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The Acquisition and Commercialization of Invention in American Manufacturing: Incidence and Impact
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ABSTRACT

Recent accounts suggest the development and commercialization of invention has become more "open." Greater division of labor between inventors and innovators can enhance social welfare through gains from trade and greater economies of specialization. Moreover, this extensive reliance upon outside sources for invention also suggests that understanding the factors that condition the extramural supply of inventions to innovators is crucial to understanding the determinants of the rate and direction of innovative activity.

This paper reports on a recent survey of over 6000 American manufacturing and service sector firms on the extent to which innovators rely upon external sources of invention. Our results indicate that, between 2007 and 2009, 16% of manufacturing firms had innovated – meaning had introduced a product that was new to the industry. Of these, 49% report that their most important new product had originated from an outside source, notably customers, suppliers and technology specialists (i.e., universities, independent inventors and R&D contractors). We also estimate the contribution of each source to innovation in the US economy. Although customers are the most frequent outside source, inventions acquired from technology specialists tend to be the more economically more significant in term of their gross commercial value. As a group, external sources of invention make a significant contribution to the overall rate of innovation in the economy. Innovation policies, both public and private, should pay careful attention to external supply of invention, and the efficiency of the mechanisms mediating between inventors and innovators.

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1. Introduction

Until recently, the dominant model of innovation conceived of the innovation process as typically carried out within the confines of a given firm, starting with the firm investing in R&D to generate inventions, and then developing and commercializing those inventions. This model, which reflected the large scale investments in internal R&D made by U.S. firms from the 1940s through the 1970s, has become less accurate as a description of the innovation process over time (Chesbrough, 2003). But we lack systematic evidence on the extent to which innovation introduced by US manufacturers relies upon external invention..

Distinguishing between invention (i.e., discovery) and innovation (i.e., the commercialization of an invention), this paper presents results from a survey of over 6000 American manufacturing and service sector firms on the extent to which innovating firms obtain inventions from external sources. We first identify innovating firms, and then document the share of innovating firms that acquire their inventions from different sources as well as the channels through which firms acquire those inventions. We also characterize how the distribution of value from invention compares across different sources. Finally, we estimate the relationship between external sourcing of inventions and the innovative performance of the manufacturing sector.

Why is our study of what Arora and Gambardella (1994) call the "division of innovative labor" important? The availability and use of external sources of invention may offer important social welfare benefits. First, there are social welfare gains from trade. When the firms best equipped to invent are not necessarily the firms most capable of commercializing invention, society benefits when an invention can transfer between them. Economic theory, starting with Adam Smith, further suggests that such a division of innovative labor should also confer system-wide efficiencies through economies of specialization.

In addition to the welfare implications of a division of innovative labor, our study offers implications for empirical scholars of technological change. For example, if reliance upon external sources of invention is pervasive, then an understanding of the factors affecting the availability of those inventions should help us understand an industry's rate of innovation. Moreover, to the degree that other firms in other industries are supplying these inventions, an understanding of an industry's innovative activity will need to extend beyond conventionally considered determinants of innovation applicable to the innovating firms' own industry (e.g., appropriability, market demand, and technological opportunity) to those applicable to the markets of the potential suppliers of invention.

A number of related literatures have already examined the links across firms and between firms and other institutions that contribute to innovative performance. One literature has focused on knowledge spillovers across rivals, as distinct from the purposeful sourcing of invention (e.g., Griliches, 1992). Other studies have focused on particular sources of inventions—including startups (e.g., Arora and Gambardella, 1990), universities (e.g., Klevorick et al., 1995; Henderson et al., 1998; Cohen et al., 2002), suppliers (Pavitt, 1984), and customers (e.g. von Hippel, 1986)—as important contributors to the innovations produced by firms.

Building upon Mueller (1962), Jewkes, Sawers and Stillerman (1969), Freeman (1991) and others, survey-based studies of the American manufacturing sector have considered a broad set of knowledge sources for innovative activities, such as buyers, suppliers and universities (Klevorick et al., 1995; Cohen et al., 2002a, 2002b). More recently, scholars using data gathered through the Community Innovation Survey (CIS) have also reported findings on the different sources contributing to firms' innovative activities in Europe. Examples of these studies include Tether (2002) for the UK, Veugelers and Cassiman (1999) for Belgium, Lhuillery, S., & Pfister, E. (2009) for France, and Belderbos et al (2004) for Netherlands. Mohnen and Roeller (2005) and Tether and Tajar (2008) are examples of studies that use cross-country CIS data. These studies tend to find that external collaborations are important for innovation. Moreover, customers tend to be the most common source of knowledge contributing to firms' innovative activities.

Other studies have examined specific channels through which firms' benefit from extramural sources of knowledge, such as licensing (e.g., Arora and Gambardella, 1990; Arora et al., 2001) and collaboration (Hagedoorn, 2003). More recently, capitalizing on successive versions of the CIS, others have focused on the contribution of collaboration to firms' innovative activities (e.g., Tether, 2002; Laursen and Salter, 2006, 2014; Grimpe and Sofka, 2009, Sofka and Grimpe, 2010, Belderbos et al. 2004).

Our paper offers several advances. First, we report on the contribution of external sources to firms' innovative activities in the U.S., as distinct from prior studies for the U.S. that focused on the contributions of external sources to R&D per se (Klevorick et al., 1995; Cohen et al., 2002a, 2002b). Second, our survey is the first to focus on whether an innovating firm obtains the underlying *invention* from an outside source, unlike prior work that examined the importance of information flows from different sources or collaboration with external sources.

Unlike the prior literature, our survey focuses on the respondent's most important product innovation rather than the respondents' innovations in general. Inquiring about a specific innovation allows us to link the source of the invention to the channel employed, as well as to other activities and outcomes, such as the percentage of sales due to the specific innovation, and whether the innovation has a patent. We are also able to tie the specific innovation to activities to commercialize the innovation, including investment in equipment, hiring of new personnel, or the development of new distribution channels. Our data also permit us to compare the relative value of inventions originating from different sources by allowing us to distinguish between the cost and benefits of different sources by providing measures of the frequency with which inventions are obtained from a particular source that we then combine with various indicators of value, such as the share of sales from the innovative product, whether it was patented, and whether the innovator made complementary investments.

To preview our findings, we find that, of the 16% of the U.S. manufacturing firms that innovated (i.e., had introduced a new or significantly improved product to the industry) between 2007 and 2009, 49% report that their most important new product originated from an identified outside source, suggesting pervasive reliance upon external sources of invention. Just over a third of these transfers involves a market transaction, such as a license, a service contract or an equity purchase. We also find that, although customers are the most pervasive source of outside invention, those originating from what we call "technology specialists"—independent inventors, contractors and universities—tend to be more valuable. Finally using two different analytic approaches, we conclude that denying firms the opportunity of going to an outside source could lead to a reduction of as much as 33% to 45% in the share of innovating firms in the U.S. manufacturing sector.

To motivate the study, section 2 offers a simple model to illustrate how external supply of inventions may affect innovation. In section 3, we describe the survey design underlying our sample. Section 4 presents our findings with respect to innovation rates, the sources of innovation, and the channels through which innovators acquire the inventions underlying their innovations. We also compare the relative cost and value of the inventions originating from different sources, and analyze the relationship between innovation rates and the extramural sourcing of invention. Section 5 summarizes our main findings, discusses the implications and concludes.

2. Background

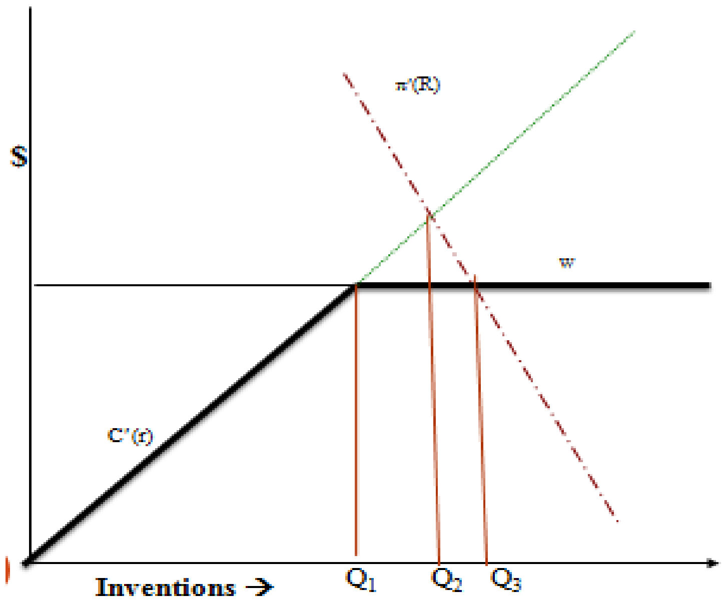
If external sourcing of invention is pervasive, this has important implications for our understanding of the drivers of innovation. To motivate our empirical analysis, we offer a simple illustrative model to show that external sources do not simply provide a choice between internal R&D and the purchase of an invention from an outside source. That is, they do not only affect a firm's "make or buy" decision.[4] External availability of invention can also affect whether firms decide to innovate in the first instance.

In Figure 1, we assume that the firm has a demand schedule for invention derived from product market demand. We also assume it faces an upward marginal cost schedule for invention, which represents the cost of generating innovation internally. Without external supply, the equilibrium quantity of inventions is Q_2. We further assume, however, that the firm can access external inventions at a constant cost, w. Figure 1 allows us to make two points. First, it shows that the availability of externally sourced invention can increase the overall rate of invention, and, in turn, innovation from what it would be in the absence of external supply, in this case from Q_2 to Q_3. Second, the presence of external sources of invention also yields some substitution of external inventions for internal inventions, represented by Q_2 - Q_1. Thus, we expect the supply of external technology to affect both the overall rate of innovation and the share of internally generated innovations.

The cost of externally available inventions, **w**, does not simply reflect the cost of their generation by external parties. There are also numerous costs associated with the acquisition of invention from external sources. The relevant information and rights must be transmissible across firms, and thus be applicable outside the context in which it was developed (von Hippel 1990; Arora and Gambardella, 1994). Once transmitted, the knowledge is at risk of misappropriation, and patents in practice offer effective protection in only a small number of industries (Scherer et al., 1959; Levin et al., 1987; Cohen et al., 2000). Williamson (1991) and

[4] For instance, Pisano (1990), in his study of pharmaceutical industry R&D, is one of many who consider the issue of relying on external invention strictly in terms of "make-or-buy."

Figure 1: Supply and Demand for Inventions



Teece (1986) also highlight the role of transaction costs in limiting market transactions in knowledge. Mowery (1983) and Kline and Rosenberg (1986) further note the need for ongoing coordination and mutual adjustment across different innovation stages that can further impede the writing of complete contracts. Finally, it is costly for buyers and sellers of inventions to find one another. Thus the transfer of inventions across entities is often fraught with difficulties, imposing costs beyond simply the price of the invention (cf. Arora and Gambardella, 2010).

