Working Paper Series
No. 15004

The Acquisition and Commercialization of Invention in American Manufacturing

Incidence and Impact

Ashish Arora
Duke University and National Bureau of Economic Research

Wesley M. Cohen
Duke University and National Bureau of Economic Research

John P. Walsh
Georgia Institute of Technology

June 2014

Hoover Institution Working Group on
Intellectual Property, Innovation, and Prosperity
Stanford University

www.hooverip2.org

NBER WORKING PAPER SERIES

THE ACQUISITION AND COMMERCIALIZATION OF INVENTION IN AMERICAN MANUFACTURING: INCIDENCE AND IMPACT

Ashish Arora
Wesley M. Cohen
John P. Walsh

Working Paper 20264
http://www.nber.org/papers/w20264

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
June 2014

This research was jointly funded by Grant Award # 080349 from the National Science Foundation, and the Ewing Marion Kauffman Foundation. Additional support was provided by The Fuqua School of Business, Duke University, The School of Public Policy, Georgia Tech and the National Human Genome Research Institute of the National Institutes of Health [Award Number P50HG003391]. You-Na Lee and Colleen Cunningham provided outstanding research assistance. We are also grateful to Vaibhav Gajulapalli and Arun Patro for helping with data construction, and to seminar participants at Carnegie Mellon, Duke, Berkeley, Georgia Tech, Michigan, Toronto, Columbia, University of North Carolina (Greensboro), Tilburg, KU Leuven, Cambridge, and London Business School for helpful comments. The customary disclaimers apply. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

The Acquisition and Commercialization of Invention in American Manufacturing: Incidence and Impact
Ashish Arora, Wesley M. Cohen, and John P. Walsh
NBER Working Paper No. 20264
June 2014
JEL No. L1,O3,O30,O31,O32,O34

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, 18% of manufacturing firms had innovated – meaning had introduced a product that was new to the market. Of these, 49% report that their most important new product had originated from an outside source, notably customers, suppliers and technology specialists. 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 customers tend to be economically less significant than those from technology specialists. As a group, external sources of invention make a significant contribution to the overall rate of innovation in the economy. Indeed, results from a multinomial logit model suggest that, were the outside availability of innovation to be removed, the percentage of innovating firms in the U.S. manufacturing sector would drop from 18% to 10%.

Ashish Arora
Fuqua School of Business
Duke University
Box 90120
Durham, NC 27708-0120
and NBER
ashish.arora@duke.edu

Wesley M. Cohen
The Fuqua School of Business
Duke University
Box 90120
Durham, NC 27708-0120
and NBER
wcohen@duke.edu

John P. Walsh
Georgia Institute of Technology
School of Public Policy
john.walsh@pubpolicy.gatech.edu

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 that U.S. firms made in the 1940s through the 1970s, has become less accurate as a description of the innovation process over time. Some accounts document the importance of technology specialists such as biotechnology firms (Arora and Gambardella, 1990) and universities (e.g., Larsen and Salter, 2004), whereas others stress the importance of suppliers (Pavitt, 1984) and customers (e.g. von Hippel, 1986) as important contributors to the innovations produced by firms. These accounts have been extended to argue that innovation has become "open" (Chesbrough, 2003).

Systematic evidence on the extent to which innovation introduced by US manufacturers rely upon external invention is, however, absent. Distinguishing between invention and innovation, this paper presents results from a survey of over 6000 American manufacturing and service sector firms on the extent to which innovating firms rely upon external sources for their inventions, as well as the importance of the different sources and channels through which firms acquire these inventions, both overall and by industry. The paper also assesses the impact of external sourcing on the rate of innovation for U.S. manufacturing, as well as the relative cost and value of inventions acquired from different types of sources.

If innovating firms indeed commonly rely upon extramural sources for inventions, then economists' understanding of the fundamental drivers of innovation requires amendment and the adoption of a more system-wide perspective. The overall rate and quality of innovation would then depend not only upon industry-level factors (e.g., demand, technological opportunity and appropriability) and firm characteristics (e.g., firms' R&D capabilities, firm size), (cf. Cohen, 2010), but also upon the extramural supply of inventions.

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

Despite its importance, this subject has been understudied, particularly for the United States.[4] One literature has focused on knowledge flows and spillovers across rivals rather than on the purposeful sourcing of invention (e.g., Griliches, 1992). Other studies have focused on particular sources of invention, such as biotechnology startups (e.g., Arora and Gambardella, 1990), universities (e.g., Cohen et al., 2002), or users (von Hippel, 1986); on particular channels such as licensing (e.g., Arora, Fosfuri and Gambardella, 2001); or on phenomena such as crowdsourcing of ideas (e.g., Jeppesen and Lakhani, 2010). In this paper we do not restrict ourselves to a particular channel, nor to a particular source. Furthermore, this prior work has not permitted estimation of the impact of outside invention on the rate of innovation.

To preview our findings, we find that, of the 18% of the manufacturing firms that innovated (i.e., had introduced a product that was new to the market) between 2007 and 2009, 49% report that their most important new product had originated from an identified outside source, suggesting pervasive reliance upon external sources of invention. Moreover, just over a third of these transfers involve a market transaction—a license, a service contract or an equity purchase. Using a multinomial logit framework, we infer that denying firms the opportunity of going to an outside source would reduce the percentage of innovating firms in the U.S. manufacturing sector by 43%, from the observed rate of 18% to 10%.

Regarding different external sources of invention, we observe that although customers are the most common outside source, inventions acquired from them tend to be less valuable than those acquired from technology specialists such as universities, independent inventors, and R&D service firms.

Section two briefly reviews the literature and locates our paper in the context of the literature on determinants of innovation, and the more recent literature on markets for technology and open innovation. We describe the survey design underlying our sample in section 3. Section 4 describes our estimates of the main variables of interest: innovation rates, the share of various

[4] Scholars have studied the importance of external knowledge sources for European countries, using the Community Innovation Surveys (CIS). See for instance Tether and Tajar 2008 and Laursen and Salter, 2006, for the UK, Veuglers and Cassiman, 1999 and 2005, for Belgium, Lhuillery, S., & Pfister, E. (2009) for France, Poot et al (2009) for Netherlands. Mohnen and Roeller, 2005 and Griffith et al., 2006, are examples of studies that use cross-country CIS data.

sources of innovation, and the channels through which innovators acquire the inventions for their innovations. We also analyze how different sources are related to the relative cost and value of innovation, and use a multinomial logit framework to estimate the impact of external sourcing on the rate of innovation, overall and by source type. Section 5 summarizes our main findings and concludes.

