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Productivity and the role of complementary assets in firms' demand for technology innovations

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This article uses data on transactions in the pharmaceutical industry to examine the demand-side of technology outsourcing. By integrating a transaction–cost economics perspective with the analysis of internal R&D capabilities, we find that firms with relatively more cospecialized complementary assets or relatively strong internal R&D productivity have a lower propensity to source a technology from outside the firm. We show, however, that since downstream capabilities and internal R&D are complementary activities in the presence of asset specificity and transaction costs, a decrease in internal R&D productivity reduces the marginal value of the downstream assets within firm boundaries, thus stimulating the demand for external technology.

1. Introduction

What factors drive the rate of external technology acquisition by pharmaceutical firms in the markets for technology? And what roles do the characteristics of demand play in such acquisitions? While substantial evidence suggests that firms are increasingly turning to external markets for technology developments (Arora *et al.*, 2001; Rigby and Zook, 2002; Gans and Stern, 2003), the focus of the markets

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for technology literature has generally been on the supply-side determinants of firms' external technology sourcing. Our article instead examines demand-side conditions that have been relatively understudied in this literature. In particular, we focus on the role of the technology buyer's ownership and strength of downstream assets cospecialized to the innovation, the buyer's overall R&D productivity, and their interaction in driving external technology acquisition strategies.

In addressing these questions, we build upon a growing body of academic research that addresses firm economics and strategy in markets for technology. While technology markets have been shown to provide important social benefits originating from comparative advantage and scale and learning economies (Arora *et al.*, 2001), firms face a number of challenges in realizing these payoffs. Most notably, market failures can undermine the incentives to supply technology in a vertically disintegrated market. Bounded rationality, uncertainty, and opportunism make complete contracting difficult (Simon, 1947; Williamson, 1975, 1985). Moreover, the tacitness or "stickiness" of knowledge often deters its transfer between organizations (Winter, 1987; von Hippel, 1990, 1994; Kogut and Zander, 1992, 1993; Arora and Gambardella, 1994). Transaction costs may also increase when buyers place themselves at risk of disclosing proprietary information to rivals via prospective suppliers or are forced to pay higher-than-market prices for technology as a result of holdup in small-numbers bargaining (Williamson, 1985; Arora and Merges, 2004; Arora *et al.*, 2007).

Despite these downsides, firms are actively using external technology markets. While research in this area has tended to focus on the supply-side perspective (Teece, 1986; Bresnahan and Gambardella, 1998; Arora *et al.*, 2001; Gans and Stern, 2003; Arora and Ceccagnoli, 2006; Fosfuri, 2006; Gambardella and Giarratana, 2006; Gambardella *et al.*, 2007), a smaller number of studies have examined empirically the demand side of markets. Pisano for instance (1990) finds support for transaction-cost theory on a sample of new product development projects in the pharmaceutical industry. He focuses on two environmental sources of transaction costs as the determinants of firm R&D boundaries: small-number-bargaining hazards and appropriability concerns.

Other demand-side research has examined complementarities between internal R&D and external technology acquisition *at the firm level*. In particular, Arora and Gambardella (1990) find evidence that large firms with higher levels of internal knowledge are more actively involved in pursuing external linkages. Nicholls-Nixon and Woo (2003) demonstrate that technology sourcing leads to a build-up of the absorptive capacity needed to generate new technical output. Veugelers and Cassiman (1999) and Cassiman and Veugelers (2006) show that, controlling for firm size, a buyer's absorptive capacity and information flows from its competitors are positively related to its external technology acquisition. Consistent with these studies, Arora *et al.* (2007) suggest that a firm's absorptive capacity is a main determinant of ex-ante technology acquisitions. Finally,

Ceccagnoli and Higgins (2008) show that in-licensing and technology acquisitions are complementary strategies for large pharmaceutical firms since their joint adoption tends to increase the marginal productivity of internal research.

Our article builds on this growing body of demand-side research by examining the role that R&D productivity and its determinants play in driving technology acquisition decisions. While the role of technological opportunities—the exogenous determinant of R&D productivity—in driving R&D incentives has been extensively studied (Dosi, 1988; Cohen, 1995; Klevorick *et al.*, 1995), the general assumption has been that markets for technology operate infrequently. Evidence suggests, however, that external technology sourcing can be a key component of firms' innovative performance, and markets for technology have expanded in the last two decades (Arora *et al.*, 2001; Chesbrough, 2003). In the pharmaceutical industry, for instance, an increasing proportion of firm revenue is generated from products derived from technology discovered outside the firm (Scherer, 2010). Our data covering the period from 1989 to 2004, which we describe below, support this notion: in almost 60% of new branded drugs introduced during this period, more than half of the patents protecting them originated outside the firm (Figure 1). External technology acquisition is clearly playing an important role in this industry.

This trend has important implications for firm R&D boundaries and the analysis of factors that define its scope. In particular, when opportunities to access technology

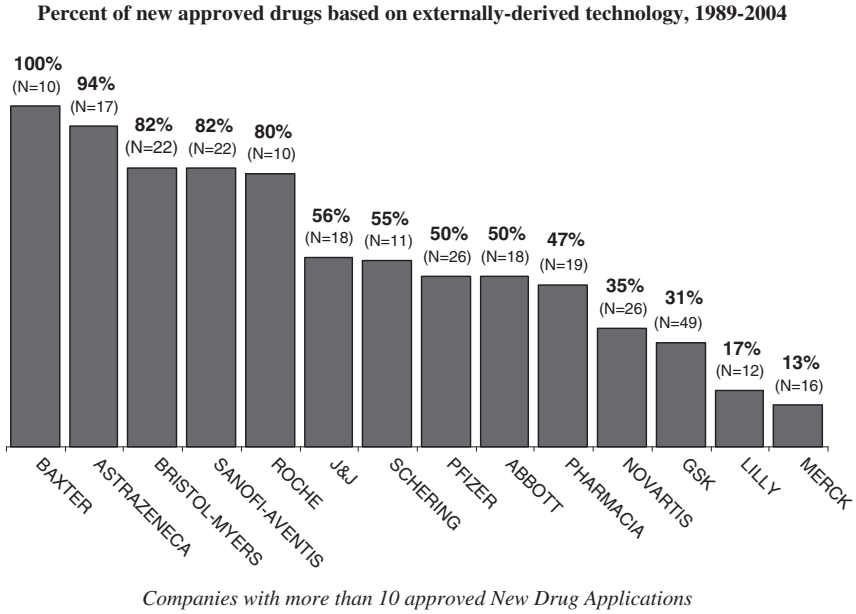

Figure 1 Widespread use of technology markets in the pharmaceutical industry.

markets are limited, we would expect firms with low R&D capabilities to invest less in innovation due to lower marginal benefits derived from internal R&D. Given expanding opportunities in the markets for technology, firms considering the technology "make" decision must explicitly recognize the opportunity cost of internal R&D investments and therefore not neglect the "buy" alternative.

To further develop an understanding of technology strategy from a demand-side perspective, we first analyze two factors that have offsetting effects on the demand of technology. Indeed we show that on the one hand the incentives to buy an externally generated technology will be lower when firms are endowed with a relatively high level of cospecialized downstream assets. On the other hand, holding constant a firm's absorptive capacity, firms with relatively weak internal R&D productivity are more likely to acquire external technology. More importantly, our central hypothesis maintains that when the transaction costs of market exchange are high, a decrease in the productivity of internal R&D among firms possessing downstream assets cospecialized to a technology will increase their willingness to buy that technology in the market. Put differently, we suggest that a change in the division of labor between firms possessing different capabilities along the firm value chain is the result of shifts in both the determinants of R&D capabilities and transaction costs, which complement each other in shaping external technology adoption.