3. Data: Survey design

Our data are from a phone survey of firms in U.S. manufacturing and selected service sector industries (see Table A1 in the appendix for a list of the industries in the sample).[5] In this paper we focus on the manufacturing sector alone. Our sampling frame was the Dun and Bradstreet (D&B) Selectory database. Note that we are not sampling on innovators (as done in studies based on patent data), nor on R&D performers (as done in the Carnegie Mellon Survey (Cohen et al., 2000).[6]

To obtain a substantial number of innovators from each industry, we stratified our sample along multiple dimensions. Because all cases stay in the sample, errors in the D&B data used for

[5] NORC, at the University of Chicago, administered our survey.
[6] This sampling strategy is analogous to that employed by the Community Innovation Survey (CIS) in Europe and the U.S. National Science Foundation's Business R&D and Innovation Survey (BRDIS).

stratification only affect the efficiency of the sampling, not its representativeness (Kalton, 1983). To begin, we selected all the D&B cases in our population of industries. We took all the Fortune 500 firms in our sample and collected information on all the subsidiaries of those firms that were in our population industries, even if those were not the main industry of the parent firm. These subsidiaries were grouped into business units, defined as a firm's activities within a given NAICS, with each subsidiary grouped by its primary NAICS. For these Fortune 500 firms, the sampling unit is the firm's activity in a NAICS (so that a diversified Fortune 500 firm may appear multiple times in the sample). All other firms were assigned a single sampling unit based on their primary NAICS. The sample was stratified into 28 industries, at the 3 or 4 digit NAICS. Finally, the sampling frame was divided by size (Fortune 500, over 1000 employees but not Fortune 500, 500 to 1000 employees, 100 to 499 employees and 10 to 99 employees, and less than 10 employees), and by startup or not (less than five years old versus five or more years old).

We oversampled large firms (Fortune 500, which were sampled with certainty across all business units, and firms of over 1000 employees), startup firms, those from more innovative industries (using Community Innovation Survey (CIS) data from Europe to estimate innovation rates for each industry), those in NAICS 533 as a primary or secondary industry (lessors of intellectual property) and less populated industries (to ensure minimum sample sizes for industry-level estimates). Other categories were under-sampled. We use a post-sample weighting procedure (described below) to make the D&B data representative of U.S. manufacturing industries.

The survey design included cognitive testing of the questionnaire against potential respondents, pre-testing of the instrument and protocol, and multiple rounds of follow-up contacts to increase response rate. The survey instrument was designed with a branching logic so that non-innovative firms received only a brief questionnaire, and firms that innovated were asked more details about their innovation process and outcomes. The sample consisted of 28,709 cases. An initial screening eliminated many cases, (for example, bakeries that are in retail, not manufacturing) leaving a final sample of 22,034. The interview protocol started with a D&B

contact name (ideally the marketing manager or, for smaller firms, the business manager), and then worked through the receptionist or other contacts to find an appropriate respondent.[7]

The survey was in the field from May to October, 2010. In the end, we received 6685 responses, yielding an adjusted 30.3% response rate. Appendix Table A2 shows the response rates by industry and firm size. Non-response bias tests comparing D&B data for respondents and non-respondents show that the sample represents the population on firm age, being multiproduct, region, or likelihood to export (how international the firm is). Units of Fortune 500 firms were somewhat less likely to respond (about 20% response rate). Similarly, large firms, multi-unit firms and public firms are somewhat less likely to respond. With regard to industry responsiveness, pharmaceuticals had a low response rate, but still over 20%. Further cleaning (based on recoding industries according to survey responses rather than initial D&B categorizations) identified another 179 out-of-population respondents. For the remaining sample, D&B business unit industry classifications were confirmed, and if necessary updated, based on survey responses. In addition, for the purposes of this paper, we exclude the very smallest establishments (less than 10 employees) and non-manufacturing establishments. The result is a sample of 6088 cases. Appendix Table A3 presents the distribution of our sample based on NAICS (disaggregated to 48 industries with at least 30 cases in each industry) and firm size (collapsed into small [less than 100 employees], medium [100-1000 employees] and large [over 1000 employees]).

We reweighted the sample with post-sample weights based on Census data on the population of firms in our industries, size strata and age. We constructed a matrix of these three dimensions of stratification from a custom report provided by the U.S. Bureau of the Census,[8] and then constructed a set of weights for our 6088 responses that reflect the population distribution on this three dimensional matrix. After applying these weights, our sample should represent the underlying population in terms of the industry-size-startup distribution (Kalton, 1984). These weights are used in all the empirical results in this paper.

[7] According to the interview script, an appropriate respondent would be "the marketing manager or another person in your company familiar with the firm's products and services." This flexibility in finding an appropriate contact person was a key rationale for using a phone survey over post-mail or email surveys.

[8] We thank Ron Jarmin and his team at the U.S. Bureau of the Census for providing this report.

4. Findings

4.1 Innovation

In this study, we focus exclusively upon product, rather than process, innovations. Following prior innovation surveys, we asked the respondent if the firm had earned any revenue in 2009 from a new or significantly improved (NOSI) product or service introduced since 2007. For those that said yes, we then asked whether their most significant innovation -- defined as that product innovation accounting for the plurality of 2009 sales in the respondent's market -- was new to the market (NTM), i.e. introduced "in this industry before any other company".[9] We do not specify a geographical boundary to the "industry" (for example, we are not limiting to a local or domestic "market").[10] Table 1 provides illustrative examples of innovations introduced by firms in the manufacturing sector. We also asked whether our respondents had developed technology for other firms.

About 10% of our respondents report that they had both supplied technology to another firm and also introduced new products to the market. Only 4% of manufacturing firms had developed technology for another firm but had not themselves introduced a new product to the market. These firms may be considered specialized technology suppliers. In this paper, we shall focus on firms that commercialize new products.

Table 2 presents summary statistics for the rates of innovation overall and by industry, where we aggregate our observations of firms in the manufacturing sector into 17 industry groups, defined largely at the 3-digit NAICs level. The figures in Table 2 and all subsequent tables are weighted to be representative of firm size (when reported at the industry level), industry (when reported by firm size) and the true firm size and industry distribution (when reported at the aggregate level).

Table 2 shows that 42% of firms report introducing a new-to-the-firm (not necessarily new to the market) or significantly improved (NOSI) product in the prior three years. We also find significant differences in the rates of new or improved product introduction across

[9] Our NTM figure may underestimate the percentage of firms introducing NTM innovations. For example, a firm's most significant (i.e., highest selling) innovation may not be NTM, but its second most significant is, implying that the firm is incorrectly classified as a not an "NTM" innovator. However, any bias is likely to be small because a sizeable fraction of firms introduce only at most one innovation during the sample period, as discussed below.
[10] We also did not count as innovators firms that reported either that they introduced their "most significant innovation" outside of the 2007-2009 time window, or reported zero 2009 sales revenue due to this innovation.

industries. For example, at least 60% of firms in electronics, pharmaceuticals and semiconductors introduced a NOSI product, while barely one-third of firms in wood or mineral products did so. If we limit product innovations to the introduction of something new to the market (NTM), we find that 16% of manufacturing firms have introduced such an innovation, with substantially higher rates in instruments, electronics and pharmaceuticals, while wood and metals have lower rates. Thus, 38% of firms with a NOSI product are the first to bring that product to market, and are classified as innovators. In what follows, the term "innovation" refers to products that are new to the market.

Table 1: Examples of innovations in sampled industries.

Industry	Innovation
Food	*Antioxidant chocolates*
Food	*Live active cheddar cheese with probiotics*
Beverage	*vitamins enhanced flavoured spring water*
Textile	*Heat resistant yarn*
Textile	*New varieties of garments*
Paper	*Low surface energy light tapes resistant to air, water, detergents, moisture, UV light, and dust*
Paper	*Hanging folder with easy slide tab*
Petroleum	*Non detergent motor oil*
Chemicals	*BioSolvents – water based emulsion technology*
Pharmaceutical	*Oral gallium to prevent bone decay*
Pharmaceutical	*inhalation anaesthetics*
Plastics	*Styrene based floor underlayment*
Minerals	*Multi-wall polycarbonate recyclable panels*
Minerals	*Solar glass and coating technologies solar modules*
Metals	*Solder system & nanofoils*
Metals	*New water faucets and bath products*
Electronics	*USB-to-GPIB Interface Adapter*
Electronics	*20-h IPS Alpha LCD Panel*
Semiconductors	*Linear voltage regulators*
Semiconductors	*Phase change memory*
Transport Equipment	*Improved alcohol sensing system*

Table 2 also shows that larger firms are more likely to innovate and more likely to introduce new products. We find that 39% of small firms but 65% of large firms introduce new NOSI products. For innovations (i.e., new to the market products), the rates were 13% and 38%

for small and large firms, respectively. Thus, larger firms are more likely to have at least one innovation. This result is expected since the respondent is reporting if there is at least one innovation, which should be more likely for larger firms (cf. Cohen and Klepper, 1996). If we interpret the difference between NOSI and NTM as measuring imitation, it follows that innovation increases by firm size but imitation is relatively stable across firm size classes. A similar stability in imitation rates is also observed across industries.

Table 2. Rates of innovation and imitation, patenting and % sales for U.S. mfg. industries.

INDUSTRY (Number of respondents)	% NOSI . **a**	% NTM . **b**	%Imitator . **a-b**	% sales from NOSI	% sales from focal NTM innovation	% NTM patented
Food/Bev (362)	40%	13%	27%	16%	9%	24%
Textiles (210)	37%	15%	22%	19%	15%	51%
Wood (385)	33%	8%	25%	15%	7%	11%
Chemicals (365)	49%	24%	25%	17%	9%	42%
Pharma (128)	62%	28%	33%	23%	13%	61%
Plastics (340)	47%	16%	31%	14%	6%	42%
Minerals (323)	30%	9%	21%	21%	14%	35%
Metals (324)	38%	9%	29%	14%	5%	23%
Fab Metals (424)	38%	10%	28%	28%	8%	35%
Machinery (384)	44%	20%	24%	24%	14%	52%
Electronics (146)	76%	33%	43%	38%	9%	58%
Semicond (302)	60%	27%	33%	29%	18%	59%
Instruments (135)	59%	37%	22%	17%	7%	54%
Elec Equip (344)	54%	26%	28%	25%	13%	53%
Auto (339)	50%	27%	23%	25%	11%	34%
Med Equip (136)	55%	22%	33%	37%	31%	72%
Misc. (510)	47%	19%	29%	30%	10%	45%
All manuf. (5157)	42%	16%	27%	22%	11%	42%
Large firms (1268)	65%	38%	27%	24%	10%	63%
Med. firms(945)	54%	23%	31%	20%	15%	47%
Small firms (2944)	39%	13%	26%	19%	12%	36%

For those respondents reporting that they innovated (i.e., introduced a NTM innovation), the fifth and sixth columns of Table 2 show the percentage of 2009 sales represented, respectively, by all new-to-the firm products introduced since 2007 and by the single most important product innovation. For all manufacturing firms, we learn that the single most important new product accounts on average for 11% of the business unit sales while *all* products that are new to the firm account for 22% of business unit sales. These figures are sales-weighted.

If we take the simple rather than sales-weighted averages, the single most important new or significantly improved product accounts on average for 20% of the business unit sales compared to 27% for *all* products that are new to the firm. The average across firms of the ratio of the percentage sales of the most important new product to that of all new products is 69%, indicating, consistent with Scherer and Harhoff (2000), that the revenue impact of new products tends to be highly skewed. Indeed, our data further suggests that a sizable share of our sample firms have only one new or significantly improved product over the sample period.

