Research on Markets for Inventions and Implications for R&D Allocation Strategies

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Abstract

Several streams of literature have examined the phenomenon of ‘markets for inventions’, that is, the trade of elements of knowledge which are ‘disembodied’ from individuals, organizations and products. The aims of this paper are to bring together the various streams of research in this area and discuss their major assumptions and limitations, in order to provide a comprehensive framework for understanding the phenomenon, and identify promising paths for future research. We start our review by identifying the object of market exchange – that is, an invention whose knowledge has been codified and disembodied from individuals, organizations or artifacts. We then identify those factors that enable firms to trade inventions, distinguishing between institutional-, firm-, and industry-level factors. We close our analysis of the extant literature by discussing the implications of markets for inventions for firm behavior and performance. Against this background, we highlight an important avenue for future research. A neglected implication of the development of invention markets is that firms are confronted with a wide variety of technological paths from which to choose, because the opportunity to acquire technologies on the market offers them a greater variety that can their internal R&D departments. However, the streams of research on markets for inventions and on R&D allocation strategies have been surprisingly disconnected so far. Hence, in the final section, we start to establish and explore the link between these literatures, and to identify a research agenda in this domain.

Introduction

Several streams of literature over the past twenty years have challenged the traditional tenet that the entire innovation process, from idea generation to commercialization, is performed within the organizational boundaries of single firms. Be it the more economic-oriented research on markets for technology (Arora, Fosfuri & Gambardella, 2001) and markets for ideas (Gans & Stern, 2003), or the more managerial literature on open innovation (Chesbrough, 2003; Chesbrough, Vanhaverbeke & West, 2006), they have all emphasized that knowledge has been increasingly traded on markets as a 'free-standing' entity, 'disembodied' from individuals, organizations and products. To provide a unifying label for all these streams we call this phenomenon 'markets for inventions' - but despite this common starting point, contributions in this area have focused on different aspects of the phenomenon, and followed different theoretical perspectives.

The more economic-oriented contributions have dealt with the creation of invention markets, the inefficiencies (information asymmetries and opportunistic behavior) that limit them, and potential solutions (e.g., Anton & Yao, 1994; Arora 1995). At the firm level, research in this area has mainly focused on identifying factors that affect firms' incentives to trade in technologies (e.g. Arora et al. 2001; Fosfuri, 2006). This literature has also explored the industry-wide consequences of markets for inventions, emphasizing that they encourage specialization and the division of labor according to comparative advantages, especially between smaller and larger firms (Arora & Gambardella, 1994a; Gans, Hsu & Stern, 2002). In contrast, organization and management scholars have focused to a greater extent on the role of norms regulating knowledge transactions (e.g., Fauchart & von Hippel, 2008), the firm capabilities that enhance the possibility of participating in technology transactions (e.g., Cohen & Levinthal, 1989), and the managerial implications of the existence of markets where inventions can be traded (e.g. Chesbrough, 2003; Chesbrough & Appleyard, 2007). The aim of this paper is to bring together all these literature streams and to discuss their major assumptions and limitations, so as to provide a comprehensive framework for understanding the phenomenon, and to identify promising paths for future research.

We start our review by identifying the object of market exchange - that is, an invention whose knowledge has been codified and which is ‘disembodied’. While knowledge codification is a pre-condition for markets for inventions to exist, the actual development of these markets also depends on other enabling factors, which we discuss next. We first identify the role of institutions, distinguishing between the formal (intellectual property rights, contracts) and the informal (social norms, relational governance). Our analysis continues by focusing on the firm and industry characteristics that affect decisions to license. In particular, regarding firm characteristics, we focus on firm-level factors - such as organizational size and structure - that influence their incentives to operate in markets for inventions, and on their capabilities; regarding industry structure, we analyze the role of competition, product differentiation and demand fragmentation. We close our analysis of the literature by discussing the implications of markets for inventions for firms. Figure 1 provides a representation of the structure of the review.

Insert Figure 1 about here

Against this background, we conclude our review by highlighting an important avenue for future research. A neglected implication of the development of invention markets is that firms are confronted with an ever-wider variety of technological paths from which to choose, because the market offers them a larger variety of technologies than can their (inevitably smaller) internal R&D departments. As a result, their decisions about how best to allocate their financial resources among all these technologies - which we define as their R&D allocation strategies - have become more crucial than ever. The R&D allocation strategy problem has certainly already been addressed by several streams of research, which have analyzed how companies should spread their resources among different technologies, with the aim of discovering their value, or, once their value is clear, of maximizing the returns to their investments in commercialization. But research on markets for inventions, on the one hand, and on R&D allocation strategy, on the other, have been surprisingly disconnected to date - so, in our final section, we propose a preliminary link between these literatures, which might suggest a fruitful research direction.

Defining Markets for Invention: Codified Knowledge Exchanged for a Price

By definition, markets are arenas in which objects are exchanged for a price. We can say that the boundaries of markets for inventions are delimited by two characteristic elements: that inventions are exchanged for a price; and that they are codified and traded in 'disembodied' form, independent from any other entity or artifact. The first factor distinguishes markets for inventions from other forms of knowledge exchange such as free revealing, while the second distinguishes them from markets for products and other markets in which knowledge is embedded within other factors or assets, such as markets for human capital or for firms. We discuss these two elements in detail below: Table 1 provides a summary of selected papers which define the phenomenon of markets for inventions.