2. Background

Notwithstanding its social welfare benefits, a division of innovative labor between inventors and innovators faces hurdles. It requires that information be transmissible across firms, and thus be applicable outside the context in which it was developed (von Hippel 1990; Arora and Gambardella, 1994). Further, once knowledge is transmitted, it is at risk of misappropriation, and patents in practice offer effective protection in only a small number of industries (Scherer et al., 1959; Mansfield, 1986, Levin et al., 1987; Cohen et al., 2000). Williamson (1991) and 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. Thus, for numerous reasons, any transfer of technology across entities, including market-based trade, is fraught with difficulties (cf. Arora and Gambardella, 2010).

Despite these obstacles to firms' use of outside sources for their inventions, numerous empirical scholars have documented such reliance. Such accounts have, however, typically focused on specific sources, such as universities, customers, suppliers or rivals.[5] Others have focused on the specific channels through which inventions may flow, such as cooperative ventures of various forms, including R&D cooperative ventures, joint ventures, etc. (Ahuja et al., 2008). Licensing has also been studied (cf. Arora and Gambardella, 2010). But these studies have focused on either specific sources or specific channels in isolation, thus not providing a sense of the overall importance of firms' reliance on external sources for their inventions.

A handful of studies have, however, considered the relative importance of different types of relationships in affecting innovation. For example, early work tied to researchers from SPRU and MERIT examined what they call "networks of innovators" (Freeman, 1991), and document

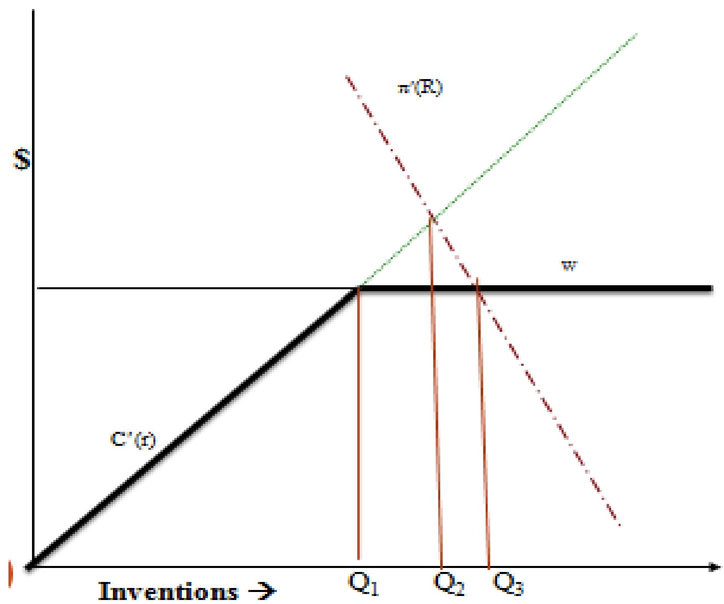
[5] The role of rivals in providing particularly non-market mediated knowledge in the division of innovative labor has been examined in the literature on R&D spillovers.

the incidence of the different types of relationships but offer limited insight into their economic importance. Subsequent survey-based studies assessed the relative importance of different sources of knowledge in their effect on firms' R&D efforts (e.g., Klevorick et al. 1995 and Cohen et al., 2002). These studies, however, offered limited opportunity to tie their measures of importance to an impact on innovation. For example, while this work finds that customers constitute the dominant source of knowledge affecting industrial R&D, we do not know if this dominance reflects the relative frequency or value of acquiring inventions from users, or both. Moreover, much of this prior work focuses on measures of knowledge flows. Although knowledge flows are more general than what we are examining—namely the transmission of specific, identifiable inventions, they are less concrete, and, perhaps for this reason, less amenable to analysis of economic outcomes.

A related literature studies firms' "make-or-buy" decisions with respect to innovation. Guided by Williamson's (1985) transactions cost framework, Pisano (1990), for example, studies this question for the pharmaceutical industry, exploring factors that may condition the make-or-buy decision, as distinct from the decision to innovate to begin with. External sources of invention do not, however, simply provide a choice between internal R&D and the purchase of an invention from an outside source. The availability of external invention may also affect whether a firm decides to innovate. Thus, external availability of inventions may affect not only the efficiency of innovation, but also the overall rate of innovation.

A simple model illustrates these two effects of external supply of invention on firm innovation. 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. Transaction costs, defined broadly to include contracting and search costs as well as the costs of transferring knowledge across contexts and firm boundaries, are a component of 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 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.

Figure 1: Supply and Demand for Innovation



The literature, therefore, leaves us with several questions to explore. How extensively do firms rely on outside sources for the key ideas and knowledge behind their innovations? How does this vary across industries? What are the sources of outside inventions, and through what channels does this division of innovative labor function? How does this variation in sources affect innovative performance? Finally, how does the external availability of inventions affect the rate of innovation?

3. Data: Survey design

In order to address these questions, we conducted a phone survey of firms in US manufacturing and selected business service industries (see Table A1 in the appendix for a list of the industries in the sample). Our sampling frame was the Dun and Bradstreet (D&B) Selectory database, which is the most complete, publicly available frame for the U.S., providing detailed information on firms, including industry, size, age and contact information (including names of potential informants in the firm). We also use a post-sample weighting procedure (described below) to make the D&B data more representative. A distinguishing feature of this sampling procedure is that we are not sampling on innovators (as is the case of studies based on patent data), nor on R&D performers (as was the case in the Carnegie Mellon survey (Cohen et al., 2000)). Our goal is to generate a sample from which we can generalize our findings about innovation and the division of innovative labor to the population of US firms in the manufacturing sector and selected service sector industries.[6] In this paper we focus on the manufacturing sector alone.

In order to increase the efficiency of our sample and, in particular, to obtain a substantial number of innovators from each industry in our dataset, we stratified our sample along multiple dimensions, using the D&B data as the basis for stratification. Because all cases stay in the sample, errors in the D&B data used for 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. We organized these subsidiaries by business units, defined as a firm's activities within a given product market, with each subsidiary grouped into 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 will 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 (less than five years old versus five or more years old). In order to focus our sample on the most relevant firms while still achieving a representative sample, 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.

[6] This strategy is analogous to that employed by the Community Innovation Survey (CIS) in Europe and the NSF's Business R&D and Innovation Survey (BRDIS).