Table 2 also provides the first industry-level estimates of patent propensity for product innovation for all U.S. manufacturing firms.[11] Fewer than half (42%) of the innovating firms reported patenting their most significant innovation, with considerable variation across industries and firms. Industries where the share of firms investing in R&D is higher than average also tend to patent new products at higher than average rates. Nearly two thirds of the large firms patent their most significant innovation compared to only 36% of small firms. Note that these figures represent patenting by the innovating firm. When the innovation is based on an external invention, we separately ask whether the inventor had a patent on the invention (see below).

A separate analysis of our data indicates that 94% of innovating (NTM) firms conduct R&D and that 89% of internally generated innovations are from R&D (Lee, 2015). For comparison, BRDIS 2011 shows that 94% of patented inventions came from R&D performing firms (National Science Board, 2014). On the other hand, 55% of new-to-firm (NOSI) innovators conduct R&D, which is to say 45% of new-to-firm innovators did not report conducting R&D (Lee, 2015).

To assess the validity of our survey, we compare our findings regarding innovation rates with those from other innovation surveys. The rank order correlation between our survey-based NTM innovation rates at the industry level, and other innovation measures such as patenting and the percentage of R&D performing firms (collected from our survey), are high, above 0.7.[12] For the cross-national comparisons, one might expect differences across otherwise comparable national economies simply due to differences in the distribution of respondents across firm size

[11] The Carnegie Mellon Survey reported the patent propensities only for R&D performing firms, not all innovating firms (Cohen et al., 2000). Nonetheless, and despite the 15 years between the two surveys, the industry-level patent propensities (i.e., percentage of innovations patented) are similar.

[12] Our patent data were obtained from PATSTAT, from which we estimated the percent of firms in each industry that had a patent application.

classes and industries and that innovation rates differ across these dimensions. Nonetheless, as compared to 42% of our respondents that earned revenue in 2009 from (NOSI) products introduced since 2007, the CIS in the UK reports that about 34% of manufacturing respondents had introduced such a new product between 2006 and 2008. For Germany, 49% of manufacturing respondents report introducing a new product. Turning to innovation (i.e., NTM), about 38% of the NOSI respondents in our survey had introduced a product that was new to the market as well. The comparable figure for the UK is 51% and that for Germany is 45%. Thus, despite differences across the three countries in the rate at which manufacturing firms introduce new products, the share of those products that are new to the market is similar. Moreover, the overall rate of product innovation is also similar to our estimate of 16%, ranging from about 17% for the UK to 22% for Germany.

4.2 Acquisition of inventions by innovating firms

A key distinction in this paper is between a product innovation (the introduction of a product that is new to the market) and the invention that underlies it. In our survey, we asked our innovating respondents if an outside source originated the associated invention. The possible sources considered include: 1) a supplier; 2) a customer; 3) another firm in the same industry as the respondent; 4) a consultant, commercial lab or engineering service provider; 5) an independent inventor; and 6) a university or government lab. [13]

Sources of invention

Table 3 shows the different external sources and the rates of reliance on each—overall, by industry, and by firm size. We find that 49% of our respondents reported their most important product innovation originated from an outside source. Customers are the single most likely source of external invention, followed by suppliers. The mean number of sources for those respondents that indicate an external source is 1.42, with 32% reporting more than one source.

The salience of customers as an external source of invention comports with prior literature that suggests that customers are an important source of knowledge flows and ideas (e.g., von Hippel, 1986, 2005, Cohen et al., 2002b; Klevorick et al., 1995). Table 3 also shows

[13] Inquiring about which of these sources may have originated the invention if it came from outside the firm, the precise wording in the questionnaire is: "Did any of the following originate this innovation, that is, create the overall design, develop the prototype or conceptualize the technology?" The firm as a whole may use more sources if it introduces multiple innovations.

that one of the most notable differences across size classes is that suppliers are a much more likely source of invention for large firms. This makes sense given that it is in suppliers' interests to provide firms with new product ideas that increase input requirements, implying that suppliers ought to pay particular attention to the largest firms among their customers.

If we classify consultants, independent inventors and universities all in the same category of "technology specialists," we see that together they account for 17% of externally sourced inventions.[14] For respondents reporting specialists as a source, the only noteworthy pattern is that independent inventors are a markedly more common source for small firms. Though not reported here, we find that there is no systematic tendency for any one source to be bundled with another, except that, when a respondent indicates a customer to be the source of an invention, the respondent is less likely to identify any other source.

We find that universities are the least frequently used source of inventions. This shows the importance of distinguishing between knowledge sources and invention sources. For example, Cohen et al. (2002b) reported that 29% of manufacturing firms' R&D projects used university research results, while only 8% of R&D projects made use of prototypes from universities. This latter number is closer to our finding.

There is substantial variation across industries in the use of different sources. For example, if we use the fraction of firms in an industry that perform R&D as a measure of an industry's technological intensity, we find that, with a correlation coefficient of 0.40, industry technology intensity is positively related to innovators' reliance upon universities. In contrast, the correlation coefficients between technological intensity and reliance on customers and suppliers are, respectively, -0.30 and -0.49, indicating that industries' technology intensity is negatively related to firms' acquisition of inventions from sources in the value chain.

The patenting of externally acquired inventions also varies by source. For example, although 42% of our innovations are patented, we find only 29% and 33% of these innovations are patented when the customer and supplier, respectively, are the sources. This compares to

[14] Our aggregation is consistent with Tether and Tajar (2008) and Nieto and Santamaria (2007) who group external collaborations into vertical (suppliers and customers), competitors, and specialists (consultancies, research organizations, and universities). Also, to test the robustness test of our grouping, in our regression results reported below in tables 5a and 5b, where we compare the relative value of inventions from different sources, we split the category of technology specialists into its three constituents. We cannot reject the null hypothesis of equality of coefficient estimates in the majority of the specifications.

72%, 68%, and 59% when the invention is sourced from, respectively, a university, an independent inventor, or an R&D service provider. Thus, where inventions originate from technology specialists generally, the patent rate for the associated innovation is 65%. We consider the implications of the differences in patent rates across sources in section 4.3 below.

Table 3: Sources of external invention, as % of innovators, by industry and firm size.

	N	Any source %	Supp-lier %	Custo-mer %	Other firm in Industry %	Consult./ Service provider %	Indep. Inventor %	Univ %	Tech. Specia-list %
Food & Bev	63	46	34	15	8	1	5	0	6
Textiles	33	50	32	26	4	3	6	0	9
Wood	52	52	22	27	11	14	1	0	15
Chemicals	102	49	17	15	5	10	3	5	16
Pharma	30	50	2	9	17	6	6	19	30
Plastics	74	53	11	28	5	11	16	4	27
Minerals	36	49	6	23	3	8	12	10	27
Metals	44	49	29	30	11	11	4	7	13
Fab'd Metal	60	48	10	38	6	0	4	3	7
Machinery	98	49	7	36	10	12	7	6	21
Electronics	50	45	11	17	10	8	6	5	14
Semicond.	91	62	16	49	9	13	8	9	23
Instruments	53	48	5	26	7	11	9	1	19
Elect Equip	98	44	12	26	4	8	7	4	17
Auto	101	52	11	28	12	6	17	15	25
Med Equip	36	49	18	22	4	13	9	15	32
Misc.	106	46	8	20	13	10	9	2	18
All Mfg.	1127	49	14	27	8	8	7	5	17
Large	457	51	22	25	9	7	4	6	14
Med	224	48	12	26	9	8	4	5	16
Small	446	49	13	28	8	8	9	5	18

Our data also indicate the extent to which startups may be a source of inventions for firms that rely on external sources. On average, across all sources, 13% of those firms relying upon an outside source for their invention report that the source is a startup (defined in our questionnaire as a "new, small company"). Our aggregate figure of 13% for the contribution of startups to other firms' innovative activities is striking when compared to the incidence of what we define to be startups in our manufacturing sample (i.e., single-product firms that are less than five years old), which is 2.5%. Although one must be cautious in comparing these numbers since what respondents report to be a startup and our definition of a startup may not correspond. Nonetheless, if one assumes that these numbers are at least roughly comparable, then the large difference between them suggest that startups may play a disproportionately important role in the division of innovative labor.

It has been argued that patents facilitate the transfer of technology (Arora and Ceccagnoli, 2006; Gans et al., 2008). Respondents reported that 24% of inventions acquired from the outside were patented by the source. Inventions originating from independent inventors were most frequently patented, at a rate of 56%, with universities next at 36%, suppliers at 34% and R&D service providers at 28%. Inventions sourced from technology specialists (i.e., universities, R&D service providers and independent inventors) are patented at a rate of 37% overall. Inventions sourced from customers are patented by the customers at a rate of 16%. In unreported results, we find that these patterns survive when we control for industry effects and characteristics of the innovator, such as age and size.

Channels

We asked those firms reporting acquisition of their invention from an outside source about the channel through which they acquired that invention. The channels considered include: 1) merger, acquisition or equity purchase; 2) joint venture or cooperative R&D; 3) license; 4) a service contract or consulting; or 5) informal means, such as informal interaction, reverse engineering or hiring. As with sources, respondents could indicate more than one channel for acquiring the invention from the outside.[15] The mean number of channels for respondents that used an external channel is 1.44 (with 33% of those listing a channel giving more than one). As with sources, we found no systematic patterns in the bundling of channels, with one exception: the use of informal channels is associated with lower than average use of other channels.

Table 4 shows that a cooperative effort (i.e., a joint venture or cooperative R&D) is the single most important channel, accounting for 61% of externally sourced inventions in manufacturing.[16] This figure suggests that, in the majority of instances in which a firm acquires an invention from the outside, the firm itself participates in the inventive process. Further,

[15] There are 155 respondents who reported an outside source for their invention but did not identify a channel. We treat these 155 observations as missing in our analyses based on channels.
[16] Tether (2002), using the CIS2 for the UK, reports that in 1997, nearly 42% of innovators in the UK reported cooperation with external partners, compared to about 30% in our sample.

suggesting that cooperative efforts may complement market channels in some cases, 27% of the 61% of firms report a cooperative effort along with a market channel (e.g., they report both a license and joint venture or cooperative R&D). We also find, however, that 35% of respondents report using a joint venture or cooperative R&D as their exclusive channel, with no reported use of a license, service contract or acquisition.

Informal channels are the next most frequently cited, named by more than a third of the respondents. A service contract or consulting is identified by a fifth of the respondents as a channel. Licensing is named by 13% of respondents, and mergers and acquisitions are the least frequently reported channel, though still identified by 10% of respondents acquiring their invention from an outside source. Table 4 also shows the share of the latter three channels combined into one category, which we call "market channels." The column identified as "Market" indicates that 37% of the respondents used at least one of these three channels. The "Market only" column indicates that 16% of respondents report at least one of the three market channels but no non-market channels (i.e., neither a cooperative effort nor an informal channel). In other words, market channels, either alone or employed in tandem with other channels, do not underpin the full extent of the division of innovative labor. Table 4 also shows that large firms favor market channels relative to small firms, while small firms favor informal channels. Medium size firms rely upon joint ventures and cooperative R&D ventures to a larger extent. We also find that startups as a source were over-represented among those who report using market channels. While overall 13% of the sources were reported to be startup firms, for those innovators who used exclusively market-based channels, 23% sourced from startups.