Insert Table 1 about here

Price as the Element Discriminating Markets for Inventions from Other Forms of Knowledge Exchange

Typically, markets are 'spaces' where buyers pay prices to sellers to acquire assets of one sort or another: and markets for inventions are no different, as the literatures on both markets for technology (e.g., Arora et al., 2001) and markets for ideas (Gans & Stern, 2003) point out.

Hence, we could use the existence of pecuniary transfer from buyer to seller as one way of discriminating markets for inventions from other forms of knowledge exchanges that occur outside markets - known as ‘free revealing’ , (e.g. Chesbrough & Appleyard, 2007; von Hippel, 2010).

To delimit better the boundaries of markets for inventions it is important to understand the conditions under which firms might be willing to freely reveal knowledge, rather than trading in it. First, inventors may be willing to reveal without pecuniary reward when revealing their ideas can increase their reputations among their peers (Merton, 1973; Stephan 1996), or when it is their only option if they want to see it in use (von Hippel, 2010). Examples of such free revealing have been identified in the medical equipment (von Hippel & Finkelstein, 1979), semiconductor (Lim, 2000), library information system (Morrison, Roberts & von Hippel, 2000) and sporting equipment industries (Franke & Shah, 2003), as well as being the basis of open source software communities (Franke & von Hippel, 2003; von Hippel, 2010; von Hippel & von Krogh, 2003).

A party might also reveal a piece of knowledge or information to gain an ‘indirect’ reward – one that is pecuniary, but is delayed beyond the moment when the knowledge is disclosed: for instance, small firms or individual inventors may disclose their inventions to establish their legitimacy, perhaps with the aim of increasing the likelihood of subsequent liquidity events, such as IPOs or acquisitions (Waguespack & Fleming, 2008). Free revealing can also provide individual inventors with access to complementary information that they can use to improve their inventions (Raymond, 1999) or to low-cost marketing channels (Gruber & Henkel, 2006; Henkel, 2006), which might be particularly crucial for those with limited resources. In other cases, firms might adopt a partial free revealing approach, where only one part of the invention is given away free, but other parts need to be bought (Chesbrough &Appleyard, 2007; Henkel, 2006).

The cases outlined above refer to circumstances in which knowledge exchange occurs without an (immediate) pecuniary transfer from seller to buyer. As such, these cases do not fall within the scope of research on markets for inventions, which focuses instead on those instances where knowledge is exchanged for a price. But the existence of a price is not a sufficient condition for defining markets for inventions – the characteristics of the object being exchanged are also fundamental in defining such markets, as we discuss below.

Codified Knowledge as the Element Discriminating Markets for Inventions from Other Markets for Knowledge

Codification as a pre-condition for markets for inventions. For the invention to be exchanged as a standalone object, the underlying knowledge it holds must be codified (at least to some extent) – that is, articulated in an intelligible form such that it can be assessed, used and stored by the buyer after the transaction with no further (or with only minimal) input from the seller. In identifying the boundaries of markets for inventions, the key distinction we use is whether the knowledge inherent in an invention is codified in such a way that it can be autonomously reproduced by the receiver, or alternatively cannot be separated either from the artifact in which it is embodied or from the original knowledge source. These cases refer to the situation in which, for instance, knowledge is sold in the form of products or services. We would refer to these as markets for products or for services rather than as markets for invention. Similarly, if the knowledge is sold as embodied in an organization as a whole, or held as tacit knowledge by individuals, we would refer to markets for firms or for human capital. All this leaves us with the view that the codification of knowledge is a pre-condition for the existence of markets for inventions, in that it allows the invention to be identified as a separate 'thing' which can be traded discretely.

Interestingly, codification is not necessarily an inherent quality of knowledge. As Nelson and Winter (1982) emphasize, the level of codification is instead determined to a great extent by individuals or organizations. In particular, they point out that whether a certain knowledge piece is codified or not depends on whether the costs of codification exceed the benefits (hence, if costs decrease, firms have more incentive to articulate their knowledge). In fact, the costs of codifying knowledge have substantially diminished since the end of the last century, mainly due to, as Arora and Gambardella (1994a, p. 525) note, "advances in three areas: theoretical understanding of problems, instrumentation, and computational capability". These factors have made it easier to understand the principles governing a phenomenon as opposed to relying on a trial and error approach – thus knowledge has become less context-dependent and can be more cheaply articulated into general and abstract codes.

This greater 'universality' of knowledge has allowed innovation processes to be organized in new ways. Tacit and context-dependent information calls for integrating the innovative process within organizational boundaries – as was traditional in the last century – because such knowledge is typically transmitted through the social interactions occurring within internal boundaries, where individuals share common "languages" (e.g., Nonaka, 1991), so can easily interact face-to-face. As Kogut and Zander (1992) point out, tacit knowledge can be shared and transferred more effectively within firms than across markets. In contrast, codified knowledge can be easily transmitted outside the firms' boundaries, so that it can facilitate a "division of innovative labor", with different, perhaps unaffiliated, organizations conducting different parts of the innovation process (Arora & Gambardella, 1994a).

Codification, the division of innovative labor and modularity. The division of innovative labor due to knowledge codification has occurred at two different levels. First, there has been a vertical division of innovative labor, where different firms specialize in different value chain activities on the basis of their comparative advantage. This has mainly led to a division of labor between small and large firms which have tended to specialize, respectively, in invention and commercialization activities (Arora & Gambardella, 1994a). Second, there has been a division of labor at the system level: greater codification has meant that knowledge components underlying many systems have become increasingly independent from each other, to the point where they can be generated, developed and managed by different organizations and re-assembled at a later stage. So, many systems have migrated towards higher levels of modularity.