Our work complements prior studies (e.g. Nelson and Winter, 1982; Teece *et al.*, 1997) which have tended to focus on R&D capabilities and technological opportunities or, alternatively, cospecialized assets as a source of transaction costs (Pisano, 1990). We combine these two approaches, consistent with a more recent stream of work in the strategy literature focusing on the interplay between transaction costs and capabilities as determinants of firms' vertical scope and the vertical disintegration of industrial sectors (Madhok, 2002; Jacobides and Winter, 2005). Our work however leaves open the question of the effect of a firm's absorptive capacity (Cohen and Levinthal, 1989) on its ability to effectively utilize external knowledge. Since our data match the "make or buy" theoretical setting represented in our research question, we do not analyze the complementarity between internal and external R&D at the firm level where "make and buy" can coexist.

We test our hypotheses on a comprehensive sample of US Food and Drug Administration (FDA) new drug approvals. There are several reasons for selecting this industry as our empirical setting. First, the pharmaceutical industry is research-intensive and relies critically upon R&D productivity. Second, it is highly-allied, showing in excess of 20,000 research alliances over the past two decades (Deloitte ReCap, 2009). The dynamic biotechnology sector coupled with such extensive alliance activities suggests vertical specialization and a robust external market for technology. Third, in the pharmaceutical industry, intellectual property is important for capturing the value from innovation and patents are commonly sought (Cohen *et al.*, 2000). This last characteristic allows for an observable footprint regarding the ownership of knowledge.

The article is organized as follows. Section 2 develops a set of testable hypotheses by drawing upon the transaction cost and productivity literature and relating these to the empirical context of this article. Section 3 explains our data and the construction of variables. Our specification and empirical results are given in Section 4. We conclude and offer directions for future research in Section 5.

2. Hypotheses development

Because we are interested in the drivers of a firm's demand for external technology, we first focus on a classical driver of a firm's "make or buy" decision in R&D—the nature of complementary assets required to profit from an innovation. Our analysis then turns to two less-explored factors: a firm's internal R&D productivity and the interplay between productivity and the ownership of cospecialized assets. We leave until the next section our discussion of other firm and technology characteristics.

2.1 The role of cospecialized complementary assets

Because transactions in the markets for technology are often characterized by uncertainty and asymmetric information, much of the literature focusing on the R&D "make or buy" decision relies on the transaction cost economics perspective (Williamson, 1975, 1985) as extended in the management literature by Teece (1986), Masten *et al.* (1991), Muris *et al.* (1992), Parkhe (1993) and Chan *et al.* (2007) among others.[1] Williamson (1985) suggests that transactional hazards increase with complexity and particularly as the contractible asset becomes more specific to the transaction. When these two characteristics are present, as is common in the markets for technology, the buyer may face substantial contractual hazards.

Research has elaborated both the character of these transactions and the associated risks that buyers face in the markets for technology. Writing mainly about the supply of innovation, Teece (1986) suggests that the innovator's profits are often predicated on access to complementary assets held by others. As these assets become more specific—or even cospecialized, where the innovation and the complementary asset are specific to each other—contracting for them becomes more difficult.

We focus on the pharmaceutical industry where firm success is conditioned on accessing both upstream research capabilities and downstream assets necessary to manufacture, market, and distribute products. In general, many of these assets are created internally, and may be specific to a certain class of product. Such specificity reduces the extent to which the assets can be redeployed to other classes of products. For example, sales forces that specialize in a particular therapeutic category are extensively trained in that specific class of drugs. Deploying these forces to other products would require time and costly retraining. The employees would also

[1]See Veugelers (1997) for a survey of this literature.

suffer costs associated with the loss of personal relationships and networks with a particular coterie of physicians in the specific market segment. Hence, there would likely be significant switching costs for the firm in transitioning a sales force from one therapeutic category to another. Accordingly, firms experience a "lock-in" effect when operating in particular therapeutic categories due to specific investments in these downstream assets (Chan *et al.*, 2007).

The downstream assets in this industry tend to be cospecialized since there is dependence between the innovations (i.e. specialized drugs) and the complementary assets (i.e. specialized sales force) that are required to commercialize them. When complementary assets are cospecialized, an innovation and its subsequent commercialization are intertwined requiring ongoing mutual adjustments between the two (Kline and Rosenberg, 1986).

In sum, when the assets needed to commercialize an innovation are cospecialized and the firm owns them, the firm faces incentives to "make" the innovation internally to avoid the risk of opportunism and transaction costs arising from coordination necessary when using the markets for technology. In other words, the "make" option avoids the problem of relationship-specific investment and ongoing interactions required when dependence exists between the innovation and the complementary assets.[2] We therefore formulate the following hypothesis:

> *H1: Firms with higher levels of complementary assets cospecialized to a technology have, ceteris paribus, a lower propensity to acquire the technology in the market.*

2.2 The effect of internal R&D productivity

Productivity in internal R&D activities is a key driver of innovative and economic performance in research-intensive industries. Because even the largest firms do not have the capacity to conduct unlimited research, the scale and the scope of their efforts are limited. Additionally, sustaining high levels of productivity over long periods of time is difficult. The pharmaceutical industry has been exemplary of these challenges; its overall research productivity has declined throughout the

[2]If assets were only *specialized*, with relationship-specific investments required only from the innovator/supply-side, we may expect the holder of specialized complementary assets to be *more likely* to buy technology in the market. Note also that, consistent with the Teece (1986) framework, one may expect a positive interaction effect between the ownership of cospecialized complementary assets and the appropriability regime on the propensity to buy technology. Indeed, when imitation is easy, the risks associated with making relationship-specific investments in a market transaction may be offsets by the incentives to imitate (rather than make) a costly technology. We do not focus on such interaction effect for at least two important reasons: (i) we empirically analyze an industry characterized by strong appropriability (Cohen *et al.*, 2000); (ii) we lack data on the firm-level drivers of appropriability.

1990s (DiMasi, 2001; Higgins and Rodriguez, 2006). Managers faced with these challenges have sought to reignite internal productivity while juggling the opportunities to reach beyond firm boundaries to tap into external knowledge (Arora *et al.*, 2001; Rigby and Zook, 2002; Gans and Stern, 2003). Transacting with parties outside the firm can take several forms including acquisitions (Higgins and Rodriguez, 2006), alliances (Lerner and Merges, 1998; Rothaermel and Deeds, 2004; Rothaermel *et al.*, 2006), R&D outsourcing (Arora and Gambardella, 1990; Granstrand *et al.*, 1992; Cockburn and Henderson, 1998), and licensing (Arora *et al.*, 2001; Thursby *et al.*, 2001; Kim and Vonortas, 2006; Gambardella *et al.,* 2007).

R&D productivity depends on industry-level technological opportunities and firm-level R&D capabilities. With more developed markets for technology, a decrease in R&D productivity (brought about by low technological opportunities or a lack of R&D capabilities) reduces incentives to invest in internal R&D and thus increases the relative payoff to external technology sourcing. The literature on the economics of innovation and technological change has focused on the first effect, particularly the effect of industry-level technological opportunities on the incentives to invest in R&D (Dosi, 1988; Cohen, 1995; Klevorick *et al.*, 1995). A few recent studies have examined the effect of internal productivity on technology acquisition through M&A in the pharmaceutical industry. Higgins and Rodriguez (2006) have shown that pharmaceutical firms with later-stage failures in their research pipelines and weakness in product portfolios are more likely to access the external markets for technology. Likewise, Danzon *et al.* (2007) find that acquisitions are responses to fill gaps in firms' product pipelines. These works focus on specific failures or gaps in product pipelines and weaknesses in product markets but remain silent on firms' overall *levels* of research productivity. From a dynamic perspective, firms may have gaps in their pipelines but not necessarily suffer R&D capability problems.