There is significant variation in the use of channels across industries. It appears that the more technology intensive sectors favor market channels. Indeed, one of the most R&D intensive industries in manufacturing, pharmaceuticals, stands quite apart from almost all other industries in its high reliance upon market channels, with 43% of the respondents reporting use of market channels alone, particularly acquisitions and licensing. More generally, if we use the fraction of firms in an industry that perform R&D as a measure of an industry's technological intensity, we find that technology intensity is positively related to the use of market channels, with a correlation coefficient of 0.42. This suggests that the type of channels used may be related to the nature of innovation, such as the extent to which it is science based, and therefore easier to codify, or protect through patents, and, in turn, transfer across firm boundaries (cf. Arora and Ceccagnoli, 2006; Arora and Gambardella, 1994).

Table 4: Channels for acquiring inventions, as % of innovators using external source.

		M&A	JV Coop R&D	License	Service Contract	Informal	Market	Market only
Food/Bev	26	11	73	17	20	15	32	17
Textiles	10	7	76	20	17	9	34	16
Wood	23	12	54	5	45	32	50	15
Chemicals	38	6	67	5	35	29	44	18
Pharma	13	39	40	56	8	17	82	43
Plastics	32	25	61	9	27	36	45	13
Minerals	15	13	69	12	11	56	36	17
Metals	14	19	64	3	17	46	39	18
Fab'd Metals	22	0	58	9	5	72	14	0
Machinery	35	11	53	6	17	42	34	22
Electronics	19	5	83	3	19	12	22	3
Semicond.	37	15	64	15	30	43	37	16
Instruments	19	6	41	42	14	14	60	45
Elect -Equip	27	19	62	21	36	42	55	22
Auto	37	11	67	33	18	21	53	29
Med Equip	13	15	45	17	30	31	57	24
Miscl	43	3	63	13	20	33	33	14
All Manuf	423	10	61	13	21	37	37	16
Large firms	173	18	53	21	21	29	47	24
Med firms	80	13	66	10	17	27	36	19
Small firms	170	8	60	13	23	41	36	14

Notes: Channels are not mutually exclusive. Market channels consist of licensing, contracts or M&A.

Among respondents that reported a channel, 27% of the inventions sourced externally were patented by the source.[17] Unsurprisingly, inventions sourced via licensing, or a merger and acquisition, are most frequently reported to be patented by the source—58% for inventions sourced via a merger or acquisition, and 76% via licensing. Also unsurprisingly, only 3% of inventions that are sourced exclusively through informal channels are reported to be patented. Inventions sourced exclusively via joint ventures or cooperative R&D are patented in only 15% of the cases. These figures suggest that patents facilitate market transactions in technology. They

[17] This is slightly higher than the 24% rate reported above that is obtained when we consider all respondents that use an external invention. Not all firms reporting acquisition of their invention from the outside responded to the question regarding channels, which accounts for the slightly different figure.

also suggest that patents are not common features of the division of innovative labor when non-market channels are employed (with about three-quarters of all externally-sourced inventions not being patented by the source).

Channels are related to sources. For example, technology specialists (i.e., R&D service providers, universities, and independent inventors) favor market channels. In contrast, ties to suppliers and especially customers are much less likely to involve market channels but, rather, rely more on informal and cooperative channels, consistent with the greater trust and familiarity bred of longstanding relationships.

Recall that Table 3 reported 49% of respondents acquiring their inventions from an outside source. This figure includes inventions acquired via informal channels, such as reverse engineering. This may strike some as too comprehensive. If we redefine reliance on outside sources to consist of only acquisition of inventions via formal channels (i.e., license, merger and acquisition, service contract, a cooperative venture), 42% of innovators rely upon an outside source of invention. Even with this more restrictive definition, we conclude that firms' overall reliance upon outside sources for their most important inventions is extensive.

4.3 Relative value of inventions by source

In this section, we combine measures of value and incidence to compare the private cost and value of inventions from different sources.[18] In terms of the graphical model presented above, we are characterizing how the cost acquiring external inventions, **w**, and their private value varies across different sources. We begin by observing that it is not clear what the high incidence of customers as a source of inventions signifies with respect to the relative value of inventions from customers versus other sources. For example, it is possible this relatively high incidence suggest that the preponderance of inventions drawn from customers are high value, similar to those originating from the lead users described by von Hippel (1986). Alternatively, it is also plausible that that the cost of acquiring inventions from customers is lower than acquiring them from specialists because repeated interactions with customers result in greater familiarity and trust, leading to lower search and transaction costs. Moreover, if a customer offers an invention to its supplier, it is likely that it believes that the supplier's adoption of that invention

[18] We rely on measures of private commercial value of inventions from various sources, and infer the private costs of obtaining inventions from these sources, as discussed below. Therefore, we can only speak of private, rather than social, costs and benefits.

will be of benefit to the inventing customer firm. Accordingly, one might think that such customer-provided inventions may well be offered at cost or even subsidized, consistent with Harhoff et al.'s (2003) finding of pervasive "free-revealing" of inventions by customers.[19]

Conversely, acquiring inventions from specialists will be more costly. First, searching for the right specialist to supply an invention may be costly, and putting in place the appropriate contractual and legal safeguards may also result in higher costs. Second, specialists will only benefit from the invention they provide to a focal firm through the price that they charge for the invention. This point is also consistent with the finding that customer-sourced inventions are patented at less than half the rate of specialist-sourced inventions—16% versus 37%. It is also consistent with our observation that customer-sourced inventions are less likely to be conveyed through market channels as compared to those inventions originating from technology specialists—26% versus 62%. To address the question of the relative value of customer-sourced versus technology specialist-sourced inventions, we will use our survey data to estimate the relative value to the innovator of inventions from different sources.

To proceed, it is helpful to develop some notation. For the focal innovation, index the source of invention by *i*, where internal invention is one possible source. The average value of an invention from source *i* to an innovator is denoted by V_i. The net surplus is given by $V_i – C_i$, where C_i represents the cost of acquiring and commercializing invention. The cost of "acquiring" an internally generated invention includes the investment in research required to generate the invention. The cost of acquiring the invention from an outside source includes any payments made to the source, as well as any search, contracting and negotiation costs. In addition, all inventions, whether internally generated or externally sourced, have to be developed and commercialized. We also include costs in the relevant cost of acquisition. Value, V_i, corresponds to what we might think of as the present value of revenues earned minus the cost of production.

The extent to which a firm's innovation draws upon a particular source should reflect the net surplus – the value of the invention from that source minus the cost of acquiring and

[19] Harhoff et al. (2003) documented "free revealing" wherein innovative users freely reveal their invention to firms, who can build upon it to develop a commercial product. Motivated by important examples, including open-source software, the authors argue that a user can derive a variety of benefits from not charging manufacturers for the invention. In Figure 1 above, "free revealing" would shift **w** downward (but still would remain non-zero assuming some search, transaction and information processing costs), thereby increasing the substitution effect (Q_2 - Q_1) and increasing total innovations (Q_3)

commercializing it. Therefore, Table 3 can be interpreted as saying that inventions sourced from customers provide the highest net surplus compared to suppliers and technology specialists. But is the net surplus from customers so high because the inventions from customers are really valuable or because these inventions are easy to commercialize and can be acquired cheaply?

Our survey provides a measure of the percentage of a firm's sales in a market generated from their most significant innovation, which can help disentangle cost from value. Sales from innovation have been widely used in the literature (e.g., Laursen and Salter, 2006; Frenz and Ietto-Gillies, 2009) as a measure of the value of the innovation. As long as the sales generate similar net margins over cost across firms in an industry, and as long as sales do not cannibalize sales of existing products, a higher share of sales will imply a higher profitability associated with the product. Column 1 of Table 5a presents results from regressing (OLS) the logarithm of the percentage of sales revenue due to a focal innovation against sources of inventions. The specification includes controls for age, size (log of employment), whether the respondent conducts R&D, as well as 45 industry dummies at the 3 digit NAICS level of aggregation. Internal invention is the reference source.

Assuming percentage of sales is a reasonable indicator of value, the first column in Table 5a suggests that, whereas inventions sourced from customers are less valuable than internal inventions, those from specialists are more valuable. Note that these results are conditional upon a source being chosen and thus may be subject to a selection bias. If the cost of inventions from customers is less than that sourced from specialists, the marginal invention actually sourced from a customer will also be lower in value than those from specialists. Consequently, the observed mean value of inventions sourced from customers will also be lower than those sourced from specialists, even if the customer and specialist-generated inventions have the same distribution of value.

This is illustrated in Figure 2. Figure 2 depicts a hypothetical distribution of value for different sources. Focusing on the value distribution for innovations sourced from customers (the solid line graph), we see that the observed mean of value is equal to the mean conditional upon the value, V, being greater than the cost, C. It is easy to see that as the cost, C, increases, the observed mean will also increase but the probability of observing an innovation from that source will fall. The challenge for us is to evaluate whether the value distribution of inventions from specialists, customers and other sources differ from each other, while allowing for the costs of acquisition to also differ.

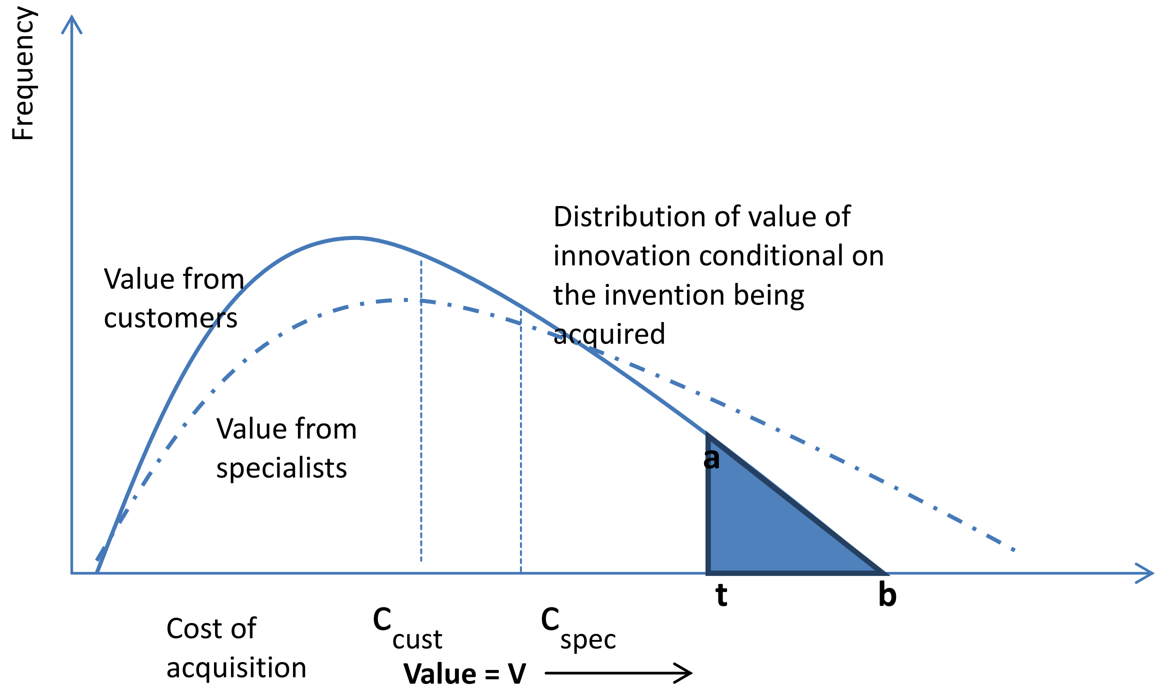


Figure 2. Value and cost of acquisition of customer and specialist sourced inventions.