Modularity refers to the extent to which a system's components are (or can be) separated and recombined, and the degree to which the 'rules' of the system enable such component recombination (Brusoni & Prencipe, 2011; Schilling, 2000). The shift toward modularity has favored the development of markets for inventions, since, as they reduce the level of coordination required among different components (Baldwin & von Hippel, 2011), modular systems are suited to being coordinated via market governance rather than by organizational hierarchies (Sanchez & Mahoney, 1996). It is important, however, to note that the effect of modularity in inducing firms to use markets rather than hierarchies is not immediate, but may take quite a long time to develop (Hoetker, 2006; Langlois, 2002; Schilling, 2000).

To sum up, the literatures on markets for inventions (e.g., Arora & Gambardella, 1994a) and modularity (e.g., Sanchez & Mahoney, 1996) both suggest that knowledge codification has been the precondition for the division of innovative labor via invention markets. They also recognize that the process leading from codification to markets for inventions can be self-reinforcing, in that firms aiming to exploit the advantages arising from the division of innovative labor may invest in further knowledge codification. Winter (1987) discusses this issue at some length, arguing that firms can choose the extent of their knowledge codification strategically. For instance, if they judge that collaborating with other organizations could be fruitful, they will invest in greater codification, as it makes exchanging knowledge between unaffiliated parties easier.

In the same way, the possibility of collaborating via markets for inventions may induce firms producing complex products to decompose the knowledge underlying their production process and articulate some compatibility design rules, thus allowing them to shift toward a more modular system and take advantage of the modular innovations produced by many independent suppliers (Baldwin & Clark, 2000). Of course, codification is a necessary but not sufficient condition for the existence of markets for inventions. Even if an invention is codified and thus available for exchange, other factors may still prevent the growth of such markets. The following sections focus on the other necessary conditions for markets for inventions to exist (or thrive).

Determinants of Markets for Inventions

Several studies have investigated the conditions under which firms use market transactions to buy or sell technologies. In particular, we can distinguish between two groups of studies. One group is more closely rooted in the economic tradition: its contributions tend to investigate firms' incentives to engage in technology transactions, and consequently focus to a greater extent on the institutional factors that increase such incentives by reducing market imperfections, especially intellectual property (IP) rights (Gans et al., 2002) and the effective design of contracts (e.g., Arora 1996). They are also interested in how industry structures affect firms' decisions to buy or sell inventions (e.g., Anton &Yao, 1994; Bresnahan & Gambardella, 1998; Fosfuri, 2006).

A second group of studies is more closely positioned instead within the organizational and management literature, and their contributions generally analyze how firms' capabilities affect their chances of engaging in technology transactions by allowing them to evaluate technologies more accurately and/or make more effective use of them (e.g., Cohen & Levinthal 1990). Such studies also compare markets for inventions with other forms of knowledge exchange (such as free revealing) that do not occur within markets, but which still might be extremely relevant for company innovation and profitability (e.g., Chesbrough, 2003; von Hippel, 2010).

But the boundaries between these two groups are blurred. Thus some contributions from an economics tradition investigate firm characteristics that might facilitate the market exchange of inventions – such as organizational structure (e.g., Arora, Fosfuri & Roende, 2013) or the ability of firms to assess technologies (Arora & Gambardella, 1994b) – while some studies from the management and organizational literatures analyze the importance of knowledge protection. In particular, some of these contributions investigate how social norms or relational governance may alleviate market imperfections (e.g., Fauchart & von Hippel, 2008). Table 2 provides a summary of selected papers that explore the determinants of markets for inventions, which are discussed further below.

Insert Table 2 about here

Formal and Informal Institutions

An important starting point for research on markets for inventions is the recognition that the characteristics of the good being transacted (i.e., the invention) can cause multiple sources of market inefficiencies. First, compared to physical goods, technology is characterized by a substantial degree of uncertainty regarding its value (Rosenberg, 1996), which intensifies the problem of information asymmetry between parties, leading to possible adverse selection (Dushnitsky & Klueter, 2011; Shane, 2002). Second, technology transactions often require highly specialized complementary investments by the buyer or the seller, who are consequently highly exposed to the risk of 'hold up' (Shane, 2002). Third, firms dealing with technology transactions often face 'small number' bargaining problems, as only a limited number of players in the market can supply or exploit a certain technology, or have access to the appropriate downstream assets to commercialize it (Caves et al. 1983; Contractor, 1981; Pisano, 1990; Schilling & Steensma, 2002).

Finally, as the knowledge underlying the technology is inherently intangible, once disclosed to a potential buyer who wants to assess its value, it inevitably leaks out (Arrow, 1962), exposing inventors to a high threat of expropriation by the buyer. Sellers, also, can display opportunistic behavior, trying to skimp on the full effort required to transfer knowledge to the buyer (Arora, 1996). Consequently, several contributions have focused on the role of institutions in reducing inefficiencies in knowledge trades (e.g., Arora 1995; Gans, Hsu & Stern, 2008): taken overall, this research has identified multiple institutional factors that could alleviate market imperfections – intellectual property rights, social norms, contracts, and relational governance – and so increase the likelihood of inventions being traded on markets.

Intellectual property rights. From a technology seller's standpoint, one of the fundamental concerns about circulating knowledge on the market is the risk of expropriation. When the technology is disclosed to potential buyers so that they can assess its value, its underlying knowledge can leak out (Arrow, 1962). Similarly, from the buyer's perspective, there can be a substantial amount of uncertainty regarding the scope of the invention, and the possibility of using it without infringing the property rights of a third party (Gans et al., 2002). Research on markets for technology has emphasized the importance of intellectual property rights (such as patents and copyright) as a fundamental condition for both preventing knowledge expropriation and reducing uncertainty about the actual scope of an invention (Arora & Ceccagnoli, 2006; Gans et al., 2002).