We argue that, with expanding markets for technology, it is critical to view the effect of productivity on the R&D boundaries of the firm within a "make or buy" framework. From this perspective, we expect that lower overall internal research productivity will reduce the incentive to "make" as compared to "buy" a needed technology so long as accessing the technology markets is a viable choice.[3] To summarize, our theory allows us to hypothesize that:

> *H2: Firms with lower levels of internal R&D productivity have, ceteris paribus, a higher propensity to acquire a technology in the market.*

[3]Our setting, however, does not take into account the effect of a firm's absorptive capacity (Cohen and Levinthal, 1989) on its ability to effectively utilize external knowledge. Given our theoretical focus and our data that are defined at the discrete technology transaction level, an analysis of the complementarity between internal and external R&D, where "make and buy" can coexist at the firm level, is outside the scope of this study.

2.3 The interplay between productivity and cospecialized complementary assets

Our first hypothesis, by positing that stronger (in-house) cospecialized downstream assets increase the incentives to innovate internally, reflects the complementarity between downstream assets and internal R&D in the presence of transaction costs in the technology markets. Indeed, it is more profitable to perform both activities internally in the presence of cospecialization between internal R&D and downstream assets.

Our third hypothesis follows directly from the first hypothesis. Since upstream R&D and downstream sales and marketing are complementary activities, any factor driving the payoff from one activity will indirectly affect the marginal value of the other activity (Milgrom and Roberts, 1990; Cassiman and Veugelers, 2006). In particular, following the definition of complementarity, a reduction in the productivity of internal R&D will *indirectly* reduce the marginal benefit of conducting R&D in-house in the presence of internal cospecialized assets, thereby increasing the relative payoff from purchasing technology in the external market. We therefore formulate the following hypothesis:

> *H3: Ceteris paribus, firms having lower internal R&D productivity coupled with higher levels of complementary assets cospecialized to a technology have a higher propensity to acquire the technology in the market.*

3. Data

We collect financial data from *Compustat*, proprietary product-level pharmaceutical sales and marketing expenditures data from IMS MIDAS^{TM}, research pipeline data from *Pharmaprojects*, new product data from the *FDA Orange Book*, and patent data from *IMS Patent Focus*^{TM} and the *United States Patent and Trademark Office* (*USPTO*). All financial variables are converted into constant 2000 US dollars. When the original source is in a foreign currency, we convert into US dollars using the average of the 12-monthly foreign/US exchange rates over the relevant year.

Our sample is restricted to firms having at least one FDA-approved product (i.e. drug) during the period from 1995 to 2004 in order to make the overall sample more homogenous and to concentrate our analysis on firms that have demonstrated commercial success. We used the FDA's *Orange Book* to identify unique firms and their portfolios of FDA-approved products. Data from subsidiaries, identified using LexisNexis's *Corporate Affiliations* database, were rolled into those of the parent.

Our focus is on the make-or-buy decision made by firms on patented technologies that are subsequently attached to new product applications to the FDA. The requirement to identify relevant patents with the New Drug Approval (NDA) application is dictated by the Drug Price Competition and Patent Term Restoration Act, informally known as the "Hatch-Waxman" enacted in 1984. An applicant for a new drug must

disclose with the application any utility patent which includes the drug in its claims or any method patent that would likely be infringed if another manufacturer began producing the drug (Marenberg, 2004). Firms face a strong incentive to disclose all their relevant patents since, by so doing, they can forestall generic entry.[4] Our definition is therefore a reasonably comprehensive selection of the key patented technologies associated with the product—a choice made more appropriate given the high propensity to patent innovations in the pharmaceutical industry (Cohen *et al.*, 2000).

We do not include biologic compounds since they are not covered by Hatch-Waxman. Because there is no current mechanism for "generic biologics," the dynamics and life-cycle of a biologic compound are very different from the non-biologic compounds covered under Hatch-Waxman. For example, the same reporting requirements for patents do not exist for biologic compounds. As a result, given our approach we are unable to identify the relevant patents for biologic compounds in the same manner as they are identified in the FDA *Orange Book* for non-biologic products. This exclusion does not mean, however, that we do not have biotechnology firms in our sample. Biotechnology firms are included in the sample if: (i) they have introduced a product during our time frame and (ii) the product is a non-biologic compound (e.g. Amgen's Sensipar®).[5]

3.1 Dependent variable

3.1.1 Reliance on external technology

We use the FDA *Orange Book* to identify our dependent variable, deriving it from the patents attached to NDAs approved by the FDA. Our main unit of analysis is thus the patent-NDA. The dependent variable, TECH_OUT, takes a value of 1 if an NDA-attached patent was originally assigned to a party other than the NDA applicant. In the US, patents must be issued to individual inventors, but are commonly "assigned at birth" to the firm employing them. In addition to examining the original assignee on granted patents, we also relied on the USPTO's patent reassignment data to determine whether patents were reassigned from the original patent assignee to the NDA applicant. Since these data are notoriously poor,[6] we complemented them by comparing the identity of the NDA applicant to the identity of the original patent

[4]Generic entrants must overcome such patents in a Paragraph IV challenge pursuant to Hatch-Waxman in order to gain early entry into a market. See Voet (2008) for a more detailed discussion.

[5]Exclusion of biologic compounds from our analysis does not imply that we are excluding bio-pharmaceutical technology transfers. Deloitte ReCap's biotech alliance database (covering 1970–2009) report the formation of 26,256 alliances, of which 40% focus on bio-informatics, devices, diagnostics, drug delivery, gene sequencing, and screening not related to biologic compounds.

[6]There is no requirement by the USPTO that reassignments in the ownership of patents be recorded.

assignee, taking account of acquisitions and mergers using the LexisNexis *Corporate Affiliations* database and the SDC *M&A* database. We were thereby able to build the dichotomous dependent variable that indicates the reliance on external technology by the NDA-applicant firm.

Note that we cannot identify with certainty whether the external technology adoption ("buy" decision) was the result of in-licensing, outright transfer, the acquisition of another patent-holding firm, or some other technology transfer mechanism. We are able, however, to determine that the patent filed and granted was not the result of purely the NDA-applicant firm's internal R&D efforts.

3.2 Independent variables

3.2.1 Cospecialized assets

Prior research has identified marketing capabilities as important cospecialized assets in the pharmaceutical industry (Chan *et al.*, 2007). To identify whether firms possess such assets, we exploit proprietary product-level sales and marketing data obtained from IMS MIDAS^{TM}. Furthermore, scholars have recently used trademarks as a measure of a firm's downstream capabilities (Gambardella and Giarratana, 2006; Fosfuri and Giarratana, 2009). As such, we computed our measure of cospecialized assets, COSP_ASSETS, as the number of trademarks held by the NDA applicant firm in the primary therapeutic category of the focal NDA, weighted by marketing expenditures as a percent of sales. The components of COSP_ASSETS have been obtained as follows.