We take two complementary approaches. A simple test of the null hypothesis that the value distributions are the same and only the cost of acquisition differs between customers and specialists is to focus on the right tail of the distribution. In Figure 2, if both customers and specialists have the distribution marked by the solid curve then the area under the curve to the right of the point *t* should be the same for both customers and specialists. That is to say, the probability of value being larger than *t* conditional upon the source being a customer should be the same as that of a specialist. This is represented by the shaded triangle *abt* in Figure 2. Intuitively, the right tail of the conditional distribution should be unaffected by the truncation due to the differing costs, and thus, if the two distributions are the same, the right tail should be the same as well.

Figure 3 shows the frequency distribution of share of sales from the focal innovation obtained from customers (light shaded bars) and specialists (dark bars).[20] Focusing on innovations of high value (i.e., which account for 50% or more of the total sales), we see that

[20] Firms indicating multiple sources were divided proportionately. Thus a respondent that indicated both a supplier and a customer is allocated 50-50 to each source.

specialists are two and half times more likely to be the source than customers, suggesting that specialist inventions are more likely to be high value. This makes it unlikely that the difference between customers and specialists in the conditional means of the share of sales from the focal innovation is due entirely to differences in the costs of acquisition. Figure 3 of course does not control for firm-characteristics or industry. Column 2 in Table 5a shows the result of a linear probability model where the dependent variable is 1 if the % sales from the focal innovation is greater than 50% (which corresponds to 9% of the sample of all innovations).[21] Even after controlling for business unit size, parent firm size, firm age, whether the respondent conducts R&D or not, and industry fixed effects, we see that 17% of inventions from specialists are high value (account for over 50% of sales) whereas only 2% of inventions from customers are high value. This regression analysis, as well as the results in column 1 do, not, however, control for selection.

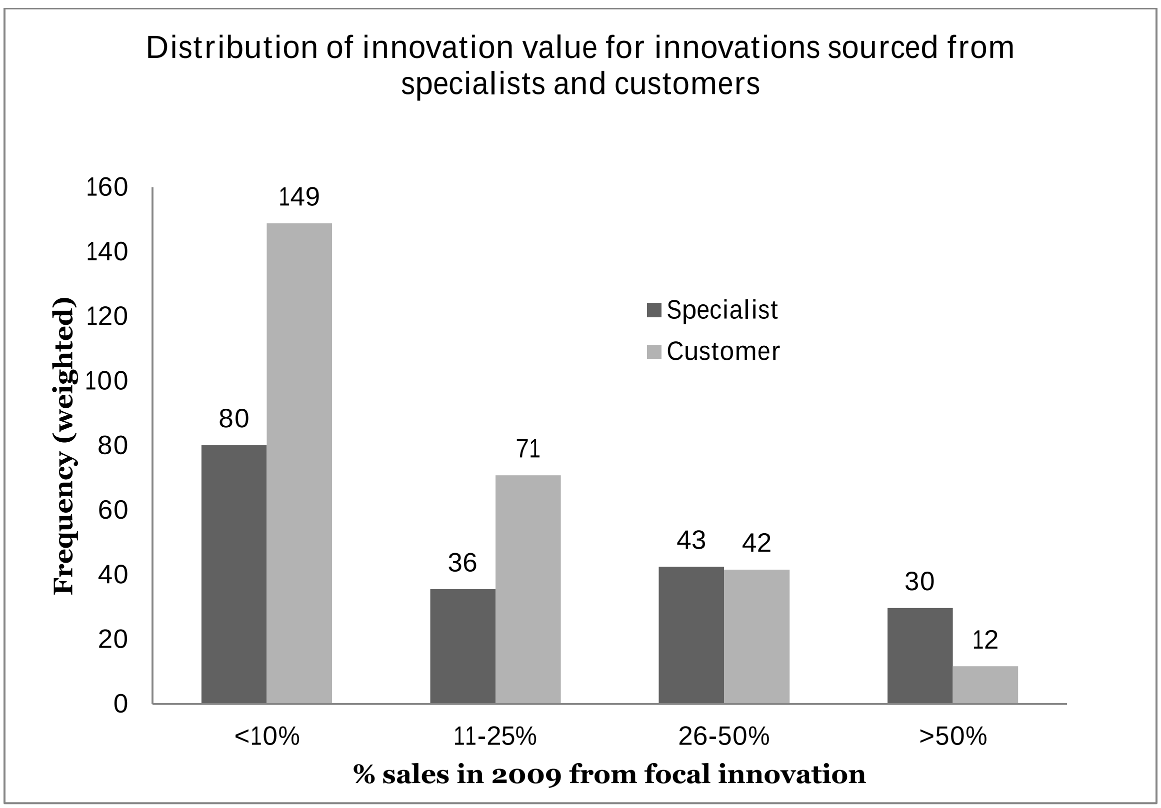


Figure 3. Frequency distribution of customer and specialist sourced innovation by % sales from the focal innovation.

[21] Using a linear probability specification rather than a probit or logit is preferred because it is robust to misspecification and more conservative.

A different approach to the selection problem from our graphical analysis in Figure 3 incorporates the possibility that a given firm can potentially choose from among different sources. Therefore, the observed innovation must not only cover the cost of acquiring it, but the net surplus from obtaining it must exceed the net surplus from alternatives. As explained in Appendix B, we follow Dubin and McFadden (1984) and use a multinomial logit framework to express the mean value of an invention conditional upon a specific source of the invention as the unconditional mean value of inventions from that source plus natural logarithm of the share of the source in the industry. The latter is analogous to the familiar Heckman selection term. We then assume that the mean value of invention from the source *i* in industry *k* for innovator *j* is a linear function of a vector of firm characteristics, X*i*, an industry fixed effect, z_k and a source fixed effect, s_j. This leads to the specifications in columns 3 and 4 of Table 5a.

Table 5a: Value of inventions by source: % business unit sales from focal invention (The reference category for all specifications is *internal invention.*). OLS regressions.

	Log of % BU sales from focal innovation **(1)**	**(% BU sales from focal innovation greater than 50%) = 1** **(2)**	**Log of % BU sales from focal innovation *(Sample Selection correction)*** **(3)**	**(% BU sales from focal innovation greater than 50%) = 1 *(Sample Selection correction)*** **(4)**
Customer	-0.17** (0.07)	-0.06*** (0.02)	-0.19** (0.07)	-0.07*** (0.02)
Supplier	0.07 (0.09)	0.06** (0.03)	0.03 (0.10)	0.05* (0.03)
Other Firm	-0.09 (0.11)	-0.03 (0.03)	-0.13 (0.12)	-0.04 (0.04)
Specialists	0.36*** (0.09)	0.07*** (0.03)	0.34*** (0.09)	0.07** (0.03)
Ln (BU Empl)	-0.32*** (0.06)	-0.07*** (0.02)	-0.32*** (0.06)	-0.07*** (0.02)
R&D	0.43*** (0.14)	0.09** (0.04)	0.43*** (0.14)	0.09** (0.04)
Ind. FE's (45)	*Yes*	*Yes*	*Yes*	*Yes*
Controls	*Parent size, Age*	*Parent size, Age*	*Parent size, Age*	*Parent size, Age*
Ln (share of source)			-0.05 (0.07)	-0.01 (0.02)
N	927	927	927	927
$\mathbf{R^2}$	0.19	0.15	0.19	0.15

Notes: The dependent variable in Columns 1 & 3 is the % sales from focal innovation. The dependent variable in Columns 2 and 4 is a binary variable taking value 1 if the sales from the focal innovation exceed 50% of total firm sales, and 0 otherwise. Standard errors in parentheses. Standard errors are in parentheses. *p<.10, **p<.05, ***p<.01

Comparing columns 1 with 3 and 2 with 4 in Table 5a shows that this correction for selection leaves the basic pattern of results unchanged. The correction term, the log of the share of the source, is imprecisely estimated. We obtain similar results (not reported here) when we use a second order polynomial in the predicted probability instead of its natural log to control for sample selection, although the coefficient on the correction term is again not significantly different from zero.[22] In sum, our results indicate that customer sourced inventions are cheaper to acquire and commercialize *and* are also lower in their commercial value.

Table 5b: Value of inventions by source: Other indicators (The reference category for all specifications is *internal invention*.) OLS regression, all with sample selection correction.

	Innovator invests equip or skills = 1 **(1)**	**Innovator invests in sales channel =1** **(2)**	**Innovator patents focal innovation=1** **(3)**	**Innovator increased market share=1** **(4)**
Customer	-0.04 (0.04)	0.00 (0.04)	-0.08** (0.03)	-0.05 (0.04)
Supplier	-0.19*** (0.05)	0.01 (0.05)	-0.11** (0.05)	0.07 (0.05)
Other Firm	0.00 (0.06)	0.02 (0.06)	-0.08 (0.06)	-0.06 (0.06)
Specialists	0.14*** (0.05)	0.10** (0.04)	0.28*** (0.04)	0.14*** (0.05)
Ln (Empl)	0.06* (0.03)	0.05* (0.03)	0.11*** (0.03)	0.03 (0.03)
R&D	-0.02 (0.07)	-0.03 (0.07)	0.18*** (0.06)	0.16** (0.07)
Ln (share of source)	-0.08** (0.03)	-0.02 (0.03)	0.03 (0.03)	-0.03 (0.03)
Ind. FE's (45)	*Yes*	*Yes*	*Yes*	*Yes*
N	1012	1017	1019	916
R^2	0.14	0.16	0.26	0.13

Notes: All specifications include a sample selection correction and control for parent size and age. Standard errors are in parentheses. *p<.10, **p<.05, ***p<.01

Table 5b reports the results using other indicators of value to probe the robustness of our results on the value offered from different sources. Each of the indicators is imperfect but they all point in the same direction, and it is the robustness of the patterns below to which we appeal. Investment associated with the commercialization of the invention is another possible indicator of value. We asked innovating firms whether, to commercialize the innovation, they developed

[22] Dahl (2002) uses a polynomial of this share as a "correction" function to correct for the selection bias. Dahl's approach does not require a multinomial framework. In a multinomial framework, the natural log of the predicted probability is the appropriate correction, as shown by Dubin and McFadden (1984).

new sales and distribution channels, and separately, whether they had invested in new types of equipment or hired employees with distinct skills. A firm will undertake these actions only if it expects a return—that is, the new product in question is valuable. In Column 1 of Table 5b, we see that innovations sourced from specialists are associated with a greater likelihood of investment in new plant and equipment or in hiring personnel with different expertise. By contrast, the coefficients on inventions from other sources are not statistically different from zero. The results in Column 2 show similarly that inventions sourced from specialists are associated with the innovating firm investing in new sales and distribution channels, while other sources do not have significant estimated coefficients.[23]

We use two other indicators of value. The first is whether the innovator filed for a patent for some aspect of the innovation.[24] Column 3 of Table 5b shows that the innovator is significantly more likely to patent inventions sourced from specialists as compared to internally generated inventions. Conversely, innovations sourced from customers or suppliers are significantly less likely to be patented. Recall that these regressions included industry fixed effects, and thus control for cross-industry differences in patent propensities.

