service\_Servt}_{it} + \text{Service\_Other}_{it}. \quad (1)$$

Product Sales Growth and Volatility. In order to measure these two variables we standardize sales and shift it to the right by a constant for positivity; we then regress the log of standardized sales on time over the past four years. Growth variable (*Growth*) will be the exponentiated slope of time and the standard deviation of residuals will be the sales volatility (*Volatility*). Fang et al. (2008) use a similar approach for computing the growth and volatility of industry sales.

Control Variables. Previous studies in innovation have demonstrated a number of variables that influence innovation. We control for the effects of these variables in our analysis. R&D intensity (*RDInt*) captures firm-level differences in innovation effort and is directly related to the amount of new knowledge and innovation generated by firms (Griliches, 1981; Pakes & Griliches, 1984; W. M. Cohen & Levinthal, 1989). Therefore, we controlled for it in our analysis. Firm size is another important factor to consider. Larger firms have more resources to generate new knowledge; they may also have a higher propensity to patent because they can more easily afford the costs of patenting and enforcing patent rights. Smaller firms may not have the resources necessary for pursuing legal action in the event of patent violation, which decreases their incentives for patenting. In order to control for firm size, we include the number of employees (*EMP*) and the total value of assets (*Assets*) in our analysis. We control for firm's return on investment (*ROA*) and return on sales (*ROS*) as measures of profitability. More profitable firms may be more willing to protect their intellectual properties. They may also be more successful in generating new knowledge due to their more effective management. Employee qualities also impact knowledge creation. We also include sales per employee (*SEMP*) to control for employee productivity.

summarizes the descriptive statistics and correlations for our variables pooled across firms and time.

Table 2. Descriptive statistics and correlations

Variable	Patents	Service	Service_pure	Service_servt	RDInt	Assets	ROA	ROS	EMP	SEMP	Growth	Mean	Std. Dev.
Patents												65.284	235.541
Service	0.315*											63.300	127.096
Service_pure	0.212*	0.348*										7.795	51.719
Service_servt	0.254*	0.804*	-0.036*									43.970	104.127
RDInt	-0.050*	-0.144*	-0.043*	-0.123*								1.896	5.987
Assets	0.276*	0.467*	0.338*	0.163*	-0.074*							605.969	2183.233
ROA	0.093*	0.227*	0.067*	0.196*	-0.227*	0.135*						-0.268	-0.619
ROS	0.061*	0.158*	0.045*	0.137*	-0.895*	0.083*	0.356*					-2.474	-7.917
EMP	0.304*	0.434*	0.392*	0.126*	-0.082*	0.753*	0.137*	0.088*				2.694	9.417
SEMP	0.054*	0.277*	0.025*	0.271*	-0.249*	0.218*	0.211*	0.274*	0.059*			185.928	205.794
Growth	0.006	-0.011	-0.033*	0.018	-0.121*	-0.041*	0.022	0.126*	-0.054*	0.108*		1.100	0.236
Volatility	-0.069*	-0.100*	-0.054*	-0.095*	0.079*	-0.078*	-0.181*	-0.080*	-0.099*	-0.045*	0.004	0.050	0.064

* $p<0.05$.

Analysis Methods

Our dependent variable, *Patents*, is a skewed count variable for which a negative binomial model is recommended (Cameron & Trivedi, 1986; Schilling & Phelps, 2007; Berk & MacDonald, 2008). We also consider multiple time lags in the models.

RESULTS

Our main hypothesis, H1, states that the level of servitization is positively associated with innovation outcomes. The results of the random effects negative binomial regression models for the main effect of *Service* are shown in Table 3. Models 1 and 2 report the regression results with a 1-year time lag between the dependent variable and the regressors. Models 3 and 4 report the regression results with a 2-year lag, and models 5 and 6 report the regression results with a 3-year lag. The estimation algorithm adjusts the multiple series for lagged data. The effect of *Service* is positive and significant under all lag structures (1–3 years). We conclude that H1 is supported.