We collected information on trademarks associated with NDAs from Lexis's Combined International, US Federal and US State Trademarks database. This file contains the trademarks and applications for Canada, the European Community, the UK, and the Word Intellectual Property Organization, as well as those of the United States, updated weekly by Lexis after publication by the relevant legal authority. Each trademark or application record in this database specifies the trademark name, its date of publication (or filing), and the registrant or owner of the trademark.

Trademarks and applications were matched to NDAs using the product name associated with the successful NDA. Each trademark was then inspected visually to ensure that the record was in fact (i) a trademark associated with the focal pharmaceutical product, and (ii) owned by the firm, its predecessors, or successors. Because we were interested in generating a proxy for the complementary assets that were developed by the firm in the marketing space, we collected the trademarks for all the nations and states in this dataset (on the theory that securing trademarks internationally or locally is an indicator of the firm building greater capabilities). We collected all trademarks associated with the focal product, including promotional materials as well as those registered on the products themselves, enabling us to generate almost 5600 unique NDA-trademark record pairs.

To weight the trademarks measure for each of our products, we used product level marketing/promotion and sales data obtained from the IMS MIDAS^{TM} database. IMS Health Inc. collects three types of promotions/marketing data: (i) the cost of direct sales visits to physicians, (ii) the cost of journal advertising and (iii) the cost of direct mail advertising. We define total promotions as the sum of these three variables from the year of NDA approval plus three additional years. We normalize such promotion expenditures by sales to both the hospital and retail markets during the corresponding period.

3.2.2 Internal R&D productivity

Prior studies have employed several different measures to account for productivity in the pharmaceutical industry. Some studies have used new FDA-approved products in their analyses (Jensen, 1987; Higgins and Rodriguez, 2006; Graham and Higgins, 2008) whereas others have used the ratio of patents to R&D expenditures (Scherer, 1983; Evenson, 1984; Griliches, 1990; Kortum, 1993; Kim *et al.*, 2004; Lanjouw and Schankerman, 2004).

One of the main advantages of focusing on the pharmaceutical industry is the availability of detailed data at the product level. To measure the overall productivity of a firm R&D effort, we use data from *Pharmaprojects* and generate the counts of new internally generated drugs at all stages of clinical testing (Phase I, Phase II, or Phase III) plus new products approved in the US and held by the NDA applicant through the drug-approval year (i.e. the period from the year $t-1$ back to the first year for which we have pipeline data, e.g. 1995). We create a variable PRODUCTIVITY representing this sum of firm-year-projects at any stage of development divided by the R&D expenditure of the firm during the same time period. By controlling for R&D expenditures, this variable captures variations in the exogenous drivers of average and marginal productivity of internal R&D effort.[7]

3.2.3 Productivity and cospecialized complementary assets interaction

Theory offers us a hypothesis concerning the interaction between productivity and cospecialized complementary assets. To test these hypotheses, we introduce a variable computed as the interaction between COSP_ASSETS and PRODUCTIVITY. This interaction term is meant to capture the joint effect on the firm's technology-acquisition choice of relatively low productivity coupled with comparatively strong cospecialized assets.

[7] This can be seen by using a standard innovation production function. Let $m = sr^{\beta}$, where m is the number of innovations generated internally, r the firm's internal R&D expenditure, β the elasticity of innovations with respect to R&D. Since $\log m/r = \log s + (\beta - 1)\log r$, holding r constant, the innovation-R&D ratio captures variations in s and β. These factors drive the efficiency of R&D and may be driven by both industry-level technological opportunities and firm-level R&D capabilities.

3.3 *Controls*

3.3.1 Controls at the new drug applicant (firm) level

We introduce several controls at the NDA-applicant (firm) level. First and foremost, we include firm size. Cassiman and Veugelers (2006), for example, find that size increases the propensity to make, buy, and make-and-buy technology at the firm level. As a measure of firm size we use the variable EMPL, which is equal to the natural log of the number of employees, as reported in *Compustat* at the time of focal NDA approval. Since we are controlling for both the R&D and cospecialized assets of the NDA applicant, we surmise that our size variable may capture information about the level of "generic" complementary assets in the firm. Accordingly, we expect size to be positively associated with the propensity to acquire technology in the market.

According to theory, stronger patent protection for the focal firm facing the "make or buy" decision ought to increase the economic rents that can be extracted by innovating internally (Arora *et al.*, 2008). As a control for patent-based appropriability that varies across NDA-applicant firms, we employ the number of patents assigned to a firm. We used USPTO data to measure the firm-level total patents granted in the year of focal NDA approval.

We also control for R&D spending both to observe how well variations in the innovations/R&D ratio capture R&D efficiency and to control for a firm's absorptive capacity (Cohen and Levinthal, 1989). In our analysis absorptive capacity has an ambiguous a priori effect on external technology acquisition, since the R&D "make" or "buy" decisions are mutually exclusive at the technology (patent) level. We measure firm-level R&D expenditures using *Compustat*, with reference to the focal NDA approval year.

To control for firm-level economies of scope in R&D we use data from *Pharmaprojects* and create a variable E_SCOPE that represents the number of different therapeutic classes (measured at the most broadly defined Anatomical Therapeutic Class 1 level) in which the NDA applicant has had approved drugs from the beginning of our sample period to the year of focal NDA approval. Finally, to control for differences associated with geographic origins we define two dummy variables (*US* and *JP*) that account for the national residence of firms in the US and Japan, respectively (with firms from Europe and Canada representing the base category).

3.3.2 Controls at the industry/therapeutic class and product levels

We control for market size, MKTSIZE, limiting ourselves, to match to our patenting measures, to sales generated in the US market. We define MKTSIZE as the aggregate sales in the primary therapeutic class of the focal NDA as a three-year average centered on the year of NDA approval. In all models, we control for primary therapeutic class fixed-effects (12 in total), defined at the first level of Anatomical

Therapeutic Chemical (ATC) classification system developed by the World Health Organization.[8]

The variable PAT_PER_INNOV is equal to the total number of patents attached to the focal NDA in the FDA's Orange Book. A second variable, PIONEER, is a dichotomous variable intended to account for the innovativeness of the NDA-described drug, taking the value one if the drug is a Reference Listed Drug (RLD) and zero otherwise.[9]

3.3.3 Controls at the patent level

Both the demand-side and the supply-side perspectives suggest reasons to control for the level of competition in the markets for technology (Pisano, 1990; Arora and Fosfuri, 2003). Accordingly, we generate *HHI5*, a Herfindahl-Hirschman concentration index of the patent assignees that have been active in patenting in the focal patent's USPTO three-digit technology class during the five years leading up to the drug approval year (i.e. years t through $t-4$). We also define the variable TOT_PAT as the count of all patents issued in the focal patent's USPTO technology class during the five years leading up to the drug approval year.

The timing of technology patenting is not necessarily coincident with its commercialization, particularly in the pharmaceutical industry (Graham, 2006). Firms have considerable control over the timing of a patent's grant, and other strategic considerations may drive the timing decision. To control for differences in the lag between patent grant and NDA approval, we generate a variable APRY-GRY that takes the value of the approval year of the NDA minus the year in which the focal patent was granted.