Our final indicator considers the outcome for the firm as a whole, instead of focusing only on the focal innovation. We asked all firms whether their market share had increased, decreased or stayed the same over the sample period. Just over 60% of the innovating firms report an increase in market share. In Column 4, we see that, relative to internally innovating firms, customer-sourced innovations are associated with a higher probability of a decline in the firm's market share. In contrast, specialist-sourced innovations are associated with an expected increase in the firm's overall market share (relative to internally generated inventions).

A consistent story emerges from all the results presented in Tables 5a and 5b: the average (unconditional) value of inventions sourced from customers are lower than those sourced from technology specialists.[25] Inventions from suppliers and other firms appear to be similar to

[23] Absence of investment in sales channels and distribution may be expected in the case of customers simply because the focal firm was already selling to the customer that was the source of the invention. But this logic does not apply to investment in plant and new types of personnel, as considered in column 1.

[24] Patents are an imperfect measure of value. An innovation may not be patentable or there may be strategic reasons not to patent.

[25] Consistent with our findings, Sofka and Grimpe (2009) report for a sample of 5000 Western European firms, the share of revenue from innovative products is higher for firms that stress collaboration with universities and research centers, and for firms that stress collaboration with suppliers.

internal invention in value. Recall, however, that Table 3 shows that, after internal invention, the relative incidence of customers as a source of invention is the highest, followed by technical specialists, suppliers, and other firms—and this relative incidence indicates that, on average, the net surplus (i.e., V – C), among external sources, is highest for customers. These two conclusions can be reconciled in only one way: while the highest gross value is realized from technology specialists, with customer-sourced inventions having the lowest, the cost of acquiring inventions from customers is low enough to make the net surplus—and hence, the incidence—of customer-sourced inventions rank highest among all externally sourced inventions. In other words, the high incidence of inventions sourced from customers reflects the low cost of acquiring and commercializing such inventions, rather than high value.

Our results suggesting that customers offer relatively low value inventions contrast with what we might expect if we think that the typical customers that provide inventions to firms are the lead users described by von Hippel (1986, 2005). Though our results our entirely consistent with a fraction of customers providing high-value inventions, they also suggest that, on average, customer-sourced inventions will be of lower commercial value relative to those of specialists.[26] And this is not surprising. First, customers may tend to anchor their suggestions on existing products. Second, insofar as customers are other firms, Christensen's (1997) work would suggest that industrial customers tend to push for more incremental invention to avoid the costs of the changing of equipment, personnel or even organizational structure that more significant innovation on the part of the supplier may entail. And it is indeed the case that industrial customers are more likely to be sources of invention than final consumers: in industries that the U.S. BEA identifies as intermediate capital goods industries, 30% of our sample innovating firms list customers as a source for their inventions, versus 18% of the innovating firms in industries identified as final goods industries.[27] In contrast to customers, technology specialists should have no systematic interest in promoting incremental invention but rather a strong interest in promoting more significant, valuable innovations if they are to compete against the firm's own R&D operations and other sources of invention.

[26] Given our focus on private value, this is consistent with Riggs and von Hippel's (1994) findings in the case of scientific instruments that the commercial value of user-originated inventions are less than that of manufacturer-originated innovations, even while the scientific or social value of the former may be greater. .

[27] Consistent with these findings, Adams et al. (2013) highlight the important contribution of industrial users to innovation in the semiconductor industry.

Our analysis not only implies that inventions from customers will be of lower average value, but also that the cost of their acquisition and commercialization will be lower still. This inference is consistent with our argument that customer-sourced inventions will tend to be more incremental, and thus easier to implement and commercialize, and requiring less development effort. Further, customer-sourced inventions will often require less investment in sales and marketing because the customer that originated the invention is likely to be among the early buyers. Finally, cost will be lower because it is often in the customer's interest to charge the upstream firm little—per Harhoff et al.'s (2003) observation of free-revealing—since the customer benefits from the downstream firm's commercialization of the underlying invention.

4.4 External supply and the rate of innovation

Given that sources differ in their costs and benefits, what can we infer about their possible contributions to innovation? To address this question, we first employ the multinomial logit framework to examine the relationship between source selection and the overall rate of innovation. We will follow this analysis with a complementary approach to the question that draws more directly from our survey data.

Subordinating the details of the derivation to Appendix B, if P_i is the probability of obtaining invention from source *i*, and P_0 is the probability of no innovation, the contribution of source *i* to the overall rate of innovation in the economy – the reduction in innovation rates if that source of invention became unavailable—is:

$$[P_0 /(1-P_0)][(P_i)/ (1-P_i)]. \tag{1}$$

We can calculate the contribution of various external sources to innovation by applying (1) to data grouped at the industry level. We use the share of inventions from source *i* to compute P_i. We use the 17 industry groups used in Table 2, and take a sales-weighted average over the industries to obtain the contribution of each source. We report bootstrap standard errors based on 500 draws. The results are summarized in Table 6.

Table 6 reports the contribution to the innovation rate for the manufacturing sector as a whole by each source, and by external sources overall. From Table 2, we see that 16% of the firms innovate, and in Table 3 we show that about 49% of these innovators rely upon external sources of invention. Equation (1) implies that removing all external sources of invention would reduce overall innovation by 45% (Table 6). Put differently, if external sources of innovation were not available, only about 9% of the firms would innovate instead of 16%. Such a hypothetical corporate self-sufficiency in innovation would cost the U.S. manufacturing dearly. Among the external sources, we also observe, consistent with Table 3 above, that customers make the greatest contribution, followed by specialists, suppliers, and other firms.

TABLE 6: Contribution to innovation by external source (% reduction in innovation rate if the source were not available).

Source	Contribution
Customer	18.9% (1.44)
Supplier	8.5% (1.06)
Other Firm	4.6% (0.69)
Specialist	10.3% (0.95)
All external	44.6% (2.06)
Internal	47.2% (2.07)

Notes: Bootstrap standard errors in parentheses based on 500 draws. Contribution to innovation calculated as: $[P_0 /(1-P_0)][(P_i)/ (1-P_i)]$, where $1-P_0$ = % innovators, P_i = Share of inventions from source *i*.

These calculations are subject to the strong assumptions of the multinomial logit framework. For one, these inferences depend upon the pattern of substitutions across sources.[28] Substitution between sources means that the drop in innovation from losing a given source *i* is less than P_i. However, because some of the substitution would result in the firm choosing not to innovate, the overall rate of innovation will decline. Specifically, since over 80% of manufacturing respondents do not innovate, this implies, in a multinomial logit framework, that "no innovation" is the most likely counterfactual outcome if a source were removed.

Such counterfactuals are difficult to test. We have, however, another basis for projecting what may happen in the absence of external sources of invention. For externally sourced innovations, we asked whether the firm could have acquired the invention from another source. Only one third (33%) of the respondents indicated that they could. Even if one assumes that the alternative source is always internal invention, then the removal of all external sources would imply that, at best, only a third of the 8% of respondents who sourced their inventions externally,

[28] In particular, the multinomial logit setup implies, for instance, that if customers were removed as a possible source, innovators using customer-sourced inventions would use the other sources in proportion to the shares of the sources, so that the relative shares of the remaining sources would remain unchanged.

or fewer than 3%, would still innovate. If so, the rate of innovation would fall from 16% to about 11% or less. In other words, if external sources of inventions were unavailable, the overall rate of innovation would fall by about 30%. This is a substantial decline, albeit less than the 45% figure implied by our multinomial logit model. Thus, both of these estimates suggest a substantial reduction in innovation if external sources of invention were not available.

Though subject to a variety of qualifications, the point of this section is to highlight that the extent to which innovations rely upon external sources of invention and the overall rate of innovation are jointly determined. As Figure 1 showed, external sources of invention may not simply substitute for internal invention; they can also condition the overall rate of innovation. Thus, removing a particular source may have two effects – a less efficient source would be selected in some cases, and in others, the firm may not innovate at all.

5. Conclusion and implications for policy and management

Based on a survey of U.S. manufacturing firms, we find that almost half of innovating firms had an external source for the invention that led to their most important (new to the market) innovation. The most common external source was customers (accounting for about one quarter of all innovations), with technology specialists (universities, consulting/contract engineering firms, independent inventors) the second most common external source (accounting for almost one fifth of all innovations). In addition, among these invention sources, startups appear to be over-represented. Furthermore, we find that only a minority of these inventions was acquired through market channels (licensing, mergers & acquisitions, and service contracts). However, when a market-based channel was employed, the source was disproportionately likely to have had a patent on the invention and was also disproportionately likely to be a startup (even compared to the rate among all external sources).

Our analysis extends beyond the reporting of the findings of our survey by offering an understanding of not only the incidence but also the relative cost and value of inventions supplied by different sources. Using information on the share of sales accounted for by our respondents' most significant product innovations supplemented by data on respondents' subsequent investments in commercialization of their innovations, patenting and market share data, we show that, inventions sourced from technology specialists tend to be privately the most valuable and those sourced from customers tend to provide the highest net surplus to innovators because they are the least costly to acquire.

External sources are not, however, simply substitutes for internal inventions; they also lead some firms to innovate that otherwise would not, thus augmenting the percentage of firms that innovate. In other words, external sourcing of invention is not simply a matter of "make-or-buy." If firms did not have access to external sources, our data suggest that the overall rate of innovation of 16% would likely drop to 11% or as low as 9%. While this estimate should be interpreted with caution given the strong assumptions underlying our analyses, the main point is that external sources contribute to the overall rate of innovation, perhaps substantially so.

Our findings raise two questions pertaining to social welfare. First, is the current state of external sourcing socially optimal? Second, is the current balance between market and non-market channels for acquiring inventions—where non-market channels currently predominate—socially desirable? Our findings do not allow us to claim neither that the current state of external sourcing of invention in U.S. manufacturing is socially suboptimal, nor whether more market-based acquisition is indicated. We conjecture, however, that the efficiency of sourcing, and especially market-based sourcing can be enhanced. There are a variety of policies and practices that would make external sourcing more efficient (i.e., lowering **w** in Figure 1). For example, more certainty in patent protection would likely increase licensing of inventions (Gans et al., 2008), as would greater transparency of the terms of deals in technology markets. The supply of high value university inventions would increase if universities were to adopt standard licensing forms and other practices that diminish transaction costs (cf. National Research Council, 2010, p. 88). Changes in private policies and practices could also increase the efficiency of the division of innovative labor. Increases in venture capital funding to independent inventors and startups would improve their ability to develop ideas to the point where they can be acquired by other firms.