The survey was administered by phone.[7] 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. However, based on a pre-test, we knew that many of these cases would be out-of-business or out-of-population (for example, bakeries that are in retail, not manufacturing). Thus, an initial screening eliminated many cases, 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.[8]

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]).

[7] NORC, of the University of Chicago, administered our survey.
[8] 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 the key rationale for using a phone survey over post-mail or email surveys.

In light of concerns about the representativeness of the D&B sampling frame, the response rate and some evidence of response bias, we constructed 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 Census report, 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. These weights are used throughout the paper when computing means in order to properly estimate the population means (Kalton, 1984).

4. Measures

4.1 Innovation

To consider the acquisition of inventions from outside sources by innovating firms, we must first identify the innovating firms. In this study, we focus exclusively upon product rather than process innovations. Following prior innovation surveys,[9] we asked the respondent if, over the prior three years, the firm had earned any revenue in 2009 from a new or significantly improved (NOSI) product or service introduced since 2007. For firms that had, we also asked whether their most significant innovation -- defined as that product innovation accounting for the plurality of sales in the respondent's market -- was new to the market (NTM). For those that said yes, we then asked about their most significant product innovation.[10] Table 1 provides illustrative examples of innovations introduced by firms in the manufacturing sector.

In contrast to other innovation surveys, we asked our respondents to answer questions with respect to the main industry of the business unit itself. Also, instead of inquiring about innovation activities generally, most of our questions focused on their most significant innovation. Most importantly for this paper, to measure externally acquired innovations, we asked whether an outside source originated the relevant invention, that is, "created the overall

[9] Our measures of innovation are similar to those employed in prior innovation surveys, such as the Community Innovation Surveys (CIS) in Europe and the NSF's Business R&D and Innovation Survey (BRDIS).

[10] Our NTM figure may underestimate the percentage of firms introducing NTM innovations. It is possible, for example, that a firm's most significant (i.e., highest selling) innovation may not be NTM, but its second most significant is an NTM innovation, implying that the firm is an "NTM" innovator—but will not show up as such. So, our NTM % is a lower bound. However, any bias is likely to be small because, as shown in Table 2 below, the focal innovation accounts on average for more than 70% of the revenues earned from all innovations, suggesting that most firms introduce only a single innovation during the sample period.

design, developed the prototype or conceptualized the technology" and, if so, what the source was, and through what channel the invention was acquired. [11]

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*

We also probed 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.

[11] This question distinguishes our data from the CIS, the Carnegie Mellon Survey, and the Yale Survey, which inquire generally about the sources of knowledge flows informing firms' R&D and other innovative activities, not about a specific invention.

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

INDUSTRY (Number of respondents)	% NOSI **a**	% NTM **b**	Imitation **a-b**	% sales from NOSI	% sales from focal innovation	% NTM patented
Food/Bev (362)	40%	15%	25%	26%	17%	25%
Textiles (210)	38%	18%	20%	20%	14%	54%
Wood (385)	33%	10%	23%	21%	20%	14%
Chemicals (365)	50%	27%	23%	23%	15%	46%
Pharma (128)	63%	36%	27%	33%	30%	59%
Plastics (340)	48%	22%	26%	24%	19%	48%
Minerals (323)	31%	11%	20%	23%	15%	34%
Metals (324)	38%	10%	28%	19%	9%	29%
Fab Metals (424)	39%	12%	26%	28%	15%	36%
Machinery (384)	46%	23%	23%	27%	19%	50%
Electronics (146)	76%	38%	39%	39%	25%	58%
Semicond (302)	61%	33%	28%	35%	25%	60%
Instruments (135)	60%	44%	16%	28%	24%	52%
Elec Equip (344)	54%	30%	25%	37%	28%	56%
Auto (339)	53%	30%	23%	35%	26%	33%
Med Equip (136)	56%	22%	34%	34%	27%	72%
Misc. (510)	48%	21%	26%	24%	19%	45%
All manuf. (5157)	43%	18%	25%	27%	20%	42%
Large firms (1268)	66%	43%	23%	20%	12%	64%
Med. firms(945)	54%	26%	29%	23%	15%	46%
Small firms (2944)	40%	16%	24%	30%	22%	38%

Table 2 presents summary statistics for our key measures of the rates of innovation by industry. For purposes of presentation, 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), as discussed above.

Table 2 shows that 43% 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. However, there are significant differences in the rates of new or improved product introduction across industries. For example, over 60% 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 18% 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, 42% of firms with a NOSI product are the first to bring that product to market, and are classified as innovators. The rank order correlation between NTM innovation rates at the industry level, and other innovation measures such as patenting and the percentage of R&D performing firms, are high, above 0.70.[12] In what follows, the term "innovation" refers to products that are new to the market.

Table 2 also shows that larger firms are more likely to innovate and more likely to introduce new products. Thus, 40% of small firms but 66% of large firms introduce NOSI products. For innovations (i.e., new to the market products), the rates were 16% and 43% for small and large firms, respectively. Thus, larger firms are more likely to have at least one innovation and the gap between large and small firms is greater for innovations as compared to new-to-the-firm products. 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.

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 20% of the business unit sales while ***all*** products that are new to the firm account for 27% of business unit sales. Thus, on average, a firm's single most important new product accounts for 74% of sales due to all new-to-the-firm products indicating that the revenue impact of new products is highly skewed.

[12] We canvassed all the firms in our sample to determine whether or not they performed R&D. We do not know, however, their level of R&D expenditures. Our patent data were obtained from PATSTAT, from which we estimated the percent of firms in each industry that had a patent application.

Table 2 also provides the first industry-level estimates of patent propensity for product innovation for all U.S. manufacturing firms.[13] Fewer than half, or about 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 tends to be higher than average also patent new products at higher than average rates. Nearly two thirds of the large firms patent their most significant innovation compared to only 38% of small firms.

To assess the validity of our survey, we compare our findings regarding innovation rates for the manufacturing sector with those from other innovation surveys, including the Community Innovation Surveys (CIS). One might expect differences across otherwise comparable national economies simply due to differences in the distribution of respondents across firm size classes and industries and that innovation rates differ across these dimensions. Nonetheless, as compared to 43% of our respondents that earned revenue in 2009 from (NOSI) products introduced since 2007, the CIS in the UK reveals 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 42% 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 18%, ranging from about 17% for the UK to 22% for Germany. Innovation surveys from elsewhere in Europe also reveal very similar rank orderings of industry with respect to rates of new products as well as product innovation.