Table 3. Random Effects Negative Binomial Regression Results – Main Effect of Service

	$Patents\_CCW_{it+1}$		$Patents\_CCW_{it+2}$		$Patents\_CCW_{it+3}$	
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	1.177***	1.305***	1.158***	1.195***	0.800***	0.847***
	(0.093)	(0.097)	(0.096)	(0.103)	(0.103)	(0.104)
RDInt	0.440**	0.119	0.459*	0.139	0.571*	0.577^
	(0.161)	(0.223)	(0.181)	(0.235)	(0.272)	(0.314)
Assets	0.013	0.004	0.009	0.005	0.080**	0.027
	(0.013)	(0.014)	(0.022)	(0.025)	(0.026)	(0.036)
EMP	0.031***	0.018***	0.041***	0.025***	0.032***	0.025***
	(0.002)	(0.003)	(0.004)	(0.005)	(0.006)	(0.008)
ROA	0.233***	0.174***	0.182**	0.118^	0.193**	0.136^
	(0.054)	(0.053)	(0.064)	(0.062)	(0.073)	(0.072)
ROS	0.006^	0.006^	0.003	0.003	0.004	0.004
	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
SEMP	0.103	0.174	0.307	0.046	0.369	0.074
	(0.177)	(0.185)	(0.210)	(0.219)	(0.261)	(0.269)
Service		2.280***		2.392***		2.576***
		(0.204)		(0.233)		(0.271)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-1.94e+04***	-1.94e+04***	-1.55e+04***	-1.54e+04***	-1.22e+04***	-1.21e+04***
AIC	38884.056	38762.368	30960.669	30867.986	24354.883	24277.708
BIC	39048.003	38933.146	31113.363	31027.319	24496.660	24425.930
N	6844	6844	5647	5647	4649	4649

Standard errors in parentheses; ^ $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Table 4 reports the results from interaction models. We estimate the interaction effect of six variables under three lag structures (eighteen models in total). For the sake of brevity we only include the models with interaction terms, although, the significance of likelihood ratio tests are included in order to show whether the addition of interaction term improved model fit.

Hypothesis 2 states that absorptive capacity positively moderates the relationship between servitization and innovation. Models 1, 2, and 3 in Table 4 indicate a positive interaction effect between *Service* and *RDInt* for the three lag structures. Therefore, H2 is supported.

Hypothesis 3 states that human resource productivity positively moderates the relationship between servitization and innovation. Model 4-6 in Table 4 indicate that the interaction effect between *Service* and *SEMP* is marginally significant for the first lag, but nonsignificant for the second and third lags. Therefore, H4 is not supported.

Hypothesis 4 requires that the effect of service sales on innovation be stronger in servitized segments than in pure-service segments. As shown in Table 5 the effect of *Service_pure* is no significant in any of the models, while, the effect of Service_servt is positive and significant. The Wald tests statistics (lag1: 21.46, p<0.0001; lag2: 8.87, p=0.0029; lag3:7.87, p=0.005) also indicate that the difference between regression coefficients of *Service_pure* and *Service_servt* in models 4, 6, and 9 are significant. We conclude that H5 is supported.

Hypothesis 5a states that product sales growth negatively moderates the relationship between servitization and innovation. Table 4 indicates that the interaction effect between *Service* and *Growth* is negative and marginally significant for the first (model 13), but nonsignificant for the second and third lags. We conclude that H7a is not supported.

Hypothesis 5b states that product sales volatility positively moderates the relationship between servitization and innovation Table 4 indicate a positive interaction effect between *Service* and *Volatility* for the second and third lags and a positive and marginally significant effect for the first lag. We conclude that H7 is supported.