There are also organizational barriers to the external sourcing of inventions. Changing the "not-invented-here" culture, for example, that still pervades some large firms could well offer social as well as private benefits. Indeed, our results reinforce the need to consider ways in which managers may improve the efficiency of acquiring inventions from external sources. The importance of listening to customers has been touted in the popular writing on the subject, and user-innovation is by now broadly accepted by innovation scholars. Our findings suggest that managers should also attend to high-value sources such as universities and independent inventors. That independent inventors appear to disproportionately favor small firms as compared to larger ones suggests that large firms may be missing an opportunity.[29]

Our findings also offer an important implication for empirical scholars studying the determinants of R&D spending and technological change. Firms' pervasive reliance on outside sources for their inventions implies that innovation rates across industries depend upon factors that condition the supply of invention from sources outside the firm and often outside the industry. In their efforts to explain the innovation rates of firms and industries, empirical scholars would be well advised to consider these factors along with those that are typically considered either at the industry level, such as demand, technological opportunity and appropriability, or at the firm level, such as firm capabilities or cash flow (cf. Cohen, 2010).

Our findings also have implications for recent debates about patent reform. Recent debates about "patent-assertion entities," sometimes called "patent trolls" have led to calls for reforming the patent system to limit the ability of such entities to sue for patent infringement. The strong link we find between patents and market-based acquisitions of inventions suggest that patents may play an important role in facilitating market transactions for technology. We find that a quarter of the inventions obtained from external sources were patented by the inventor, implying that the overwhelming majority of the inventions transferred do not rely upon patents. High value inventions from universities, independent inventors, and R&D contractors are, however, much more likely to be patented than those from the other sources. Thus, our results suggest that one should be quite cautious in crafting such legislation in order to not undermine technology specialists (e.g., independent inventors, universities) who appear to rely heavily on patent protection, and are also the most valuable source of inventions.

Our results also address important issues for survey-based indicators of innovation. A key contribution of our study is that, by focusing questions on a single innovation, we are able to link the particular innovation directly to several indicators of its value. This allows us to address the ambiguity surrounding the notion of an innovation or what might be a new or significantly improved product that has been a concern for the CIS surveys (cf. Arundel, 2006; Tether, 2001; Smith, 2005). Our data also focus on the sources of *inventions* tied to specific innovations, rather

[29] A different interpretation is that small firms act as a bridge between independent inventors and larger firms, who may find it too costly to deal with independent inventors. Indeed in biopharmaceuticals, biotech firms function as a bridge between university-based inventors and large pharmaceutical firms (Edwards, et al., 2006).

than the broader category of knowledge sources (cf. Cohen, et al., 2002b; Frenz and Ietto-Gillies, 2009), permitting us to characterize the division of innovative labor between inventors and innovators. Also, by asking about a single innovation, we can estimate the share of innovations that are externally acquired, thus providing precise estimates of the extent of the division of innovative labor between inventors and innovators.

In conclusion, our results clearly suggest that the division of innovative labor involves multiple types of actors and institutional arrangements linking them. Policy, both public and private, must address this as a system rather than simply focus on the individual elements. Further work on the firm and industry-level drivers of that supply, the demand, and the transaction costs are needed to develop a system-level understanding of the division of innovative labor.

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Appendix A: Supplemental tables

Table 1A Response rates by industry

	Denominator	Numerator		
NAICS Strata	**sample out**	**Responses**	**percent**	%over/under mean
311 Food Manufacturing	1188	336	28.3%	-6.8%
312 Beverage and Tobacco Product Manufacturing	264	67	25.4%	-16.4%
313 Textile Mills	262	67	25.6%	-15.7%
314 Textile Product Mills	289	107	37.0%	22.0%
315-6 Apparel, Leather and Allied Product Manufacturing	403	110	27.3%	-10.0%
321 Wood Product Manufacturing	243	82	33.7%	11.2%
322 Paper Manufacturing	581	165	28.4%	-6.4%
323 Printing and Related Support Activities	608	197	32.4%	6.8%
324 Petroleum and Coal Products Manufacturing	257	76	29.6%	-2.5%
325 Chemical Manufacturing (except Pharmaceutical and Medicine)	1161	349	30.1%	-0.9%
3254 Pharmaceutical and Medicine Manufacturing	724	160	22.1%	-27.2%
326 Plastics and Rubber Products Manufacturing	1192	370	31.0%	2.3%
327 Nonmetallic Mineral Product Manufacturing	1118	342	30.6%	0.8%
331 Primary Metal Manufacturing	971	336	34.6%	14.1%
332 Fabricated Metal Product Manufacturing	1297	466	35.9%	18.4%
333 Machinery Manufacturing	1343	466	34.7%	14.4%
334 Computer and Electronic Product Manufacturing (except Semicon)	1213	325	26.8%	-11.7%
3344 Semiconductor and Other Electronic Component Manufacturing	1199	370	30.9%	1.7%
335 Electrical Equipment, Appliance, and Component Manufacturing	1231	377	30.6%	0.9%
336 Transportation Equipment Manufacturing	1190	347	29.2%	-3.9%
337 Furniture and Related Product Manufacturing	895	308	34.4%	13.4%
339 Miscellaneous Manufacturing	1286	438	34.1%	12.3%
511 Publishing Industries (except Internet)	378	90	23.8%	-21.5%
512 Motion Picture and Sound Recording Industries	186	54	29.0%	-4.3%
517 Telecommunications	628	149	23.7%	-21.8%
518 Data Processing, Hosting and Related Services	517	138	26.7%	-12.0%
533 Lessors of Nonfinancial Intangible Assets (except Copyrighted Works)	181	53	29.3%	-3.5%
541 Professional, Scientific, and Technical Services	1229	340	27.7%	-8.8%
Total	22034	6685	30.3%	0.0%

Notes: In this paper we do not analyze data from services

Table A2 Response Rates by Size and Age

	Denominator	Numerator		
Size strata	**sample out**	**responses**	**percent**	%over/under mean
F500	1569	309	19.7%	-35%
Large	6435	1524	23.7%	-22%
Med	2211	659	29.8%	-2%
N533	117	31	26.5%	-13%
Small	7727	2880	37.3%	23%
Startup	2499	844	33.8%	11%
Tiny	936	289	30.9%	2%
Tiny Startup	540	149	27.6%	-9%
Total	22034	6685	30.3%	0%

Table A3.1 Distribution of respondents, by Industry.

Industry	**Frequency**	**Percent**
3110 Food	317	5.21
3120 Beverage	62	1.02
3130 Textile Mills	41	0.67
3140 Textile Product Mills	80	1.31
3156 Apparel, Leather	100	1.64
3210 Wood Products	79	1.3
3220 Paper	129	2.12
3230 Printing	193	3.17
3240 Petroleum	48	0.79
3250 Chemicals, other	115	1.89
3251 Basic Chemicals	76	1.25
3252 Resins	36	0.59
3254 Pharmaceuticals	133	2.18
3255 Paint	42	0.69
3256 Soap	58	0.95
3260 Plastics and Rubber	350	5.75
3270 Mineral Products	339	5.57
3310 Metals, other	235	3.86
3315 Foundries	98	1.61
3320 Fabricated Metal, other	231	3.79
3323 Structural Metals	103	1.69
3327 Machine Shops	108	1.77
3330 Machinery, other	154	2.53
3331 Heavy Machinery	40	0.66
3332 Industrial Machinery	44	0.72
3333 Commercial Machinery	37	0.61

3334 HVAC	36	0.59
3335 Metalworking Machinery	89	1.46
3340 Electronic Equipment, other	76	1.25
3341 Computers	30	0.49
3342 Communications Equipment	51	0.84
3344 Semiconductors	315	5.17
3345 Instruments	138	2.27
3350 Electrical Equipment	326	5.35
3360 Transportation Equipment, other	106	1.74
3361 Auto	62	1.02
3363 Auto Parts	121	1.99
3364 Aerospace	73	1.2
3370 Furniture	271	4.45
3390 Miscellaneous Manufacturing	257	4.22
3391 Medical Equipment	142	2.33
5112 Software Publishers	90	1.48
5121 Motion Picture and Sound	49	0.8
5170 Telecommunications	107	1.76
5180 Data Processing	84	1.38
5410 Professional, Scientific, and Technical Services, other	171	2.81
5413 Architectural, Engineering	138	2.27
5415 Computer Systems Design	108	1.77

Table A3.2. Distribution of respondents, by Size.

Size strata (number of employees)	Frequency	Percent
Large (over 1000)	1477	24.26
Medium (100-1000)	1079	17.72
Small (under 100)	3532	58.02

Appendix B: The Multinomial Logit Model

Assume all firms are potential innovators, and that a firm will introduce at most one innovation.[30] Further, assume that the firm has access to both internal as well as external inventions. The average value of an innovation to an innovator from source *i* is denoted by V_i, and the costs of acquiring the invention are denoted by C_i.

Assuming that the value of the invention to the firm from source *i* has a firm-specific stochastic component, ε_{ij}, the net surplus from the invention u_{ij} can be written as

$$u_{ij} = V_i - C_i + \varepsilon_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Firms may differ, for example, in their abilities to realize value from the same innovation, as captured by ε_{ij}. The multinomial framework assumes ε_{ij} has a double exponential distribution with mean zero and variance $\theta^2\pi^2/6$ and is *iid* for all *i* and *j*.

The firm chooses the option that provides the highest net surplus. Since the net surplus may be negative (i.e., it may cost more to acquire and commercialize the invention than the additional revenue gained), it is possible that the firm will not introduce an innovation. We therefore include "no innovation" as an option, and normalize the net surplus associated with this option to zero. P_{ij}, the probability that firm j obtains its innovation from source *i* can be expressed as

$$P_{ij} = \exp(u_i/\theta)/\Sigma_k(\exp(u_k/\theta)), \qquad (2)$$

where k = 1,..i, K, and K is the number of options. Notice that the choice among the options depends upon the net surplus associated with each option. P_{ij} is the probability that firm *j* chooses source *i*, and therefore the share of source *i* is an estimate of the expected value of P_{ij}. The expected net value of an innovation conditional upon it being from source *i* is (Dubin, 1985)

$$E(u_{ij} \mid \text{source} = i) = \gamma\theta + V_{ij} - C_i - \theta Ln(P_i), \qquad (3)$$

where γ is Euler's constant. If C_i does not have any unobserved variation across individuals, then it follows that

$$E(V_{ij} + \varepsilon_{ij} \mid \text{source} = i) = \gamma\theta + V_{ij} - \theta Ln(P_i). \qquad (3')$$

[30]The actual unit of observation in our study is the business unit—reflecting a firm's activity in one market.

$E(V_{ij} + \varepsilon_{ij}|$ source = i) can be interpreted as the value earned by the firm from an innovation from source *i,* which we proxy by the share of sales accounted for by the focal innovation. Equation (3') is analogous to the familiar Heckman selection equation where the expected value of a variable is equal to its unconditional expectation plus a selection term. This motivates the use of the natural log of the share of source *i* to control for selection. Specifically, we group the data into the 17 industry classes used in Tables 2-4, and use the share of innovators in each industry that use inventions from a source as the predicted probability for that industry class-source pair. We use the natural log of this predicted probability for the source actually chosen as a regressor to control for selection. We assume V_{ij} is a linear function of firm and industry characteristics plus a dummy, δ_i, that represents the particular source, i.e.,

$$V_{ij} = X_{ij}\beta + \delta_i \quad (4)$$

Combining (3') and (4) leads to the specification in Columns 3 and 4 of Table 5a, where $\gamma\theta$ is subsumed in the constant term.