4.2 Acquisition of inventions by innovating firms

A key distinction in this paper is between innovation (the introduction of a product that is new to the market) and the invention that underlies the new product. 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

[13] 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.

the respondent; 4) a consultant, commercial lab or engineering service provider; 5) an independent inventor; and 6) a university or government lab. In addition, for those firms reporting acquisition of their invention from an outside source, we asked 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. Respondents to our survey had the option of indicating more than one source or channel.

Sources of inventions

In this section, we summarize our data on the outside sources for invention. The mean number of sources for those that indicate an external source is 1.42, with 32% reporting more than one source. 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. Sources in the industrial chain—customers and suppliers—and hence most economically proximate to the focal firm, tend to be the most frequent outside source of invention. Whether this high incidence of sourcing from customers and suppliers reflects low cost or higher value is an important question to which we will return.

The salience of customers in particular as an external source of invention comports with prior literature that suggests that customers are an important source of knowledge flows and ideas (von Hippel, 1986, 2005, Cohen et al., 2002; Klevorick et al., 1995). Table 3 also shows 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 18% of externally sourced inventions. 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.

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	73	46	33	16	7	1	8	0	8
Textiles	38	45	30	23	3	3	5	0	8
Wood	60	55	18	34	9	11	1	1	13
Chemicals	115	49	15	14	4	13	6	4	20
Pharma	39	45	5	7	14	4	4	17	26
Plastics	95	59	15	29	4	13	15	4	28
Minerals	44	38	5	18	3	6	9	8	21
Metals	52	48	26	29	11	9	4	7	12
Fab’d Metal	71	43	8	31	5	0	5	5	10
Machinery	112	47	8	35	9	11	7	6	19
Electronics	58	46	13	15	12	7	5	9	17
Semicond.	108	58	14	43	10	13	11	10	26
Instruments	62	47	4	26	9	9	7	2	16
Elect Equip	111	44	10	24	5	7	7	5	18
Auto	110	52	11	29	12	05	16	14	24
Med Equip	40	49	17	23	5	13	9	15	32
Misc.	120	50	8	22	15	1	13	2	22
All Mfg.	1308	49	13	26	8	8	8	5	18
Large	520	50	22	24	8	7	5	7	15
Med	256	46	11	25	8	7	4	5	15
Small	532	49	13	27	8	8	10	5	19

There is substantial variation in the use of different sources across industries. 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 0.42, technology intensity is positively related to innovators’ reliance upon universities, which is not surprising. In contrast, heavier industry reliance upon customers and suppliers is more likely in less technology intensive industries; the correlation coefficients between technological intensity and reliance on customers and suppliers are, respectively, -0.30 and-0.25. One telling correlation is that between innovators' reliance upon customers and the share of the industry's output that goes to final consumers versus firms, a measure constructed from U.S. BEA data. The correlation, -0.52, tells us that it is much more likely that firms acquire inventions from customers when those customers are other firms rather than end consumers.

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, 14% of those firms relying upon an outside source for their invention report that the source is a startup (defined as a "new, small company"). Unsurprisingly, the source most often characterized as a startup—by 37% of the respondents—is independent inventors. Our aggregate figure of 14% for the contribution of startups to other firms' innovative activities is striking when compared to the incidence of startups in our manufacturing sample more generally, which is 2.5%, suggesting that startups 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 25.5% of inventions acquired from the outside were patented by the source. Inventions originating from independent inventors were most frequently patented, at a rate of 52%, with universities next at 40%, and then suppliers at 35%. Inventions sourced from customers are patented by the customers at a rate of 16%. Inventions sourced from technology specialists (i.e., universities, R&D service providers and independent inventors) are patented at a reported rate of 40% overall. 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.

Patenting reflects the underlying value of the invention and whether it embodies a sufficient technical advance to be patentable. These figures suggest that inventions sourced from customers have less technical content than those derived from other sources, especially technology specialists, and are also the least valuable. Patenting may also reflect a strategic choice of how the invention will be commercialized. Therefore, a different, though not mutually exclusive, interpretation is that specialists rely more heavily on patents to profit from their inventions than suppliers and customers, because the latter can use other appropriability mechanisms as well. Patents are especially useful to facilitate trade in technology upon which technology specialists rely more heavily than others.

Channels

Table 4 presents our summary statistics on respondents' use of channels for acquiring their inventions from the outside, by industry and firm size.[14] As is the case with sources, respondents could indicate more than one channel for acquiring the invention from the outside. The mean number of channels for respondents that used an external channel is 1.43 (with 32% 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.[15] 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, suggesting that cooperative efforts may complement market channels in some cases, 17% (i.e., 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 36% 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.

After cooperative channels, 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 14% 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. Since respondents can list multiple channels, 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" includes those respondents who identify at least one of these three channels while possibly also indicating one of the other channels such as an informal channel or a joint or cooperative venture. We find that 37% of our

[14] There are 155 respondents who reported an outside source for acquiring their invention but did not identify a channel. For our analyses based on channels, we treat these 155 observations as missing.

[15] Tether (2002), using the CIS2 for the UK, reports that in 1997, nearly 42% of innovators in the UK reported cooperation with external partners. In our sample, fewer than 25% of innovators report cooperation with external partners. Tether (2002) also finds that the probability of external cooperation increases with R&D intensity. The definitions of cooperation are not directly comparable, but do suggest that cooperation is an important channel.

respondents fit this category. If we limit the cases to those where respondents report at least one of the three market channels but no non-market channels, then 16% of the respondents report relying on market channels alone, as indicated in the "Market only" column**.** One important implication of our findings is that market channels, either alone or employed in tandem with other channels, do not fully delineate the extent of the division of innovative labor. Table 4 also shows that large firms favor market channels relative to small firms, which favor informal channels. Medium size firms rely upon joint ventures and cooperative R&D ventures to a larger extent.

As is the case with sources discussed above, 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 47% 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 0.57. 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.

Among respondents that reported a channel, 27.7% of the inventions sourced externally were patented by the source.[16] Unsurprisingly, inventions sourced via licensing, or a merger and acquisition, are most frequently reported to be patented—58% for inventions sourced via a merger or acquisition, and 69% via licensing. Also unsurprisingly, only 4% 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 13% of the cases. These figures suggest that patents facilitate market transactions in technology. And they also suggest that patents are not common features of the division of innovative labor when non-market

[16] This is slightly higher than the 25.5% rate reported above that is obtained when we consider all respondents that use an external invention. As noted in footnote 14 above, not all firms reporting acquisition of their invention from the outside responded to the question regarding channels, which accounts for the slightly different figure.

channels are employed (with about three-quarters of all externally-sourced technology not being patented).