Gans et al. (2002) show that companies are more likely to license their technology when intellectual property rights are effective, but when they provide weaker protection, companies are more inclined to try to profit from their innovations via downstream integration. Interestingly, the importance of intellectual property rights aligns with our earlier argument that the codification of knowledge is a pre-condition for the rise of markets for inventions. As Arora et al. (2001) point out, codified knowledge can be written more clearly (e.g., in blueprints), and thus the object to be protected can be defined less ambiguously. In the context of patented inventions, for instance, the fact that they will be codified in the patent documentation strengthens patent holders' ability to enforce protection, and thus encourages knowledge trade. In this vein, Gans et al. (2008) show that licensing usually takes place within a narrow time window around the date of the patent grant, arguing that the grant reduces uncertainty and information asymmetry about the extent of property rights, and thus facilitates trade.

However, the effectiveness of formal intellectual property rights can differ in different industries. For instance, markets for inventions tend to be more pervasive and operate better in the chemical and pharmaceutical industries, where patent systems are relatively effective in protecting firm knowledge (Anand & Khanna 2000; Cohen, Nelson & Walsh, 2000; Levin, Klevorick, Nelson & Winter, 1987; Teece, 1998). The relevance of formal property rights in facilitating the development of markets for inventions can also depend on the alternative mechanisms which may be used to protect and/or successfully commercialize firm's inventions. For instance, Arora and Ceccagnoli (2006) suggest patent protection only facilitates out-licensing where firms lack complementary assets. For those possessing such assets, greater patent protection increases the payoff from commercialization by reducing imitation after the product enters the market. Similarly, Hall and Ziedonis (2001) note that the strength of intellectual property rights in the semiconductor industry has promoted the entry of design firms that sell intellectual property but do not themselves manufacture chips.

Social norms. While the economics literature has generally analyzed the relevance of formal institutions in protecting inventions, another stream of research – rooted more in organizational literature – has investigated the existence of mechanisms other than law-based intellectual property protection, such as norm-based intellectual property (Fauchart & von Hippel, 2008; Ostrom, 1990; Rai, 1999). Such systems are based on sets of implicit social rules that define accepted behaviors within a certain community. These 'social norms' are normally not written down, or even discussed explicitly, yet their violation tends to bring punishments, such as loss of status, shaming or denial of future community benefits.

Several types of social norms are common in scientific communities, regulating different aspects of the scientific process, including invention, disclosure or social exchange (e.g. Bercovitz & Feldman, 2008; Lakhani & von Hippel, 2003; Merton, 1973; Rai, 1999), and such community norms can reinforce, or be reinforced by, organizational norms (Henkel, 2006). Norm-based intellectual property mechanisms are especially relevant in contexts where law-based intellectual property systems are not particularly effective in protecting knowledge. For instance, Fauchart and von Hippel (2008), examining the context of French cuisine, identify recipes as a form of innovation that is protected through norm-based intellectual property. It is seen as dishonorable for a French chef to copy another's recipe or pass it around without permission. But one of the main limitations of norm-based intellectual property systems is that they tend only to be effective among members of specific communities, and are not enforceable beyond their boundaries, which limits the possibility of exchanging inventions outside such well-defined communities.

Contracts. Several studies rooted in the economic tradition focus on how contract design can be a way to avoid opportunism in technology transactions by aligning the incentives of the transacting parties. For instance, Arora (1995) models the case of a licensing transaction in which, along with the technology, a licensor had to transfer a piece of complementary know-how, which risked generating double-sided opportunism. The licensor has an incentive to skimp because providing such know-how is costly and the licensee will find it difficult to verify, objectively, the amount of effort exerted in transferring it. The licensee, meanwhile, has the incentive of claiming inadequate knowledge transfer of know-how if payments are conditional on its provision. A possible contractual solution to this problem is that of staging payments to the licensor over time, which acts as a safeguard for the licensee, while the licensor can rely on intellectual property rights to protect its technology. The value to the buyer depends on the technology and know-how. Once transferred that know-how cannot be withdrawn, but by withdrawing the licensees' rights to use the technology, the licensor gains a 'hostage', as the know-how is less valuable without such a license. A similar outcome can be produced by bundling the technology with complementary inputs, such as specialized machinery (e.g., Arora, 1996).

The structure of payments can also play an important role in reducing opportunistic behaviors. In general, royalty schedules address the problem of moral hazard by aligning the incentives of the licensor and licensee (Arora, 1995, 1996; Contractor, 1981). Nevertheless, different types of firms might have different preferences about payment structures: for instance, startup licensors might prefer fixed fee contracts as a form of financing. So there is a trade-off between satisfying the cash needs of a financially constrained licensor, which will probably involve upfront payment (Kulatilaka & Lin, 2006), and minimizing the moral hazard problem, which instead requires payments based on royalties.

Other contractual clauses can also help reduce opportunistic behavior. In a cross-country survey of both licensors and licensees, Caves et al. (1983) found several licensing agreements that included clauses specifically aimed at protecting one party from the other's opportunistic behavior. For example, exclusivity clauses are especially common when licensees must make technology-specific investments to commercialize the invention they have licensed in. Similarly, when the technology being licensed is at an early stage, the help of the licensor may be more critical for the licensee, so exclusivity can act as a 'hostage' held by the licensee (Somaya, Kim & Vonortas, 2011), restricting the licensor's possibility to license the invention to other parties. Exclusivity restrictions imply some risks for the licensor though, such as the risk that the licensee fails to devote enough resources to ensure its successful commercialization or expropriates the knowledge and develops substitutes. Licensors can restrict the scope of the exclusivity they offer – to specific products or geographies (Somaya et al., 2011) – to mitigate such risks.