Another patent characteristic, the so-called forward citation, has been shown to be a correlate of importance and value (Harhoff *et al.*, 2003; Lanjouw and Schankerman, 2004). To normalize, we create a variable NORMFCITE by dividing the focal patent's

[8]These therapeutic classes and the associated number of NDAs in our sample are: A, Alimentary tract and metabolism, $N = 38$; B, Blood and blood forming organs, $N = 5$; C, Cardiovascular system, $N = 35$; D, Dermatologicals, $N = 13$; G, Genitourinary system and sex hormones, $N = 25$; H, Systemic hormonal preparations, excl. sex hormones and insulins, $N = 9$; J, Anti-infectives for systemic use, $N = 53$; L, Antineoplastic and immunomodulating agents, $N = 32$; M, musculoskeletal system, $N = 6$; *N*, Nervous system = 69; P, Antiparasitic products, insecticides and repellents, $N = 2$; R, Respiratory system, $N = 30$. Interested readers can visit http://www.whocc.no/atcddd/ for more information on the ATC classification system. In all models, these class-fixed effects were jointly significantly different from zero.

[9]An RLD is an approved drug product that is the basis against which any new generic versions are compared for bioequivalence. A generic firm seeking approval from the FDA to market a generic equivalent of the RLD must refer to it in its Abbreviated New Drug Application (ANDA). Because the FDA uses the RLD as a standard to minimize variations among generic drugs and the brand-name counterpart, our use of it captures information about the inventive step embodied in the particular technology.

Table 1 Descriptive statistics

	Description	Source	Mean	Std. Dev.	Min	Max
Dependent variable						
TECH_OUT		USPTO/FDA Orange Book/Lexis Nexis	0.56	0.50	0	1
Main independent variables						
PRODUCTIVITY	New products per mil.$ R&D (firm)	Pharmaprojects/Compustat	0.66	3.10	0	33.82
COSP_ASSETS	Trademarks weighted by promotion intensity in focal therapeutic class (firm)	USPTO/IMS MIDAS IMS MIDAS	12.97	72.09	0	861.22
Firm-level control variables						
R&D	R&D (in mil. $; log)	Compustat	6.43	2.28	−0.96	9.41
PAT_FIRM	N. of patents granted [log(1 + PAT_FIRM)]	USPTO	3.07	1.86	−3.73	5.62
EMPL	Employees (log)	Compustat	3.45	1.09	0.69	6.79
E_SCOPE	Number of therapeutic classes (log)	Pharmaprojects	2.03	0.65	0	2.64
US	U.S.A. drug applicant	Compustat	0.54	0.50	0	1
JP	Japan drug applicant	Compustat	0.05	0.22	0	1
Industry-level control variables						
MKTSIZE	Industry sales in focal therapeutic class (log)	IMS MIDAS	15.19	1.28	11.88	17.38

(continued)

Table 1 Continued

	Description	Source	Mean	Std. Dev.	Min	Max
Patent-level control variables						
NSCIREF	Science references [log(1+NSCIREF)]	Delphion	1.56	1.34	0	6.12
HHI5	Concentration index of patent assignees in focal class (HHI5)	USPTO	0.29	0.24	0.01	1
TOT_PAT	Sum of all patents in focal tech. class [log(1+TOT_PAT)]	USPTO	3.03	1.64	0.69	7.79
NORMFCITE	Normalized forward citations	USPTO	2.32	3.02	0	23.15
NORMGEN	Normalized GPT index	USPTO	1.27	0.90	0	8.01
PRODPAT	Product patent	IMS Patent Focus	0.23	0.42	0	1
PROCPAT	Process patent	IMS Patent Focus	0.01	0.09	0	1
COMPPAT	Composition patent	IMS Patent Focus	0.21	0.41	0	1
MUSEPAT	Method of use patent	IMS Patent Focus	0.18	0.38	0	1
DDELPAT	Drug delivery system patent	IMS Patent Focus	0.08	0.27	0	1
APRY-GRY	Drug approval year minus patent grant year	USPTO/FDA Orange Book	3.42	4.85	−8	19
Product-level control variables						
PIONEER	Approved NDA is a Reference Listed Drug	FDA Orange Book	0.66	0.47	0	1
PAT_PER_INNOV	Number of patents attached to the approved NDA	FDA Orange Book	5.11	3.36	1	16

N=954 NDA-patent observations.

We have also included a full set of primary therapeutic class dummies associated with the NDA (see main text).

count of forward citations through 2006 inclusive by the mean number of such citations collected by all patents in the same technology class (three-digit US class level) and grant year of the focal patent. In order to control for the pervasiveness of a technology, we similarly create a normalized variable NORMGEN which is equal to the generality score (Hall and Trajtenberg, 2004) of the focal patent divided by the mean generality score of all patents issued in the same technology class (three-digit US class level) and grant year of the focal patent.

Research has shown that *science-based* technology can be more easily codified and hence are characterized by a lower cost of information exchange (Teece, 1977; Arora and Gambardella, 1994; von Hippel, 1994). In particular, a firm's use of external technology markets should increase with the "basicness" of the knowledge underlying the focal technology. We therefore create a control, NSCIREF, equaling the count of references to scientific papers to measure the importance of science in the focal patented technology. These counts were calculated using *Delphion* patent data.

In addition to these controls, we include dummy variables derived from the IMS *Patent Focus*^{TM} database describing the underlying function of the focal patent. The subject matter basis for a US patent is wide and includes processes, machines, manufactures, or compositions of matter. Drug patents are no less broad, and in our data each patent's descriptive field falls into one of the following categories: product patent, process patent, composition patent, method of use patent, or drug delivery system patent. Accordingly, we create five dichotomous variables, PRODPAT, PROCPAT, COMPPAT, MUSEPAT and DDELPAT, each taking the value one if the focal patent corresponds to one of the afore-mentioned descriptive fields, respectively, and zero otherwise.

We also exploit two other sources of patent information, backward references and claims, shown to be correlates of importance (Lanjouw and Schankerman, 2004) and value (Harhoff *et al.*, 2003). Sensitivity analysis, not reported here, reveals that their effect is either insignificant or innocuous to our results. Table 1 presents the descriptive statistics of the variables and identifies the corresponding data sources that were used in the model specifications.

4. Empirical results

4.1 Specification and estimation

We use a standard Probit model to estimate the effects of observed firm-, product-, and patent-level covariates on the probability that a patented invention protecting an approved NDA originated outside the firm commercializing the drug.[10] As a robustness check, we also conducted analysis on a sample collapsed on NDAs, taking the

[10]Results are qualitatively robust in the logit specification.

averages of both outcome and explanatory variables but replacing the dependent variable with one representing the proportion of acquired patents in the NDA as a measure of the firm's reliance on external technology. Results derived from this alternative approach, not shown here, are consistent with those presented in this article.

Our results should be interpreted with the understanding that we observe only the focal firm's reliance on external technology, and not its specific motivations for accessing external technology. We note that such outsourcing is the outcome of incentives both to buy and to sell technology. We are thus unable to identify whether changes in the dependent variable reflect changes in the demand for technology per se. To address this problem we have included several variables at the technology level to control for the supply side of the market. We have also noted in our discussion of the results whether the main variables of interest might influence both the willingness to buy *and to sell* the technology. Where appropriate, we have also offered an interpretation on the direction of such an effect in order to supplement our discussion of the results.

4.2 Results

4.2.1 Main hypotheses

Coefficient estimates are reported in Tables 2. In our first two models, we include only the variables of interest (those related to the hypotheses we test), both with and without the interaction between cospecialized assets and productivity (Models 1–2). We then progressively consider the effects of the control variables, including firm-, industry-, patent-, and product-level controls (Models 3–6). Table 3 presents the marginal effects computed (based on the estimates from Model 6 in Table 2) as the changes in the probability of external technology sourcing given a 1% change in the independent variables while holding other explanatory variables at their sample means. The average predicted probability of external technology acquisition is 0.55, almost identical to the actual mean of the dependent variable. We will refer to Table 3 to interpret the magnitude of the effects of explanatory variables.