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

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

		M&A	Coop R&D	License	Service Contract	Informal	Market	Market only
Food/Bev	29	10%	76%	15%	18%	14%	28%	15%
Textiles	10	7%	76%	20%	17%	9%	34%	16%
Wood	27	10%	50%	11%	36%	39%	47%	12%
Chemicals	42	7%	68%	5%	38%	33%	47%	18%
Pharma	15	43%	35%	58%	7%	19%	80%	47%
Plastics	44	16%	68%	10%	20%	30%	35%	13%
Minerals	15	13%	69%	12%	11%	56%	36%	17%
Metals	18	17%	65%	5%	15%	42%	37%	16%
Fab'd Metals	24	1%	60%	9%	5%	68%	14%	1%
Machinery	37	11%	53%	7%	16%	41%	33%	22%
Electronics	22	13%	76%	12%	16%	11%	28%	12%
Semicond.	44	16%	61%	16%	31%	39%	42%	19%
Instruments	21	6%	48%	37%	12%	12%	54%	40%
Elect -Equip	32	28%	59%	18%	32%	37%	60%	26%
Auto	39	11%	66%	34%	18%	21%	53%	29%
Med Equip	15	15%	47%	16%	29%	30%	56%	23%
Miscl	50	6%	64%	14%	20%	36%	33%	12%
All Manuf	484	10%	61%	14%	20%	36%	37%	16%
Large firms	197	18%	54%	22%	19%	28%	45%	24%
Med firms	87	12%	67%	9%	16%	28%	34%	18%
Small firms	200	8%	61%	14%	21%	40%	36%	14%

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

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), 40% 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 indeed extensive.

4.3 Innovation performance

As suggested above, 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, does this relatively high incidence suggest that the preponderance of inventions drawn from customers are typically high value, similar to those originating from the lead users described by von Hippel (1986)? 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 from an innovation to an innovator from source *i* is denoted by V_i. The net surplus is given by $V_i - X_i - C_i$,where X_i represents the cost of commercializing the invention, and C_i represents the cost of acquiring invention. The cost of acquiring an internally generated invention is simply the investment in research required to generate the invention. Inventions acquired from outside also have to be generated, which have to be paid for. Thus, 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. Once the invention is generated, it will need to be developed, and the innovating firm may need to invest in equipment, and sales and marketing. Together, these investments are represented by X_i. Therefore, value, V_i, corresponds to what we might think of as 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 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. This outcome measure allows us to begin to disentangle cost from value. As long as the sales generate similar net margins over cost, 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. Table 5 presents results from regressing (OLS) the percentage of sales revenue due to a focal innovation against sources of inventions. The specification includes controls for age, size (log of employment), as well as 45 industry dummies at the 3 digit NAICS level of aggregation. Internal invention is the reference source.

The first column in Table 5 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 self-selection bias. It is plausible that inventions from customers can be acquired and commercialized more cheaply than those acquired from, say, specialists. If the cost of inventions sourced 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 average value of inventions sourced from customers will also be lower than those sourced from specialists, even if the true average value of customer inventions is similar or even higher in value from specialists. In econometric language, if $C_i + X_i$ varies across sources, the observed mean V_i is different from the true expectation of V_i. We therefore need to correct for the unobserved differences in the cost of acquiring inventions from various sources. To do so, we follow Dahl (2002) by using predicted probabilities of choice of a particular source to control for self-selection.[17] 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.

[17] Dahl (2002) analyses the case of workers choosing which state to locate in, and conditional on their choice, the observed labor market return to the worker. Dahl uses the share of a given type of worker that move to a particular state as the estimate of the probability that a worker of that type will move to state k. He uses a polynomial of this share as "correction" function for correcting for the selection bias. Dahl's approach does not require a multinomial framework. However, we use a multinomial logit framework to analyze the choice of the source of invention adequately to estimate the contribution of each source to innovation in Table 7. In a multinomial framework, the natural log of the predicted probability is the appropriate correction, as shown by Dubin and McFadden (1984).

Table 5: Value of inventions by source. Dependent variables: 1.) Percent sales from focal innovation; 2.) Invests in new distribution channels or in personnel and equipment

	% firm sales from focal innovation	% firm sales from focal innovation	Innovator invests in distn. channels or personnel/equip.	Innovator invests in distn. channels or personnel/equip.
Customer	-4.16** *(1.44)*	-4.74** *(1.58)*	-0.00 *(0.03)*	-0.00 *(0.03)*
Supplier	2.48 *(1.92)*	1.76 *(2.07)*	-0.03 *(0.04)*	-0.02 *(0.05)*
Other Firm	0.64 *(2.32)*	-0.27 *(2.53)*	0.02 *(0.05)*	0.03 *(0.06)*
Specialists	6.75** *(1.70)*	6.14** *(1.83)*	0.18** *(0.04)*	0.18** *(0.04)*
Ln (Empl)	-5.01** *(1.26)*	-5.00** *(1.26)*	0.07** *(0.03)*	0.07** *(0.03)*
Ind. FE's (45)	*Yes*	*Yes*	*Yes*	*Yes*
Controls	*Parent size, Age*	*Parent size, Age*	*Parent size, Age*	*Parent size, Age*
Seln. Corr. (Ln (share of source))		-1.26 *(1.40)*		0.00 *(0.03)*
N	1080	1080	1185	1185
R^2	0.16	0.16	0.13	0.13

Notes: Reference category= internal invention. Standard errors in parentheses.

Column 2 in Table 5 shows that this correction for selection leaves the basic pattern of results unchanged. The correction term (analogous to the Heckman selection in a binary choice model) is not, however, precisely estimated. We obtain similar results (not reported here) when we use a second order polynomial in the predicted probability instead of its natural log, although the coefficient on the correction term is again not significantly different from zero.

Another indicator of value is whether the innovating firm is willing to make significant investments to commercialize an innovation. In our survey, we asked innovating firms whether, to commercialize the innovation, they either developed new sales and distribution channels or invested in new types of equipment or hired employees with distinct skills. The results from an OLS regression in column 3 in Table 5 shows that innovating firms were more likely to undertake such investments for inventions sourced from specialists as compared to any other source, including internal invention, and particularly customers. Again, as shown in column 4, this result is robust to correcting for selection.