Economic research on markets for technology and ideas relies on the assumption that contracts are the dominant mechanism firms use to regulate the dynamics of value creation and appropriation. But contract design might be particularly challenging in highly uncertainty contexts, due to the difficulty in foreseeing all possible future contingencies (Williamson, 1989). And the effectiveness of contracts is at stake in situations where a third party (typically the state judicial system) cannot enforce them successfully.

Relational governance. Organizational and managerial research emphasizes the existence of alternative mechanisms that firms can use to support contractual ones. This literature builds on the idea that firms can substitute or complement contract design mechanisms with relational ones in order to avoid market failures due to opportunism. Such relational mechanisms allow the creation of self-enforcing agreements, which, in contrast to legal contracts, do not require a third party to enforce them (Dyer & Singh, 1998). These types of agreements are based on informal governance safeguards, such as trust or reputation. For example, the frequency and intensity of prior relationships build trust between partners and can exert a positive effect on the likelihood that they will engage in further transactions (Aggarwal & Hsu, 2009). In this vein, Gans et al. (2008) show that, where technology producers frequently interact, such as in Silicon Valley, knowledge transactions occur even before patents are granted. Furthermore, retaining previous partners helps firms reduce search costs (Aggarwal & Hsu, 2009).

Reputation and prestige can also substitute for more formal safeguards. Firm reputation is based on the quality of past performance (Aggarwal & Hsu, 2009), whereas prestige is perceived quality, which may depend on factors such as the firm's size, age, network position, and status (Podolny, 1993). Good reputation and prestige increase the probability of selling a technology, because potential buyers have positive expectations about the quality of the firm's technology when it is placed on the market. They know that firms with high reputations and prestige have incentives not to behave opportunistically, in order to preserve those assets, which also reduce information asymmetry. In addition, more prestigious sellers are more visible, which reduces buyers' search costs (Sine, Shane & Di Gregorio, 2003).

Discussion. The analysis of previous literature suggests that research on the institutional determinants of markets for inventions has focused on the market imperfections associated with the characteristics of the object (the invention) being exchanged. Within this area, different groups of studies have investigated many types of formal and informal institutions that can alleviate this problem. Both formal intellectual property rights and social norms address opportunistic behavior at a contextual (e.g. industry or community) level by establishing forms of punishment for knowledge expropriation, reducing its attractiveness as an option and thus the incentives to choose it. Contracts and relational governance, instead, constitute solutions at the individual transaction level. Research on contracts builds on the assumption that market imperfections can be reduced if a third party enforces the contract, whereas research on relational governance emphasizes instead that agreements do not have to be formally written and can be self-enforceable, given the operation of some informal mechanisms, such as trust or reputation.

Research rooted in the economic tradition has focused on studying the effectiveness of formal intellectual property rights in facilitating knowledge transactions (e.g. Gans et al., 2008). This research stream has also identified some of the limitations of this protection mechanism. For instance, intellectual property rights mechanisms do not have the same level of effectiveness in all technological domains, and, because of the costs they can involve, are often unavailable to the smallest firms (e.g. Arora et al., 2001). Research in this area has also suggested how contracts should be designed in order to overcome market imperfections (e.g. Arora, 1995, 1996). Nevertheless, this stream of literature has not addressed the question of whether markets for inventions can exist and operate efficiently in contexts which are not strongly regulated by intellectual property rights or by contractual agreements.

This research gap has been partly filled by studies more closely rooted in the managerial tradition, which have explored issues of heterogeneity among the transacting parties more closely at the individual, dyadic and community levels, and its role in explaining their differing abilities to engage successfully in transactions (e.g. Chesbrough, 2003; von Hippel, 2010). These contributions are important for advancing our knowledge of markets for inventions because they emphasize how such markets might still function even where intellectual property rights are weak. Although these studies have begun to identify alternative "softer" mechanisms for knowledge protection (e.g. Fauchart & von Hippel, 2008), research in this area to date has only explored a limited number of contexts or well-defined conditions in which these mechanisms can be effective. More studies in this area would be very useful.

In order to get a more complete picture of how markets for inventions might exist and operate successfully, we need to be able to show how different mechanisms interact, and whether they reinforce or weaken each other's effectiveness. For instance, an interesting debate concerns the extent to which informal institutions can be considered substitutes or complements to formal ones. Empirical findings here are mixed, with some studies suggesting that the presence of trust can obviate the need to have formal governance in place (e.g. Dyer & Singh, 1998; Gulati & Singh, 1998; Li, Eden, Hitt, & Ireland 2008) and others showing trust as a valuable factor in reinforcing formal contracts (e.g. Poppo & Zenger, 2002). However, research on markets for inventions has generally overlooked how law-based and norm-based intellectual property systems interact, and with what effects on technology transactions.

Firm Characteristics

Some firm level factors may influence a firm's willingness or ability to buy or sell inventions. In this respect, the economics literature has mainly considered the role of the incentives which might encourage companies (or even individuals within companies) to engage in knowledge transactions. Such incentives, in turn, can depend on such firm characteristics as size (as in Fosfuri, 2006) or degree of R&D decentralization (as in Arora et al. 2013). In contrast, the literature rooted in management and organization theory has stressed the role of firms' capabilities, suggesting that some are more able than others to search for and to absorb external technologies (e.g., Cohen & Levinthal, 1990).