Table 4. Random Effects Negative Binomial Regression Results – Moderation Effects

	ACAP			SEMP		
	Lag 1	Lag 2	Lag 3	Lag 1	Lag 2	Lag 3
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-1.338***	-1.216***	-0.813***	-1.306***	-1.178***	-0.813***
	(0.095)	(0.103)	(0.101)	(0.097)	(0.104)	(0.105)
Service	2.062***	2.046***	2.371***	1.876***	1.970***	2.578***
	(0.217)	(0.249)	(0.293)	(0.318)	(0.357)	(0.433)
RDInt	0.052***	0.029^	0.031*	0.056***	0.033*	0.035*
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Assets	0.006	-0.021	0.029	0.002	-0.017	0.033
	(0.014)	(0.021)	(0.039)	(0.014)	(0.022)	(0.038)
EMP	0.020***	0.030***	0.019*	0.020***	0.028***	0.018*
	(0.003)	(0.005)	(0.008)	(0.003)	(0.006)	(0.008)
ROA	0.128*	0.102	0.114	0.123*	0.095	0.098
	(0.054)	(0.064)	(0.074)	(0.054)	(0.065)	(0.074)
ROS	0.033**	0.019	0.021	0.037**	0.023^	0.024^
	(0.012)	(0.012)	(0.013)	(0.012)	(0.012)	(0.013)
SEMP	-0.168	-0.033	-0.121	-0.317	-0.194	-0.126
	(0.186)	(0.219)	(0.271)	(0.211)	(0.251)	(0.307)
RDInt* Service	2.723***	3.713***	3.711**			
	(0.735)	(0.961)	(1.288)			
SEMP* Service				1.649^	1.513	0.174
				(0.855)	(1.006)	(1.318)

Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-1.94e+04	-1.54e+04	-1.21e+04	-1.94e+04	-1.54e+04	-1.21e+04
AIC	38753.881	30859.017	24273.090	38760.887	30867.868	24279.691
BIC	38931.491	31024.989	24427.756	38938.497	31033.840	24434.357
N	6844	5647	4649	6844	5647	4649

Standard errors in parentheses; ^ p<0.10; * p<0.05; ** p<0.01; *** p<0.001.

Table 4. Random Effects Negative Binomial Regression Results – Moderation Effects *(continued)*

	Growth			Volatility		
	Lag 1	Lag 2	Lag 3	Lag 1	Lag 2	Lag 3
	(7)	(8)	(9)	(10)	(11)	(12)
Constant	-1.475***	-1.040***	-1.000***	-1.224***	-0.852***	-0.902***
	(0.144)	(0.157)	(0.182)	(0.093)	(0.091)	(0.109)
Service	4.199***	3.127**	2.877*	2.352***	2.008***	2.348***
	(1.012)	(1.118)	(1.430)	(0.234)	(0.259)	(0.322)
RDInt	0.057***	0.039*	0.035^	0.060***	0.042*	0.040*
	(0.016)	(0.017)	(0.018)	(0.016)	(0.018)	(0.019)
Assets	-0.012	-0.047*	-0.020	-0.015	-0.055*	-0.036
	(0.016)	(0.024)	(0.041)	(0.016)	(0.025)	(0.042)
EMP	0.020***	0.041***	0.035***	0.021***	0.041***	0.038***
	(0.003)	(0.007)	(0.009)	(0.003)	(0.007)	(0.009)
ROA	0.124*	0.106	0.040	0.099^	0.071	-0.013
	(0.057)	(0.071)	(0.082)	(0.057)	(0.071)	(0.083)
ROS	0.035**	0.027^	0.026	0.038**	0.031*	0.032^
	(0.013)	(0.015)	(0.016)	(0.014)	(0.015)	(0.017)
SEMP	-0.236	0.079	0.246	-0.247	0.061	0.207
	(0.197)	(0.233)	(0.292)	(0.196)	(0.233)	(0.293)
Growth	0.221*	0.158	0.071			
	(0.103)	(0.119)	(0.139)			
Growth* Service	-1.477^	-0.812	-0.242			
	(0.897)	(1.007)	(1.278)			
Volatility				-1.491***	-1.562**	-2.137***
				(0.439)	(0.518)	(0.623)
Volatility* Service				4.675^	8.671***	8.702**
				(2.386)	(2.223)	(2.701)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-1.72e+04	-1.36e+04	-1.05e+04	-1.72e+04	-1.35e+04	-1.04e+04
AIC	34529.015	27223.481	20997.576	34430.321	27094.782	20911.694
BIC	34703.764	27386.555	21149.354	34605.006	27257.777	21063.408
N	6131	5029	4122	6116	5013	4111