We interpret these findings as showing that the average (unconditional) value of inventions sourced from customers are lower than those sourced from specialists. Inventions from suppliers and other firms are similar to internal invention in value.

Thus, whereas Table 3 implies that V – X – C is the highest for customers among all external sources, Table 5 implies that V is the highest for specialists. This suggests that though lower in value, inventions can be acquired more cheaply from customers relative to technology specialists (low C), are cheaper to implement and commercialize (low X), or both.

The next set of results suggest that value net of the cost of commercialization, V – X, is higher for inventions from specialists compared to suppliers and customers. Our indicator of net value, V – X, is whether the innovator reports patenting the innovation. Assuming the innovation is sufficiently novel so as to be patentable, it will be patented if the benefits (i.e., the

Table 6: Indicator of value net of commercialization cost, by source of invention. Dependent variable = Innovator has patent on invention

	Innovator has patent on invention	**Innovator has patent on innovation**
Customer	-0.13** (0.03)	-0.11** (0.03)
Supplier	-0.09* (0.04)	-.06 (0.04)
Other firm	-0.06 (0.05)	-0.03 (0.05)
Specialist	0.25** (0.04)	0.27** (0.04)
Ln(Employment)	0.09** (0.03)	0.09 (0.03)
Industry FE (45)	*YES*	*YES*
Controls	*Parent firm size, Age*	*Parent firm size, Age*
Seln. Corr. (Ln (share of source)		0.05 (0.03)
N	1164	1164
R^2	0.22	0.22

Notes: Reference category= internal invention, and the sample consists of all innovators without missing values due to item non-response.

profit minus the cost of commercialization) outweigh the cost of patenting. Indeed, the literature on patenting also indicates that more valuable inventions are more likely to be patented (e.g., Arora et al., 2008).[18] Table 6 reports how the source of the invention conditions whether the innovator (the focal firm) has filed for a patent on the innovation. The OLS results presented in the first column shows that the innovator is significantly less likely to report patenting an invention sourced from a customer relative to an internal invention. However, the opposite is true for inventions from specialists. As shown by the results in the second column, the results are again robust to our correction for selection.

Taken together, the results from Tables 3, 5 and 6 imply that the net surplus (i.e., V – C – X) is the highest for customers, followed by technical specialists and suppliers. However, technical specialists offer inventions with the highest value even after we net out the expected costs of commercialization. In other words, the high incidence of inventions sourced from customers reflects principally the low cost of acquiring and commercializing such inventions, rather than value.

Our results suggesting that customers offer 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 a fraction of customers may provide high-value inventions, there are reasons to believe that on average customer-sourced inventions will be of lower value relative to that of specialists. 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. Indeed, we observe that industrial customers are more likely to be sources of invention than final consumers, with 30% of innovating firms listing customers as a source for their inventions in industries that the U.S. BEA identifies as intermediate capital goods industries, versus 18% in industries identified as final goods industries. In contrast to customers, technology specialists should have no systematic interest in promoting incremental invention. Indeed, they would have 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.

---

[18] Moreover, science and technology based inventions, and more significant inventions are more likely to satisfy legal patentability requirements, whereas incremental inventions are less likely to be patentable.

Not only does this line of reasoning imply inventions from customers will be of lower average value, it also implies that they will be easier to implement and commercialize. Insofar as the invention are incremental, less development effort is needed. Further, they will require less investment in sales and marketing because the customer that originated in the invention is likely to be among the early buyers.

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 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. 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, unlike the customer that may benefit indirectly and thus charge less, specialists will only benefit from the invention they offer to a focal firm through the price that they charge.

4.4 The contribution to innovation by source

Given that sources differ in their costs and benefits, what can we say about their contribution to innovation? To address this question, we employ the multinomial logit framework to calculate the impact of the average contribution of source selection on the overall rate of innovation.

Assume all firms are potential innovators, and that a firm will introduce at most one innovation.[19] The firm has access to both internal as well as external inventions. 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. Using the notation used earlier, the average value of an innovation to an innovator from source i is denoted by V_i, and the costs of acquiring and commercializing the invention are denoted by C_i and X_i respectively.

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

Assuming that the value of the invention to the firm from source *i* has a firm-specific stochastic component, the net surplus from the invention $u_{ij} = V_i - X_i - C_i + \varepsilon_{ij}$.[20] Firms may differ, for example, in their abilities to realize value from the same innovation, perhaps due to differing development or marketing capabilities, 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—including not innovating—that provides the highest net surplus. We observe not only the source of invention for firms that innovate, we also observe firms that do not innovate. We therefore include "no innovation" as an option, and normalize the net surplus associated with this option to zero.

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:

$$[P_0 /(1-P_0)][(P_i)/ (1-P_i)]. \qquad (1)$$

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 Tables 2-5, and take a 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 7.

Table 7 reports the contribution to the innovation rate for the manufacturing sector as a whole, by each source, and by external sources overall. Substitution between sources means that the drop in innovation from losing a given source *i* is less than P_i.[21] However, because some of the substitution would result in the firm choosing not to innovate, the overall rate of innovation will decline. As reported above, 18% of the firms innovate and about 49% of these innovators rely upon external sources of invention. Equation (1) implies that removing all external sources

---

[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. Recall also that each respondent receives a census weight based on its industry, size class and startup status.

[21] In particular, the multinomial logit setup implies that the substitution between two sources depends only on their market shares. Thus if, for instance, customers were removed, the innovators using customers 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. Recall also that we include no-innovation as a "source". In our sample, more than 80% of respondents do not innovate. Thus, the multinomial logit implies that a very substantial portion of those using customers would therefore not innovate if inventions from customers were not available.

of invention would reduce overall innovation by 43%. Put differently, if external sources of innovation were not available, only about 10% of the firms would innovate instead of 18%. 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 7: Contribution to innovation by external source (% reduction in innovation rate if the source were not available).

Customer	17.6% (1.47)
Supplier	8.1% (0.85)
Other Firm	4.4% (0.62)
Specialist	10.8% (0.95)
All external	43.4% (2.06)
Internal	46.7% (2.02)

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*.

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—a point that is implied by our discussion of Figure 1 above. Put differently, external sources of invention do not simply substitute for internal invention; they 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. Our results also suggest that sources vary in the value and costs of their inventions, and thus, in their contribution to the overall rate of innovation: Customers tend to offer low value inventions at low cost, and specialists offer high value inventions at high cost. In future analyses, we shall explore how these patterns are conditioned by firm and industry characteristics.