Firm size and organizational structure. The literature on markets for technologies suggests two main arguments to show that large firms may be less likely to trade their technologies. First, the incentives to license out naturally decrease with the potential licensor's share in the product market (Fosfuri, 2006), as each firm which buys a firm's technology becomes a potential new competitor. So the decision to sell a technology depends on the extent to which revenues generated from selling are higher than the potential rents dissipated as a result of greater rivalry. Other things being equal, firms with a small market shares are therefore more likely to license out their technologies than are larger firms, because they should suffer a smaller loss in profits from increased competition.

Second, small firms may gain advantages from specializing in technology development when trading their technologies, by getting access to the more effective downstream assets and capabilities of larger firms (Arora et al., 2001). Although markets for inventions only allow inventors to appropriate a share of the 'profit pie' generated on the product market, small technology suppliers still may be able to gain from such trades as the pie becomes larger. Empirical evidence corroborates this argument, showing that a firm's size has a negative relation with the likelihood of it licensing out its technology (Gambardella, Giuri & Luzzi 2007). This negative correlation holds even though large firms with multiple businesses are more likely to have non-core technologies that one might expect they could license out to increase their profits (Rivette & Kline, 2000).

A related issue concerns the organizational structure of a firm's R&D activities. In pioneering this important new research direction, Arora et al. (2013) argue that, when licensing decisions are decentralized to business units (rather than retained at headquarters), firms are less likely to license, because top managers reward divisions less for their licensing profits than for their (more easily observed) production profits. Thus business unit managers' incentives to scout for new technologies also diminish. Since larger firms are more likely to have decentralized R&D structures, this implies that they will be less likely than smaller firms to engage in technology transactions. Managerial evidence suggests that some companies (such as GE and IBM) have tried to reduce this problem by sharing the revenues from licensing a technology with the business unit that developed the technology (Chesbrough, 2006).

Other organizational characteristics may also influence a firm's incentives to use markets for invention. The characteristics of the firm's incentive system may affect how many of its inventions it is willing to sell on the market rather than developing internally (Chesbrough, 2006). For instance, incentivizing R&D units on the basis of patents generated is likely to result in a surplus of inventions, some of which will probably be sold on the market. Firm's R&D budget allocations may also lead to similar results. For instance, allocating research funds to broad areas rather than to very specific projects might result in inventions that are less likely to be used within the company and are therefore potential candidates for licensing out. Conversely, the likelihood that a firm's inventions are used internally as opposed to being sold off and developed externally may depend on the existence of organizational mechanisms that enable business units to compete with external competitors to use internally-generated technologies (Chesbrough, 2006). Thus, some might decide that internally generated inventions can only be used by one of its business unit up to a defined time limit, after which they are made available to others. On the other hand, setting such limits might create a sense of urgency in assessing the potential usefulness of a technology to the firm itself, perhaps reducing the chances of it being sold on the market.

Firm capabilities. Apart from a few studies, most research on markets for technologies emphasizes the importance of incentives in motivating firms' decisions to trade their technologies. Although incentives are certainly relevant, another important determinant is those firm capabilities that can facilitate technology transactions. On the demand side, absorptive capacity might be crucial (Cohen & Levinthal, 1989): in particular, a licensee's stock of knowledge and the degree to which it has searched broadly in the past is likely influence its ability to exploit externally-acquired knowledge (Laursen, Leone & Torrisi, 2010). Such external search processes will also be enhanced by firm's possession of relevant information technologies capabilities that can facilitate data mining, analysis and management (Dodgson, Gann & Salter, 2006; Sakkab, 2002).

However, we note an important distinction between the 'ability to evaluate' and 'ability to utilize' technologies (Arora & Gambardella, 1994b). The former refers to the firm's ability to predict the value of the technology, and relates more closely to its scientific capability; the latter denotes its capacity to extract value from that technology, which requires technical competence as well as downstream assets such as manufacturing and marketing capabilities. These two distinct dimensions of absorptive capacity have different implications for a firm's demand for external technology. In particular, firms with a greater ability to utilize them may be keener to acquire more external technologies (and thus more likely to license in new technologies), whereas firms with greater ability to evaluate them may acquire fewer external technologies, being better able to judge exactly which have the most promise.

The overall intuition from this research is that, for any specific external technology they may be considering, firms receive signals about its likely future value to them, based on which they decide whether or not to acquire it. So firms establish a threshold against which to assess the signals that they receive and only buy those technologies that exceed that threshold. Firms which are better able to utilize new technologies tend to set lower thresholds, and so buy more, because they can extract higher value from any they acquire. In contrast, firms better able to judge the value of such technologies are more selective (i.e., set higher signal thresholds) and will buy fewer. These firms recognize that a low signal is likely to equate to a low final outcome – but firms with less ability to judge may not be as sure about this relationship (Arora & Gambardella, 1994b).

Absorptive capacity can also be partner-specific. Over time firms may develop the ability to recognize and assimilate valuable knowledge from a particular alliance partner (Dyer & Singh, 1998). Partner-specific absorptive capacity can depend on the extent to which they have exchanged knowledge in the past, and so have developed overlapping knowledge bases and effective interaction routines (Dyer & Singh, 1998). Technological exchanges can also be facilitated by an effective transformative capacity, that is, the firm's ability to constantly adapt and restructure its knowledge base (Garud & Nayyar, 1994). In a sense, this resembles absorptive capacity, in that it refers to the ability to assess technologies before choosing and using them. But here the focus includes the maintenance, reactivation and synthesis of those technologies: buyer firms need these capacities because time lags in the development of technologies and markets may mean firms cannot immediately utilize all the technologies they acquire.