We can quantify the contribution of a particular source to the overall rate of innovation in the economy -- the reduction in innovation rates if that source of invention became unavailable. The probability of no innovation = $P_0 = \exp(u_0/\theta)/A$, where $A = \Sigma_k(\exp(u_k/\theta))$. By assumption, $u_0 = 0$. So we have $P_0 = 1/A$. The overall rate of innovation in the economy is equal to the probability of innovation, which is simply $1\text{-}P_0$.

The probability of no-innovation without, for example, specialists = $P_0^* = 1/A^*_{spec}$, where $A^*_{spec} = \Sigma_k(\exp(u_k/\theta))$ where $k \neq$ *specialist*.

The contribution of specialists to innovation is $P^*_0 - P_0 = P_0 (P_{spec})/ (1-P_{spec})$. Expressed as a share of the rate of innovation we get contribution of specialists to innovation,

$$(P^*_0 - P_0)/(1-P_0) = [P_0 /(1-P_0)][(P_{spec})/ (1-P_{spec})]. \quad (A3)$$

Equation (A3) can be interpreted as the net contribution of specialists to the overall rate of innovation. It can be readily modified to any subset of sources, including, for instance, all external sources of inventions.

ACS: 2/19/10 (DUKE VERSION)

1. Does [insert D&B primary NAICS description from COL. E] include [THREAD IN PARENT COMPANY NAME FROM D&B SPREADSHEET, COL. D]'s main line of business for which you are responsible?
    1. YES
    2. NO
    3. RESPONDENT DOES NOT WORK FOR COMPANY → **ASK Q1A**

1A. What is the name of your company? ______________________

1B. Has [NAME OF COMPANY FROM 1A] merged with or acquired [THREAD IN PARENT COMPANY NAME FROM D&B SPREADSHEET, COL. D]?

1. YES → **Continue to Q2**
2. NO → **Exit**
77. DK → **Exit**
99. REF → **Exit**

2. **IF NO TO Q1 OR YES TO Q1B:** In a couple of words, what is your main line of business?:________________

INTERVIEWER NOTE: USE ANY NEW COMPANY NAME AND IDENTITY OF LINE OF BUSINESS PROVIDED AS ANSWERS TO QUESTION 2 FOR THREADING BELOW.

3. In 2009, have you earned revenue from any new or significantly improved goods or services in [THREAD INDUSTRY] introduced since 2007, where "New" means new to your firm. Also, please exclude simple resale of goods purchased from others or purely aesthetic changes. YES NO DK REF

4. IF YES TO 3, ASK. ELSE, GO TO 5. In 2009, what percent of your revenues in [THREAD INDUSTRY] is from new or significantly improved goods or services introduced since 2007?_________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q4

4.1. 0%
4.2. 1-5%
4.3. 6-10%
4.4. 11-25%
4.5. 26-50%
4.6. More than 50%
4.7. DK

5. In the last 3 years, have you licensed any technology or product to another party, or have you developed any technology or innovation for another party. YES NO DK REF

- **IF NO to 3 (or answered "zero" to 4) & NO to 5, GO TO BACKGROUND.**
- **IF NO to 3 but YES TO 5, GO TO LICENSING/CONTRACT R&D SECTION.**
- **IF YES TO 3 and No to 5, CONTINUE TO QUESTION 6 and skip LICENSING/CONTRACT R&D SECTION.**
- **If YES to 3 and YES to 5, CONTINUE TO QUESTION 6 and answer <u>only Q26</u> in LICENSING/CONTRACT R&D SECTION.**
- **IF DK TO 3 AND 5: Ask "Is there someone else in the company who might be more familiar with your new products and services in [THREAD INDUSTRY]?" GET CONTACT INFORMATION, THANK RESPONDENT AND GO BACK TO BEGINNING OF SCRIPT.**

INTERVIEWER: READ THE FOLLOWING TO THE RESPONDENT
Of all the new or significantly improved products or services you brought to market in **[THREAD INDUSTRY]** during the three years, 2007-2009, think of the one that accounts for the most revenue. Please keep this innovation in mind when answering the next set of questions.

6. Did your company patent any part of this innovation? YES NO DK REF

[INTERVIEWER: IF QUERIED, "PATENT" REFERS TO WHETHER A PATENT WAS APPLIED FOR OR GRANTED]

7. Did you introduce this innovation in your industry before any other company? YES NO DK REF

- **IF NO to Questions 6 <u>AND</u> 7 GO TO QUESTION 26;**
- **TREAT A "DK" OR A "REF" AS A YES FOR PURPOSE OF SKIP LOGIC**

8. In what year was this innovation introduced to the market? __________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q8

8.1. 2007
8.2. 2008
8.3. 2009
8.4. DK
8.5. REF

R responds with a date prior to 2007: if YES to Q5, skip to LICENSING/CONTRACT R&D SECTION; if NO to Q5, skip to BACKGROUND SECTION.

9. To commercialize this innovation, did you:

9.1. Develop new sales and distribution channels? YES NO DK REF
9.2. Buy new types of equipment, or hire employees with skills different from existing employees? YES NO DK REF

10. Did you license this innovation or any related technology to others? YES NO DK REF

11. Approximately how many other companies in your industry have introduced or will likely introduce innovations that compete with this innovation? ___________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q11

11.1. None
11.2. 1-3
11.3. More than 3
11.4. DK
11.5. REF

12. Did any of the following originate this innovation, that is, create the overall design, develop the prototype or conceptualize the technology?

		select all that apply
i.	A Supplier	[ ]
ii.	A Customer	[ ]
iii.	Another firm in your industry	[ ]
iv.	A consultant, commercial lab, or engineering service provider	[ ]
v.	An Independent inventor	[ ]
vi.	A collaboration between your firm and others	[ ]
vii.	Universities or government labs	[ ]
viii.	The public domain, such as, publications or public meetings	[ ]
ix.	Other (specify)_______________________________	[ ]
x.	DON'T KNOW	[ ]
xi.	REFUSED	[ ]

13. [IF YES to ANY **ONE** of 12.i through 12.vi or 12.ix: Was this source [OR IF **MORE THAN ONE** "YES" , SAY INSTEAD: "Were any of these sources"] a startup company, that is, a new, small company]? YES NO DK REF

14. [IF YES to ANY **ONE** of 12.i through 12.vii, or 12.ix] Did this source [OR IF **MORE THAN ONE** "YES", SAY INSTEAD: "Did any of these sources"] have a patent on any part of this innovation? YES NO DK REF

15. [IF ANY OF 12.i THROUGH 12.ix SELECTED] How did you acquire this innovation?

		select all that apply
i.	Merger, acquisition or equity purchase	[ ]
ii.	Joint Venture or Cooperative R&D	[ ]
iii.	License	[ ]
iv.	Service contract or consulting	[ ]
v.	Informal means, such as reverse engineering, hiring or informal interaction	[ ]
vi.	Other (specify)_______________________________	[ ]
vii.	DON'T KNOW	[ ]
viii.	REFUSED	[ ]

16. [IF YES TO ANY OF 12.i through 12.ix] Could you have acquired a similar innovation from elsewhere? YES NO DK REF

17. [IF NO TO ALL OF 12.i through 12.ix] Was it mainly [THREAD COMPANY] that originated this innovation? YES NO DK REF
    17.1. IF 17 is YES, or YES to 12.vi : Did this innovation largely originate from R&D activity in your company? YES NO DK REF
    17.2. [ASK OF ALL RESPONDENTS UNLESS ANSWERED "YES" TO 17.1] Does your company conduct R&D? YES NO DK

18. In 2009, roughly what percent of your total sales in [THREAD INDUSTRY] were from this innovation?______

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q18

18.1. 1-5%
18.2. 6-10%
18.3. 11-25%
18.4. 26-50%
18.5. More than 50%
18.6. DK
18.7. REF

PREAMBLE: We are now going to ask about the business as a whole

19. Is there another division or business of [THREAD COMPANY] that is one of your main customers? YES NO DK REF

20. Is there another division or business of [THREAD COMPANY] that is an important supplier for you? YES NO DK REF

IF YES TO 5 AND NO TO 3 ASK ALL QUESTIONS IN LICENSING AND CONTRACT R&D SECTION

IF YES TO 5 AND YES TO 3, <u>ASK ONLY 26</u> IN "LICENSING AND CONTRACT" SECTION BELOW AND SKIP THE PREAMBLE IMMEDIATELY BELOW (PRIOR TO QUESTION 21)

<u>LICENSING AND CONTRACT R&D SECTION</u>

PREAMBLE: Of the innovations you licensed or developed for another party in the period 2007 to 2009, please think of the one that generated the most revenue

21. Which one of the following would best describe this innovation?

		select one
i.	A product or service	[ ]
ii.	A process (or method for delivering a service)	[ ]
iii.	A technology, know-how, information or software	[ ]
iv.	NO REVENUE GENERATING LICENSING IN 2007-2009 → SKIP TO BACKGROUND	

22. Did your company patent any part of this innovation? YES NO DK REF

23. Please indicate the number of buyers or licensees for this innovation to date:__________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q23

23.1. 1
23.2. 2-5
23.3. 6-10
23.4. More than 10
23.5. DK
23.6. REF

24. Did you develop this innovation for a specific customer YES NO DK REF

IF RESPONDENT NEEDS CLARIFICATION: Did the customer contract for this innovation before it was developed?

25. How was the innovation transferred? (check all that apply)

		select all that apply
i.	License (excluding packaged software)	[ ]
ii.	Service contract or consulting	[ ]
iii.	Merger, acquisition or equity purchase	[ ]
iv.	Joint or cooperative venture	[ ]
v.	Other (specify)________________________________	[ ]
vi.	DON'T KNOW	[ ]
vii.	REFUSED	[ ]

26. In 2009, roughly what share of [THREAD COMPANY]'s revenues in [THREAD INDUSTRY] came from out-licensing of technology or developing technologies or innovations for another party?________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q26

26.1. None
26.2. 1-10%
26.3. 11-25%
26.4. 26-50%
26.5. More than 50%
26.6. DK
26.7. REF

BACKGROUND

PREAMBLE: [SKIP THIS PREAMBLE IF COMING DIRECTLY FROM Q5] The next several questions focus on BACKGROUND information. Please provide your best estimates.

27. Approximately how many years ago did [Thread Company Name] enter [Thread industry name]?______

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q27

27.1. Less than 5 years ago
27.2. 5 or more years ago
27.3. DK
27.4. REF

28. In the last 3 years, have you introduced any new or significantly improved processes for making a product or delivering a service in [THREAD INDUSTRY]? **YES NO DK REF**

29. Roughly how many employees does [THREAD COMPANY] have in [THREAD INDUSTRY], including employees at other locations worldwide?_________________

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q29

29.1. Less than 25
29.2. 25 to 100
29.3. 101 to 500
29.4. 501 to 1000
29.5. Between 1,001 and 10,000
29.6. Greater than 10,000
29.7. DK
29.8. REF

30. From 2008 to 2009, what was the approximate percent change in [THREAD COMPANY]'s market share in [THREAD INDUSTRY]?_____________ DK REFUSED

ONLY PROMPT CATEGORIES IF "DK" RESPONSE TO Q30: Do you think it…

30.1. Remained about the same?
30.2. Declined?
30.3. Increased?
30.4. DK
30.5. REF

RESPONDENT INFORMATION

31. How long you have been employed by [THREAD COMPANY]?______

32. What is your current title or position?_____________________________________

33. For the report benchmarking your business, what e-mail address should we send it to?__________