All our hypotheses find strong support from the data. In particular, with reference to Hypothesis 1, the probability of adopting external technology decreases by about 1% for a 1% increase in the level of cospecialized complementary assets. Transaction cost economics (Williamson, 1985) suggests that as assets become more specific to a transaction the risk of opportunism and holdup increases, and that under those circumstances transacting in the markets for technology is hazardous (Teece, 1986). We find that, all else equal, firms specializing in downstream assets dependent on a specific innovation are less likely at the margin to turn to external markets for the acquisition of that technology.

We note that our measure of cospecialized assets is at the level of the technology buyer. The nature of complementary assets also plays an important role in defining

Table 2 Firm reliance on external technology (Probit regressions)

Dependent variable: Patent attached to NDA is not owned by NDA applicant	(1)	(2)	(3)	(4)	(5)	(6)
Main independent variables						
PRODUCTIVITY	−0.007	0.042	−0.130**	−0.126**	−0.135**	−0.072*
	0.033	*0.047*	*0.065*	*0.055*	*0.060*	*0.041*
COSP_ASSETS	−0.002**	−0.002*	−0.003***	-0.002**	−0.002**	−0.002**
	0.001	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*
PRODUCTIVITY X		−0.004**				−0.005**
COSP_ASSETS		*0.002*				*0.001*
Firm-level control variables						
R&D			−0.233**	−0.257**	−0.282***	−0.290***
			0.107	*0.102*	*0.109*	*0.108*
EMPL			0.019	0.051	0.047	0.044
			0.09	*0.097*	*0.104*	*0.104*
PAT_FIRM			−0.118**	−0.190*	−0.167	−0.154
			0.054	*0.101*	*0.104*	*0.105*
E_SCOPE			0.160	0.175	0.236	0.287
			0.225	*0.227*	*0.232*	*0.233*
US			−0.135	−0.096	−0.087	−0.074
			0.160	*0.165*	*0.164*	*0.163*
JP			0.262	0.106	0.118	0.146
			0.685	*0.644*	*0.698*	*0.751*
Industry-level control variables						
			0.060	0.057	0.069	0.070
MKTSIZE			*0.057*	*0.057*	*0.058*	*0.058*
Patent-level control variables						
NSCIREF	0.076*	0.097**	0.096**	0.125***	0.123***	0.135***
	0.044	*0.042*	*0.042*	*0.044*	*0.045*	*0.045*
HHI5				−0.619	−0.542	−0.472
				0.429	*0.446*	*0.453*
TOT_PAT				−0.117**	−0.114**	−0.103**
				0.045	*0.045*	*0.045*
NORMFCITE				0.056***	0.057***	0.056***
				0.018	*0.018*	*0.018*
NORMGEN				−0.153**	−0.153**	−0.151**
				0.061	*0.062*	*0.062*
PRODPAT				0.013	0.013	0.022
				0.151	*0.150*	*0.150*
PROCPAT				1.473***	1.294***	1.258***
				0.438	*0.440*	*0.439*
COMPPAT				−0.230	−0.228	−0.217
				0.170	*0.172*	*0.172*

(continued)

Table 2 Continued

Dependent variable: Patent attached to NDA is not owned by NDA applicant	(1)	(2)	(3)	(4)	(5)	(6)
MUSEPAT				0.024	0.035	0.061
				0.189	*0.188*	*0.189*
DDELPAT				0.541*	0.549*	0.550*
				0.309	*0.331*	*0.324*
APRY-GRY				0.038***	0.037***	0.037***
				0.014	*0.014*	*0.014*
Product-level control variables						
PIONEER					-0.435***	−0.478***
					0.165	*0.165*
PAT_PER_INNOV					−0.036	−0.031
					0.024	*0.024*
Primary therapeutic class of NDA (dummy variables)	Yes	Yes	Yes	Yes	Yes	Yes
(Joint Sig.)	sig	sig	sig	sig	sig	sig
N. of Obs.	954	954	954	954	954	954
Log pseudoL	−612.177	−604.694	−584.545	−550.419	−533.751	−528.226
McFadden R^2	0.066	0.078	0.108	0.160	0.186	0.194

***$P<0.01$, **$P<0.05$, *$P<0.1$

Standard errors, shown in italics, are robust to heteroscedasticity and adjusted for 338 clusters in NDA.

An intercept is included in all specifications.

the incentives for the *sellers* of technology (Teece, 1986; Gans *et al.*, 2002; Arora and Ceccagnoli, 2006). In particular, the technology-holding firms that do not own such downstream assets and cannot easily acquire them have greater incentives to access necessary specialized or cospecialized downstream assets in the market (Teece, 1986). This implies that, if COSP_ASSETS captured a supply-side effect, its sign would be positive since specialized technology suppliers are typically smaller firms in this industry. In other words, despite our imperfect controls for the supply-side of the market, the negative effect of COSP_ASSETS on technology sourcing appears to reflect our hypothesized demand-side effect.

We also find support for Hypothesis 2. The first-order marginal effect of PRODUCTIVITY is generally negative as expected, and significant at least at the 10% level in our benchmark specifications (Models 5 and 6, Table 2). This suggests that, as internal R&D productivity increases, firms turn less frequently to external sources for technology. In the models without firm-level controls, however, this

Table 3 Change in the probability of external technology acquisition for a 1% change in the independent variable

	Description	Estimate	Std. Error
Main independent variables			
PRODUCTIVITY	New products per mil.$ R&D (firm)	−0.04	0.016**
COSP_ASSETS	Trademarks weighted by promotion int. in focal therap. class (firm)	−0.01	0.005**
Firm-level control variables			
R&D	R&D (in mil. $; log)	−0.11	0.043***
PAT_FIRM	N. of patents granted [log(1+PAT_FIRM)]	−0.07	0.041*
EMPL	Employees (log)	0.02	0.041
E_SCOPE	Number of therapeutic classes (log)	0.09	0.091
US	US drug applicant[a]	−0.03	0.064
JP	JP drug applicant[a]	0.05	0.268
Industry-level control variables			
MKTSIZE	Industry sales in focal therapeutic class (log)	0.03	0.023
Patent-level control variables			
NSCIREF	Science references [log(1+NSCIREF)]	0.05	0.018***
HHI5	Concentration index of patent assignees in focal class (HHI5)	−0.06	0.051
TOT_PAT	Sum of all patents in focal tech. class (log(1+TOT_PAT))	−0.04	0.018**
NORMFCITE	Normalized forward citations	0.02	0.007***
NORMGEN	Normalized GPT index	−0.06	0.024**
PRODPAT	Product patent[a]	0.01	0.059
PROCPAT	Process patent[a]	0.36	0.065***
COMPPAT	Composition patent[a]	−0.09	0.068
MUSEPAT	Method of use patent[a]	0.01	0.074
DDELPAT	Drug delivery system patent[a]	0.20	0.107*
APRY-GRY	Drug approval year minus patent grant year	0.05	0.018***
Product-level control variables			
PIONEER	Approved NDA is a Reference Listed Drug[a]	−0.17	0.062***
PAT_PER_INNOV	Number of patents attached to the approved NDA	−0.07	0.049

***$P<0.01$, **$P<0.05$, *$P<0.1$ Standard errors, shown in italics, are robust to heteroscedasticity and adjusted for 338 clusters based on NDAs.

Elasticities are computed using the 'mfx, dyex' command in Stata after probit ('mfx, dydx' for variables in logs).