Table 5. The Effect of Organizational Proximity

	Patents_CCW$_{it+1}$			Patents_CCW$_{it+2}$			Patents_CCW$_{it+3}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	-1.116***	-1.204***	-1.209***	-1.108***	-1.139***	-1.145***	-0.787***	-0.814***	-0.814***
	(0.095)	(0.097)	(0.098)	(0.098)	(0.101)	(0.103)	(0.107)	(0.108)	(0.108)
R&D	0.432*	0.111	0.071	0.558*	0.333	0.222	-0.760**	-1.014**	-1.018**
	(0.179)	(0.229)	(0.234)	(0.217)	(0.243)	(0.293)	(0.289)	(0.351)	(0.352)
Assets	0.007	0.012	0.017	-0.030	-0.020	-0.016	0.075*	0.072*	0.072*
	(0.015)	(0.015)	(0.015)	(0.025)	(0.027)	(0.029)	(0.029)	(0.033)	(0.033)
EMP	0.031***	0.030***	0.028***	0.043***	0.039***	0.036***	0.034***	0.032***	0.031***
	(0.003)	(0.003)	(0.003)	(0.005)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
ROA	0.227***	0.174**	0.173**	0.164*	0.116^	0.115^	0.159*	0.120	0.119
	(0.057)	(0.056)	(0.056)	(0.069)	(0.068)	(0.068)	(0.079)	(0.079)	(0.079)
ROS	-0.005	-0.005	-0.005	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
SEMP	-0.054	-0.415*	-0.423*	0.375^	0.056	0.058	0.427	-0.032	-0.031
	(0.195)	(0.208)	(0.208)	(0.225)	(0.240)	(0.240)	(0.290)	(0.308)	(0.308)
Service (Pure)	-0.022		0.407	-0.139		0.522	-0.599		0.157
	(0.358)		(0.419)	(0.578)		(0.601)	(0.795)		(0.796)
Service (Servt.)		2.156***	2.183***		1.836***	1.875***		2.101***	2.108***
		(0.216)	(0.218)		(0.253)	(0.257)		(0.291)	(0.293)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood†	-1.30E+04	-1.29E+04***	-1.29E+04***	-1.00E+04	-1.00E+04***	-1.00E+04***	-7708.4	-7686.8***	-7686.8***
AIC	26009.1	25923.8	25924.8	20113.7	20067.9	20069.1	15458.7	15415.5	15417.5
BIC	26158.8	26073.4	26081.0	20251.9	20206.0	20213.5	15586.1	15542.9	15550.9
N	4937	4937	4937	3931	3931	3931	3166	3166	3166

Standard errors in parentheses; † log likelihoods are tested against the base model (not shown). ^ $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

Robustness of Results

We checked the robustness of the results in a number of ways. First, we assessed the robustness of our results across different lag structures. The negative binomial panel models developed by Hausman et al. (1984) are commonly used for modeling patent data. However, Allison and Waterman (2002) argue that Hausman et al.'s (1984) fixed effects negative binomial model controls for the fixed effects on the dispersion factor but not on the conditional mean, and therefore, does not fully control for the time-invariant covariates. An alternative is estimating a random effects negative binomial model but embedding a fixed effect estimator in the model to avoid a potential heterogeneity bias (Neuhaus & Kalbfleisch, 1998; Allison & Waterman, 2002). Use of this method confirmed our conclusions regarding the main effect as well as the interaction effects of sales growth, and sales volatility. It did not, however, confirm the results for the interaction effects of absorptive caacity and human resource productivity.

We followed Blundell et al. (1995) and Schilling and Phelps (2007) and control for the heterogeneity of firms' patenting behavior due to differential knowledge stocks prior to entering the sample. Blundell et al. (1995) show that in patent data models controlling for the patent stock with which firms enter the sample adequately adjusts for the unobserved heterogeneity in firms' knowledge stocks and eliminates persistent serial correlation. We used the citation-weighted cumulative number of patents from 1976 to 1990 to compute the *Pre-sample Patent Stock* as a measure of firm's pre-sample accumulated knowledge. Following the literature (Q. Liu & Wong, 2011) we assume an annual depreciation rate of 20 percent for the value of older patents.