5. Conclusion and implications for policy and management

On the basis of a broad survey of the U.S. manufacturing industry, we observe that a substantial fraction of innovating firms acquire the inventions that they subsequently commercialize from outside sources, including customers, suppliers and what we call technology specialists, namely universities, independent inventors, consultants and R&D service providers. These inventions are acquired through cooperative R&D and joint ventures, informal channels, and the market channels of licensing, acquisitions and service contracts. Firms' pervasive reliance on outside sources for their inventions implies that an understanding of the drivers of innovation rates across industries requires not only an understanding of industry and firm level determinants of innovation, but also an understanding of those factors that condition the supply of invention from sources outside the firm and often outside the industry. Moreover, use of externally generated inventions is not simply a matter of make-or-buy; the external supply of invention will affect the decision to innovate to begin with, and thus the overall rate of innovation. Indeed, our analysis of the patterns of the acquisition of innovation from outside sources allows us to estimate the impact of such external supply upon the overall rate of innovation, and this impact is large. The removal of external sources of invention that feed firms' innovation activity will depress the frequency of innovation in the manufacturing sector (i.e., the percentage of firms that innovate) by nearly a half.

Going beyond estimating the effect of external supply on the innovation rate overall, we can also distinguish the impacts by source, distinguishing particularly between customers and technology specialists. An important implication of our analysis is that the relative incidence of reliance on a given source reflects both the value of inventions offered by the source as well as the cost of acquiring and commercializing the invention from the source. By exploiting data on the share of sales accounted for by our respondents' most significant product innovations, we are able to show that, although customers are a pervasive external source for innovation, the value of the innovations originating from customers tends to be relatively low, and the highest value externally acquired innovations originate from technology specialists. Thus, our analysis extends beyond the reporting of the findings of our survey by developing an understanding of factors associated with the incidence and value of external supply.

Our results speak to the policy emphasis in the United States and elsewhere on innovation policies targeted at small firms. These policies are often based on the idea that small firms are superior innovators and that various market imperfections are especially baneful for small firms. Our findings suggest that the search for some specific type of firm—whether small, large, etc.—that is ideally suited for innovation is misplaced. Policy should focus on increasing the efficiency of the institutions that facilitate the division of labor between inventors and innovators.

Intellectual property rights are a case in point. Our results suggest that slightly more than 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 (though other types of intellectual property may well be involved). However, for certain types of inventors, notably universities, independent inventors, and R&D contractors, patents appear to be much more important. Further, inventions from these sources tend to be higher value as well, and tend to involve market transactions. Therefore, although we cannot be definitive, our results suggest that an efficient patent system may enhance the rate at which inventions originating from a notably valuable source of inventions may be transferred to potential innovators and developed into valuable new products.

For managers, our results reinforce the need to consider ways in which they may improve the efficiency of acquiring inventions from external sources, and their approach to managing the cooperative relationships, which are important channels for acquiring external inventions. The results also suggest that managers should pay particular attention to especially high value sources such as universities and independent inventors.. 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, but clearly what we are calling technology specialists are also critical to performance. Moreover, the fact that independent inventors appear to disproportionately favor small firms as compared to larger ones suggests that large firms may be missing an interesting opportunity.[22]

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 this system-level understanding of the division of innovative labor.

[22] 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).

References:

Arora, A. & Ceccagnoli, M. (2006). Patent protection, complementary assets, and firms' incentives for technology licensing." Management Science **52**(2): 293-308.

Arora, A., & Gambardella, A. 2010. "The market for technology", in The Handbook of Economics of Technical Change, Bronwyn H. Hall, and Nathan Rosenberg (eds.), 2010, North-Holland, Elsevier Press, Amsterdam and Oxford

Arora, A., & Gambardella, A. 1994. The changing technology of technological change: general and abstract knowledge and the division of innovative labour. Research policy, 23(5), 523-532.

Arora, A., and Gambardella, A. 1990. "Complementarities And External Linkages: The strategies of large corporations in biotechnology", The Journal of Industrial Economics, 38(4): 361-379.

Arora, A., Fosfuri, A., & Gambardella, A. 2001. Markets for technology and their implications for corporate strategy. Industrial and corporate change, 10(2), 419-451.

Arora, A., Fosfuri, A., & Gambardella, A. 2001.Markets for Technology: The Economics of Innovation and Corporate Strategy, MIT Press, Boston MA..

Athreye, S., & Cantwell, J. (2007). Creating competition?: Globalisation and the emergence of new technology producers. Research Policy, 36(2), 209-226.

Baumol, W. J. (2002). The free market innovation machine: Analyzing the growth miracle of capitalism. Princeton university press.

Berry, S., Levinsohn J.and Pakes, AP.1995. Automobile Prices in Market Equilibrium. *Econometrica* , Vol. 63, No. 4 (Jul., 1995) , pp. 841-890

Chesbrough, H. W. (2003). Open innovation: The new imperative for creating and profiting from technology. Harvard Business Press.

Christensen, C. (1997). The innovator's dilemma: when new technologies cause great firms to fail. Harvard Business Press.

Cohen, W. M. (2010). Fifty years of empirical studies of innovative activity and performance. Handbook of the Economics of Innovation, 1, 129-213.

Cohen, W. M., & Klepper, S. (1996). A reprise of size and R & D. The Economic Journal, 925-951.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. Administrative science quarterly, 128-152.

Cohen, W. M., 1995, 'Empirical Studies of Innovative Activity,' in Stoneman, P. (ed.), Handbook of the Economics of Innovation and Technological Change, Basil Blackwell, Oxford.

Cohen, W. M., Goto, A., Nagata, A., Nelson, R. R., & Walsh, J. P. (2002). R&D spillovers, patents and the incentives to innovate in Japan and the United States. Research Policy, 31(8), 1349-1367.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2000). Protecting their intellectual assets: Appropriability conditions and why US manufacturing firms patent (or not) (No. w7552). National Bureau of Economic Research.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: the influence of public research on industrial R&D. Management science, 48(1), 1-23.

Dahl, G. B. (2002) Mobility and the returns to education: testing a Roy Model with multiple markets. Econometrica 70: 2367–2420.

Dubin, J., and D. McFadden (1984): “An Econometric Analysis of Residential Electric Appliance Holdings and Consumption,” Econometrica, 52, 345–362.

Dubin, J. 1985. Consumer Durable Choice and the Demand for Electricity. New York-Amsterdam: North-Holland Publishing Company, 1985

Dorfman, N. S. (1986). Innovation and market structure: Lessons from the computer and semiconductor industries. Ballinger Publishing Co.