Finally, from the supply side, firms' knowledge transfer capabilities are particularly valuable in stimulating technological transactions, especially where potential buyers have weak absorptive capacities (Ceccagnoli & Jiang, 2013). Such capabilities help inventors communicate the knowledge underlying the technology effectively and explain how it can add value to buyers' products or markets.

Discussion. Research on the organizational determinants of markets for technology is still limited. In particular, it has largely overlooked the complexity of decision-making dynamics at the individual and group levels within firms, seeing them just as monolithic decision makers. Arora et al.'s (2013) study goes in this direction, but much remains to be done.

In fact, firms' decisions emerge as the results of social and political interactions among individuals, within and beyond the organization. Because these different actors will have different utility functions (e.g., Jensen & Meckling, 1976; Stern, 2004), react to different institutional logics (Greenwood, Raynard, Kodeih, Micelotta & Lounsbury, 2011), and use different frames to "make sense of ambiguous information from their environments" (Kaplan, 2008, p. 729), they are likely to develop different preferences about which technologies should be bought and which should be discontinued, and perhaps sold on the inventions market. Employees operating in stable groups often develop a 'not-invented-here' bias, which encourages them to believe that their internally-developed knowledge is superior to that originating outside the group (Katz & Allen, 1982). Nevertheless, in highly competitive organizations, internal knowledge may be ignored to avoid building the reputation of a colleague responsible for its development (Menon & Pfeffer, 2003). To influence firms' decisions to align with their own preferences, employees may engage in political behaviors (Kaplan, 2008), using different forms of power (Daft, 1978; Ibarra, 1993; Kaplan & Tripsas, 2008). Managers and shareholders can exercise more formal sources of power, based on their hierarchical authority; scientists will rely on more structural and informal sources of power that originate from their expertise in core technical activities (e.g., Krackhardt, 1990). We suggest the range of political dynamics within companies, and how they affect individuals' decisions to buy or sell inventions, constitute promising paths for future research.

Industry Structure

Existing research on markets for inventions has suggested that structural characteristics at the industry level may play an important role in affecting firms' choices to trade in these markets. In particular, two broad dimensions have been considered by previous research: competition and market structures.

Competition. The nature and extent of competition are likely to play an important role in determining the rate of exchanges in the invention market. As discussed earlier, Fosfuri (2006) and Arora and Fosfuri (2003) study the effect of competition in licensing agreements, and argue that firm decisions to out-license a technology depend on the comparison between the 'rent effect' and the 'dissipation effect', that is (respectively) the revenues they stand to gain from licensing (i.e., a share of the licensee's profits) and the rents the technology would have earned in the product market (which equates to the difference in profits pre and post out-licensing).

The dissipation effect overcomes the rent effect both when there are few competitors and when there are many competitors. On the one hand, when there are few incumbents in the market, the rent dissipation due to an increase in competition is huge. On the other hand, when there are many competitors the rent effect is small. Hence, as Fosfuri (2006) argues and tests empirically, firms are less likely to license when there are few or very many competitors in a product market: too few mean the rents dissipated by licensing are too high, and too many will mean licensing revenues are too low. Thus, firms are more likely to license when they face moderate numbers of competitors.

The impact of competition on the invention exchange also depends on the degree of product differentiation in the industry. In more differentiated product markets, each firm enjoys more profits because it is more sheltered from competition (Fosfuri, 2006). In such a situation, a firm which licenses its technology to a competitor in the same product niche will see more of its profits destroyed than if both are operating in a more homogenous market. So the incentives to out-license are lower in a market where products are more differentiated. As we shall also see below, a crucial assumption in this logic is that the licensed technology is dedicated to the product market in which the licensor operates, and can only be used in a 'head-to-head' product rivalry with the licensor. If the technology is also applicable to distant product markets, a more differentiated product market might, in fact, produce more licensing, as the licensor would have the opportunity to strategically select licensees from beyond its own market niche.

Competition among potential buyers can also be leveraged to mitigate market imperfections. In this respect, Anton and Yao (1994) consider a model in which intellectual property rights cannot be enforced, there is more than one buyer (and thus demand side competition), and the only way an inventor can profit from an idea is by selling it to a downstream producer. Buyers are uncertain about whether the idea is valuable or not, and so want it disclosed so they can evaluate it. But, of course, once they see it, they may opportunistically steal the idea (which lacks patent protection). Anton and Yao (1994) argue that in this case the optimal solution for the seller is to disclose the idea to one potential buyer and threaten to disclose it to another firm if the first behaves opportunistically. This threat is likely to induce the first firm to not behave opportunistically, because, if it does not pay for the idea, but goes ahead and opportunistically exploits it anyway, the inventor can disclose it to the second buyer, thereby both making a sale and destroying some of the rents of the first (non)buyer.

Market structure. Along with competition and product market differentiation, market structure can also influence technology exchanges because it affects the extent to which firms develop more general or more dedicated technologies. In this vein, Bresnahan and

Gambardella (1998) focus on market size, arguing that it has two components: ‘breadth’ (the number of diverse segments it includes) and ‘depth’ (the average size of each segment). As breadth increases, technology specialist firms will tend to try to produce general purpose technologies – those that can be fruitfully commercialized across several market segments – and aim to license these technologies out to downstream producers operating in different market segments. When a market gains greater depth, downstream firms are more likely to integrate backward themselves to produce dedicated technologies specific to their business needs.