Finally, we examined the robustness of results relative to our chosen method for measuring service revenues. In the models reported above we have assumed that when revenue is reported in a business segment with both service and non-service activities, service revenues were equal to half (0.5) of the total revenues, i.e. equal to product revenue. We changed this weight parameter from 0.5 to 0.1, 0.25, 0.75, and 0.9, and re-ran the main-effects models. The results remained qualitatively unchanged.

DISCUSSION AND CONCLUSIONS

Many manufacturers have realized that competition in the global market is not limited to products. This has ignited a race among manufacturers to offer services and integrated product-service solutions (Neely, Benedettini, & Visnjic, 2011). Because services can create new channels of communication with the market and customers, this paper posits that servitization can enhance innovation by providing manufacturers with new sources of knowledge and intelligence. Proper use of such sources can generate knowledge of how the products are performing in relation to the market needs, which product attributes are most critical to improve, and what new products can be developed to satisfy the unmet customer needs. The current paper is the first to use a large scale study to empirically examine innovation in servitized organizations.

We analyzed 17 years of data (1990-2006) from publicly-traded manufacturers in the US using random effects negative binomial regression. The results indicate a strong and robust association between servitization and innovation. Services extend manufacturers' contact with the market and enable a richer communication with customers. Manufacturers who wish to enhance their innovation outcomes can leverage the potential of services to absorb external knowledge.

This result also provides a potential explanation for the bridge decay phenomenon in service outsourcing (Li & Choi, 2009). Li and Choi (2009) argue that there is valuable knowledge in operating services in-house, that would be lost in outsourcing, an assertion confirmed by our findings.

We find that the innovation value of servitization is especially higher for firms with high absorptive capacity. A servitized firm with higher absorptive capacity is better positioned to absorb knowledge from service interactions with the customers. Contrary to our expectation, we did not find a strong moderating effect for human resource productivity. One possible reason is that our measure of productivity, sales per employee, is a ratio which is not solely driven by factors related to employee competencies. The added variation due to the changes in competitive landscape and market conditions, which influence total sales, may have decreases our ability to detect the effect, especially considering that the effect is marginally significant for the first lag as well as in the hybrid model. We also found that proximity of service and manufacturing activities improves the innovation outcomes of servitization. The higher relevance of information coupled with the added benefit of richer and more frequent interaction between employees make organizational proximity especially important for spillover between service and manufacturing activities.

Finally, we see evidence of the influence of environment on the learning that occurs from services. Particularly the effect of servitization on innovation was stronger when product sales had been volatile in the past recent years. Volatility in product sales can indicate stronger competitive dynamics and instability of market conditions. Servitized firms that operate in more volatile conditions appear to be more effective in transforming service-generated knowledge into intellectual property. One potential explanation is that higher business dynamism requires stronger environmental sensing and knowledge absorption skills and firms build higher dynamic capabilities in such an environment (Teece, Pisano, & Shuen, 1997). It is also possible that instability in the product market motivates the manufacturer to offer more services and solutions, which improves the role and influence of the service department.

We acknowledge the limitations of this study. First, we do not directly observe the learning and knowledge absorption that occurs as a result of service offering. While our theory suggests knowledge transfer is the mediating mechanism, there may be other mechanisms by which services are linked to innovation. For instance a differentiation strategy may induce higher emphasis on innovation as well as on superior service. Our adjustments for firm-specific effects, time effects, and firm's past patenting behavior aimed at mitigating such influences. In future research, event history analyses of servitized firms could help validate the theoretical model proposed here. Second, in absence of a direct measure of service sales, we needed to estimate the fraction of total revenue due to services. Our assumption that product and service revenue are equal is unbiased with respect to our hypotheses, and the use of multiple observations of the same firms further mitigates any potential bias. Moreover, lower reliability in a regressor will attenuate the regression coefficient of that regressor, all else equal, and make the results more conservative (K. Liu, 1988). Finally, our robustness check indicated that results were consistent under different weightings between product and service revenue, so we are confident in the validity of the results reported here.

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