Edwards, M., Murray, F. & Yu, R. (2006). Gold in the ivory tower: equity rewards of outlicensing. Nature Biotechnology 24(5): 509-515.

Gans, J. S., Hue, D.H. & Stern, S. (2008). The impact of uncertainty intellectual property rights on the market for ideas: evidence from patent grant delays." Management Science **54**(5): 982-997.

Griliches, Z. (1992). The Search for R&D Spillovers. The Scandinavian Journal of Economics. S29-S47.

Griffith, R., Huergo, E., Mairesse, J., and Peters, B. 2006. Innovation and Productivity Across Four European Countries. Oxford Review of Economic Policy (Winter) 22 (4): 483-498

Harvard University. Graduate School of Business Administration, & Scherer, F. M. (1959). Patents and the corporation: a report on industrial technology under changing public policy.

Henderson, R., Jaffe, A., Trajtenberg, M. 1998. Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965–1988. Review of Economics and Statistics. February Vol. 80, No. 1, Pages 119-127

Jeppesen, L. B., & Lakhani, K. R. (2010). Marginality and problem-solving effectiveness in broadcast search. Organization Science, 21(5), 1016-1033.

Jewkes, J., Sawers, D., & Stillerman, R. (1969). The sources of invention (Vol. 214, p. 215). London: Macmillan.

Kalton, G. (Ed.). (1983). Introduction to survey sampling (Vol. 7, No. 35). SAGE Publications, Incorporated.

Kalton, N. J. (1984). An F-space sampler (Vol. 89). CUP Archive.

Klevorick, A. K., Levin, R. C., Nelson, R. R., & Winter, S. G. (1995). On the sources and significance of interindustry differences in technological opportunities. Research policy, 24(2), 185-205.

Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. The positive sum strategy: Harnessing technology for economic growth, 14, 640.

Laursen, K., and Salter. A. 2004. Searching high and low: what types of firms use universities as a source of innovation? Research Policy. 33(8), 1201–1215

Laursen, K., and Salter. A. 2006. Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms. Strategic Management Journal. 27(2): 131–150.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., (1987). Appropriating the returns from industrial research and development. Brookings papers on economic activity, 1987(3), 783-831.

Lhuillery, S., & Pfister, E. (2009). R&D cooperation and failures in innovation projects: Empirical evidence from French CIS data. Research Policy, 38(1), 45-57.

Mansfield, E. (1986). Patents and innovation: an empirical study. Management science, 32(2), 173-181.

Mohnen, P. and Röller, R. 2005. Complementarities in innovation policy. , European Economic Review. Volume 49, Issue 6, August 2005, Pages 1431–1450
Mowery, D. C. (1983). The relationship between intrafirm and contractual forms of industrial research in American manufacturing, 1900–1940. Explorations in Economic History, 20(4), 351-374.
Nelson, R. R., Peck, M. J., & Kalachek, E. D. (1967). Technology, economic growth, and public policy: A Rand Corporation and Brookings Institution study. Brookings Institution.
Pavitt, K. 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. Research policy 13 (6), 343-373
Poot, T., Faems, D., & Vanhaverbeke, W. (2009). Toward a dynamic perspective on open innovation: A longitudinal assessment of the adoption of internal and external innovation strategies in the Netherlands. International Journal of Innovation Management, 13(02), 177-200
Robbins, C. A. (2009). Measuring payments for the supply and use of intellectual property. In International trade in services and intangibles in the era of globalization (pp. 139-171). University of Chicago Press.
Scherer, F. M. (1980) Industrial market structure and economic performance. Chicago : Rand McNally College Pub. Co.
Schumpeter, J. (1942). Creative destruction. Capitalism, socialism and democracy.
Stinchcombe, A (1990). Information and organizations. Chicago: Chicago.
Teece, D. J. (1986). Transactions cost economics and the multinational enterprise An Assessment. Journal of Economic Behavior & Organization, 7(1), 21-45.
Tether B. 2000. Who co-operates for innovation, and why: An empirical analysis. Research Policy. Volume 31, Issue 6, August 2002, Pages 947–967
Tether, B. S., & Tajar, A. (2008). Beyond industry–university links: Sourcing knowledge for innovation from consultants, private research organisations and the public science-base. Research Policy, 37(6), 1079-1095.
Veugelers, R., & Cassiman, B. (2005). R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing. International Journal of Industrial Organization, 23(5), 355-379.
Veugelers. R. & Cassiman, B., 1999, Make and buy in innovation strategies: evidence from Belgian manufacturing firms. Research Policy. 28(1): 63–80.
Von Hippel, E. (1986). Lead users: a source of novel product concepts. Management science, 32(7), 791-805.
Von Hippel, E. (1990). Task partitioning: An innovation process variable. Research policy, 19(5), 407-418.
Von Hippel, E. (2005). Democratizing innovation: The evolving phenomenon of user innovation. Journal für Betriebswirtschaft, 55(1), 63-78.
Williamson, O. E. (1991). Comparative economic organization: The analysis of discrete structural alternatives. Administrative science quarterly, 269-296.

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

Consider the "representative" firm, so that we can drop the firm specific subscript *j*. P_i, the probability of an innovation sourced from source *i* can be expressed as

$$P_i = \exp(u_i/\theta)/\Sigma_k(\exp(u_k/\theta)), \qquad \text{(A1)}$$

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_i is the probability that the representative firm chooses source *i*, and therefore also the share of source *i*. The expected net value of an innovation conditional upon it being from source *i* is (Dubin, 1985)

$$E(u_i \mid \text{source} = i) = \gamma\theta + V_i - C_i - X_i - \theta Ln(P_i), \qquad \text{(A2)}$$

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

$$E(u_i + C_i + X_i \mid \text{source} = i) = \gamma\theta + V_i - \theta Ln(P_i). \qquad \text{(A2')}$$

Equation (A2') 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* in Table 5 to control for selection. Note that adding the costs of acquisition and commercialization to the net surplus is equal to the profit from the innovation, i.e., the revenue minus the production cost. That is $u_{ij} + C_i + X_i$ = profit to the *j*th firm from introducing an invention from source *i*.

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 $1-P_0$.

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*. $P_0/P_0^* = A^*_{spec}/A = 1- \exp(u_{spec}/\theta)/A = 1-P_{spec}$ implying that $P_0^* = P_0/(1-P_{spec})$.

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,

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

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.