[a]Change in probability is for a discrete change of dummy variable from 0 to 1.

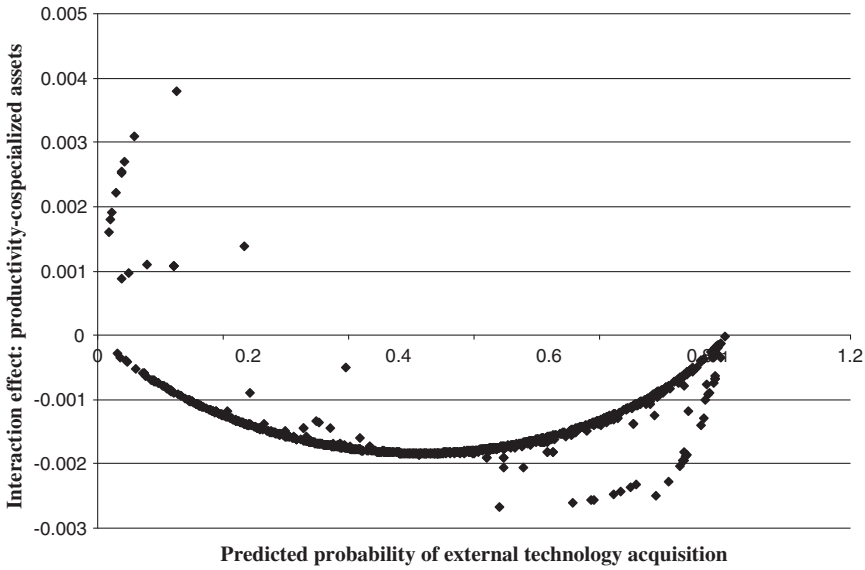

Figure 2 The impact of productivity and cospecialized complementary assets (Hypothesis 3). *Notes:* When all independent variables are at their sample means, the predicted probability of external technology acquisition is 0.55. The estimated interaction effect when all independent variables are at their sample means is –0.002 (standard error = 0.001), which is different from zero at the 1% significance level.

effect is not significant. This is not surprising because, with diminishing returns to R&D, the innovations/R&D ratio decreases with the level of R&D. Hence, the negative effect of productivity may have been offset by the omission of R&D effect on external technology sourcing. Therefore we interpret our result as suggesting that it is only by controlling for the level of firm R&D expenditures that our internal productivity measure reflects the exogenous variation in R&D capabilities and technological opportunities.

The results also show support for Hypothesis 3. The interaction between PRODUCTIVITY and COSP_ASSETS is negative as expected at the 1% level in our benchmark specification (Model 6, Table 2). The cross-partial effect between productivity and cospecialized assets is presented in Figure 2 for each observation, demonstrating a nonlinear effect that is greatest around the baseline probability.[11]

[11]This is computed using the "inteff" Stata command, which provides correct marginal effects of a change in two interacted variables for Logit/Probit models, following Ai and Norton (2003). As they suggest, the interaction effect is always positive for some observations and negative for others and typically follows an S-shaped pattern when plotted against predicted probability in Logit/Probit. The fact that the interaction effect is greatest where most of our observations are clustered adds robustness to our results.

On average, the cross-partial effect is equal to –0.002, which equals those corresponding to observations with the baseline predicted probability (computed with all explanatory variables set at their sample means) of about 0.55.

We find that firms with (i) relatively more internally generated product innovations (at any stage of development) per million dollars of R&D and (ii) comparatively high levels of cospecialized assets (within the same therapeutic class as the focal approved drug) are less likely to acquire technology in the external markets (within that same therapeutic class). This result is consistent with Hypothesis 3, and follows from the complementarity between upstream internal R&D and downstream assets in the presence of asset specificity. Since these two activities are complementary, increased transaction costs coupled with an exogenous shift in any of the drivers of internal R&D productivity will also necessarily and indirectly change the relative payoff of the "technology buy" decision.

4.2.2 Other results

Our models present other noteworthy results related to the effect on external technology acquisition of appropriability conditions (PAT_FIRM), technological competition (HHI5 and TOT_PAT), firm size (EMPL), technology generality (NORMGEN), patent value (NORMFCITES) and patent type (PRODPAT, PROCPAT, COMPPAT, MUSEPAT, and DDELPAT).

Controlling for R&D and productivity, the negative coefficient of PAT_FIRM is consistent with the expectation that stronger patent protection decreases the probability of external technology acquisition. The marginal effect of PAT_FIRM in Table 3 suggests that a 1% increase in the number of patents held by the NDA applicant reduces the probability of acquiring external technology by 7%. This effect is significant at the 10% level.

Considering that supply-side factors could confound our findings, we first note that appropriability conditions also affect the incentives to sell technologies. While the first-order effect of appropriability on the incentives to out-license a technology is generally ambiguous (Arora and Ceccagnoli, 2006), for firms with weak downstream specialized assets the impact of enhanced appropriability opportunities should increase and may become positive (Gans *et al.*, 2002; Arora and Ceccagnoli, 2006). In other words, if PAT_FIRM captures a supply-side effect, our pharmaceutical industry setting (where technology suppliers tend to be smaller) should dictate that its effect is negative. We are therefore reasonably confident that the negative relationship we find between PAT_FIRM and the likelihood of NDA-attached patents being sourced from outside the firm reflects the expected demand-side effect of appropriability.

The two variables we use to capture different dimensions of technological competition are the concentration index of patent assignees (*HHI5*) and the total number of patents issued in the focal technology class (TOT_PAT). The coefficients on *HHI5* suggest that more concentration (i.e. less competition) reduces the observed reliance

on external technology although the effect is not significant at conventional levels. Similarly, a higher value in TOT_PAT is associated with a lower likelihood of relying upon external technology. The implied marginal effect of a 1% increase in TOT_PAT corresponds to a 4% decrease in the probability of external technology acquisition (Table 3).

Other results suggest that larger NDA applicants (i.e. those with a greater number of employees) have a higher propensity to acquire their NDA-attached patents in the external market. We interpret this result in the following way: since we are controlling for R&D *and* the presence of cospecialized assets, the additional information contained in the number of firm employees may capture the intensity of firm investments in *generic* complementary assets. Because such assets are neither specialized nor cospecialized, they bring with them lower transactional hazards (Williamson, 1985; Teece, 1986) and tend to represent the firm's scope in terms of "making or buying" a technology. Possessing cospecialized assets, conversely, creates incentives for the firm to generate technology internally. The size coefficient (EMPL) is positive, but not significant at conventional levels. The lack of significance is due to multicollinearity with the R&D variable. In fact, when we include R&D intensity instead of R&D levels, we obtain a positive and significant coefficient. Nevertheless, we prefer to use R&D levels to directly control for diminishing returns to R&D, which, as explained earlier, is necessary for correctly interpreting the variations in innovations/R&D ratio as a measure of R&D efficiency.

Although not significant at conventional levels (due to multicollinearity), the implied elasticity related to size suggests that a 1% increase in the number of employees induces a 2% increase in the probability of external technology acquisition. This result complements those presented by Gambardella *et al.* (2007) who find that larger firms are less likely to license-out their technology. Indeed, their finding refers to the size of the technology *supplier* rather than that of the *buyer* as our results do. From the supplier's perspective, and without directly controlling for asset cospecialization, larger firms are more likely to "make" than "buy" a specific technology for reasons similar to those indicated in Hypothesis 1 and suggested by Teece (1986): larger firms are more likely to own the cospecialized assets required to commercialize an innovation and are therefore less likely to out-license their technology. Combined, these findings suggest that smaller firms are more likely to supply technology in the market, while larger firms are more likely to buy it. Put differently, markets for technology favor a division of labor between small and large firms.

The coefficient on technology generality (NORMGEN) is negative and significant across specifications. The magnitude of effect is also quite large: the marginal effect implies that a 1% increase in standard elasticity is associated with a 6% lower probability of external technology acquisition. This result is noteworthy given the finding in Gambardella *et al.* (2007) that general purpose technology (GPT) suppliers may have *greater* incentives to sell their technologies. Reading our findings with those in the earlier literature suggests that suppliers and buyers of GPTs may face very

different and in fact diametrically opposite incentives. Perhaps, buyers and sellers may be supplying and demanding qualitatively different types of technology in the markets.

We also find that more valuable patents (NORMFCITES) have a greater likelihood of being acquired in the external market: a 1% increase in NORMFCITES is associated with a 2% increase in the probability of external technology acquisition, suggesting that technologically more important patents (as compared to other patents in their grant year and technology cohort) are more prone to be acquired. This effect is significant at the 1% level. The result is consistent with Gambardella *et al.* (2007) who find that correlates of patent value, such as whether a European patent was opposed at the Patent Office, have a significant and positive impact on the probability that a patent is licensed.

Our estimates also suggest that patented technologies with greater science linkages (NSCIREF) are associated with a greater probability of external technology adoption. The coefficient is generally significant across models and, in particular, is significant at the 1% level in our benchmark specification. The estimates presented in Table 3 imply that a 1% increase in the number of science references contained in the focal patent is associated with a 5% increase in the probability of external technology adoption.[12]

Finally, we obtain some noteworthy results concerning the type of patents involved in pharmaceutical market transactions in technology. In particular, *process* and *drug delivery system* patents are significantly more likely to be acquired in the external market. The marginal effects suggest that the probability of being externally acquired increases by 36% when the focal patent is a process patent and by 20% when the focal patent protects a drug delivery system.[13]

[12]Since the nature of knowledge is expected to stimulate both the demand- and supply-side of technology markets (Gambardella *et al.*, 2007) and since our dependent variable reflects the actual adoption of external technology, we cannot claim that the observed change is entirely due to a change in the demand for external technology.

[13]We note, however, that only six of our sample patents are identified in the IMS *Patent Focus*™ dataset as process patents, and hence this result should be interpreted with caution. Because this process patent effect relies on a very small subset of patents, it limits our ability to further elaborate on this finding. We did, however, conduct a more in-depth examination of these patents. Research suggests that patented process technology in the pharmaceutical industry is associated with technology specialization, and hence with the supply of specialized technology (in our context, drug manufacturing process technology). In fact, five of these six patents were produced by firms other than the drug applicant, and the originators of these "external" patents (e.g. Health Research, Tanaka Kikinzoku Kogyo) appear to be fairly specialized in the drug manufacturing process technologies (judging from the number and share of process patents they have generated). For instance, Health Research Inc. (NY) has more than 200 US patents, many of which are on the process of manufacturing drugs. Similarly, Tanaka Kikinzoku Kogyo (Japan) has over 150 US patents, many of which cover process technologies. This finding is consistent with Arora and Merges (2004), who imply that technology suppliers will resort to intellectual property rights ownership to guard

5. Concluding remarks

This article uses data on transactions in the pharmaceutical industry to examine the drivers of external technology acquisition strategies of profit-seeking corporations. We make several contributions to the literature. First and foremost, we perform a demand-side analysis of the markets for technology, partly confirming prior findings as well as providing new evidence on the determinants of the demand for technology in the markets for technology. We brought together a unique combination of data to explore these issues at various levels. We chose the pharmaceutical industry as our research setting not only because the industry is economically important but also because high-quality, fine-grained data are available.

We focus on the ownership of cospecialized assets, R&D productivity, and their interaction as the main drivers of a firm's "make or buy" decision in R&D. In particular, our findings suggest that firms possessing cospecialized complementary assets and stronger R&D productivity are less likely to source technologies developed outside the firm as inputs into their new products. However, we find an important interaction effect: for firms that hold comparatively high levels of cospecialized complementary assets, the presence of relatively poor internal R&D productivity tends to increase the firm's propensity to acquire technology in the external market.

Our approach integrates the transaction-cost economics perspective with the analysis of internal R&D capabilities as drivers of the R&D "make or buy" decision, thus adding to perspectives on the existence and expansion of markets for technology. In fact, it appears to us that the existence of high transaction costs and asset specificity in the pharmaceutical industry is inconsistent with the division of labor that has long characterized this industry; greater cospecialization suggests vertical integration (Williamson, 1985) and not necessarily the use of markets for technology. Combining the transaction-cost economics perspective and R&D capability argument allows us to offer explanations for the increased use of markets for technology by the firms that own cospecialized complementary assets and face productivity declines. Our hypotheses and results therefore offer some explanation for the sustained division of labor characterizing this industry. Indeed, since downstream capabilities and internal R&D are complementary activities in the presence of cospecialization, a decrease in internal R&D productivity can be expected to reduce the marginal value of the downstream assets within firm boundaries.

Our finding that the demand for external technology is positively related to the interaction of cospecialized complementary assets and internal R&D productivity is consistent with recent studies suggesting that firms may be locked in to research

themselves from opportunism in contracting with technology buyers. It is noteworthy that on the demand side for these process technologies the buyers of these technologies in our sample have either very few patents (e.g. Axcan Scandipharm) or hold mostly non-process patents (e.g. Sanofi Aventis).

streams by the possession of hard-to-imitate cospecialized assets (Chan, *et al.* 2007; Graham and Higgins, 2009) and may face strong incentives to turn to the external technology markets when their internal R&D productivity is flagging. However, the argument in Chan *et al.* (2007) is only theoretical and focuses on dynamic adjustment costs that are contingent on the state of a firm's product pipeline. We view R&D productivity in a more holistic way and go beyond simply specifying a "gap." In fact, firms may possess strong R&D capabilities yet still experience gaps in their pipelines due to the long and uncertain development process in pharmaceuticals.

Our results have several other implications. Since the combination of low internal productivity and high cospecialized downstream capabilities tend to create a demand for technologies in the market, one implication of our findings is that buyer firms may be pushed into the technology markets with weakened relative bargaining positions. This weak position could affect the terms of the deals that are forged and the firm's ability to appropriate value relative to the technology seller. While the bargaining and control rights literature has used simple measures of internal productivity (Higgins, 2007) in an effort to capture the relative bargaining position of the firm in the external market, our findings suggest that the role of complementary assets should also be taken into consideration. More generally, our findings suggest that there may be a more nuanced story to value appropriation for both technology buyers and suppliers.

Finally, our study raises questions about whether the movement by firms to the external technology markets serves as a short term "patch" or a "jump-start" which can serve to ultimately improve internal R&D productivity. To the extent that such technology acquisitions improve the marginal productivity of internally-conducted upstream research, technology markets may not only allow gains through specialization and division of labor, but also improve firms' internal R&D capabilities. In the context of absorptive capacity, the work of Cohen and Levinthal (1989) implies that firms making such moves would not obtain long term gains since their low internal R&D capabilities would not facilitate an effective utilization of external technology. While the question of what role absorptive capacity plays is an interesting one, our data did not allow us to examine it other than controlling for its effect. Understanding the relationship between internal R&D productivity and external technology acquisition, particularly in consideration of the complementarity between the two, therefore represents a line of inquiry deserving deeper investigations.

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