The rationale behind their model is that in broader markets specialized technology suppliers can gain economies of scale at the industry level by producing a general purpose technologies and selling them to different downstream segments of the final market. By contrast, when markets are deeper, the final segment of a specific application is large enough to justify a fixed cost investment in a dedicated technology. For instance, the Japanese machine tool sector developed and licensed-out compact general-purpose machines for the differentiated needs of small final producers in many manufacturing industries, while US machine tools largely involved technologies dedicated to the need of the large automobile industry.

Gambardella and Giarratana (2013) develop this argument further. Drawing on Fosfuri’s (2006) framework, they consider the possibility of licensing a general purpose technology to product markets that are distant from that in which the licensor operates (in contrast to Fosfuri’s (2006) concentration on a dedicated technology that can only be used in the licensor’s product market or market segment). The implication is that, when product markets are differentiated, licensees destroy incumbents’ profits even more, so licensing is less likely, but where the technology is general-purpose, a fragmented market may induce the licensor to supply the technology, provided the licensee operates in a different market segment.

Discussion. Existing research on the impact of competition on trading in inventions emphasizes how trading or licensing a technology generally increases the level of competition within an industry by creating a new competitor. However, the relationship between competition and markets for inventions is far more complicated (and recognizing this issue opens avenues for future research). On the one hand, markets for inventions indirectly stimulate competition in the downstream market, by increasing the chances of entry of technologically weak firms that would probably not enter or prosper if they had to develop inventions internally. For example, Arora, Fosfuri and Gambardella (2000) show that the supply of technologies from chemical processing industry specialists has favored downstream domestic chemical producers in developing countries who lacked the capacity to produce them internally. But the supply of technologies by technology specialists has not affected multinational firms, which have the capabilities to develop such technology in-house. This illustrates the point that markets for inventions benefit technologically less-advanced firms in particular, and can thereby enhance the degree of competition in an industry. Greater competition among downstream producers, in turn, typically results in greater horizontal differentiation in the downstream market, because companies try to 'escape' from the greater competition by developing heterogeneous products (Arora et al. 2001).

However, the very existence of a market for inventions might also weaken competition. For instance, licensing might be used to deter entry: that is, an incumbent can use licensing strategically to reduce potential entrants' incentives to develop their own technology (which could be superior, and thus make the incumbent's product obsolete (Gallini, 1984; Hill, 1992)). An innovative leader might also use licensing to control competition, such as when a ‘patent monopolist’ chooses, after its patent expires, to license its technology to weak competitors to crowd the market and deter entry by stronger ones (Rockett, 1990).

Markets for inventions also reduce the costs of rivalry by allowing cross-licensing between companies. In certain fields, such as electronics and semiconductors, the set of technological skills a firm needs to master to go into production is quite broad, so that it is virtually impossible for a single firm to develop all the required technologies internally (Arora et al., 2001). In addition, when knowledge is cumulative, new inventions tend to build on previous ones (Grindley & Teece, 1997; Scotchmer, 1991), which can often produce overlaps between different firms’ innovations. To avoid the risk of infringing each others’ patents and the costs of patent enforcement, firms might enter cross-licensing agreements, where two or more firms grant each other licenses to use broad portfolios of patents within defined technological areas.

Implications of Markets for Inventions

Two main groups of studies have analyzed the implications of markets for inventions for firm behavior and performance. A first group – mainly including economic contributions from the literatures on markets for technology and markets for ideas – has analyzed how markets for inventions lead firms to specialize in those activities were they possess comparative advantages: invention for small firms and large scale development, manufacturing or commercialization for large firms (e.g., Arora et al., 2001; Gans, Hsu & Stern, 2002). A second group of studies – which includes both economic and management contributions – has focused instead on the consequences of knowledge transaction for firm innovative performance (e.g., Gans & Stern, 2000; Chesbrough, 2003). Table 3 provides a summary of selected papers which explore the implications of markets for inventions.

Insert Table 3 about here

Specialization and Trade

From a firm perspective, economic research has found that firms can capture the benefits of markets for inventions by specializing in the activity in which they enjoy comparative advantages, and then trade the outputs of those activities. Hence, young, small firms should specialize in upstream innovation development processes where they have comparative advantage. Arrow (1983) notes that the low organizational distance between corporate researchers and managers in such firms reduces asymmetric information between the inventors and the managers making decisions about the internal allocation of resources, which makes them more likely than large firms to pursue novel and riskier innovation projects.

By contrast, large, established firms have comparative advantages in performing large-scale development, production and marketing, as they are usually endowed with the assets required to commercialize their technologies effectively (Teece, 1986). Along a similar line, Holmstrom (1989) argues that diverse organizational structures have different advantages in performing innovative activities vis-à-vis the more routine activities involved in development and commercialization. The high level of bureaucratization typical of large firms is efficient for coordinating many repetitive tasks, but is detrimental to inventions. These different comparative advantages mean that markets for inventions are characterized by a division of innovative labor, because firms exhibit relatively superior performance when they specialize in the activities in which they possess more appropriate capabilities, and thus enjoy comparative advantages (Arora et al. 2001).

Recent work by Serrano (2012) has confirmed empirically that gains from specialization and trade do exist, and can be large. He develops a model that uses information about patent renewals as a measure of the value of patent rights. He identifies the gains from trade as the difference between the value if the patent is traded and if it is not (and uses an appropriate approach to identify counterfactual evidence), and shows that patents which are traded are three times more valuable than those which are not. Finally, he shows that the gains from trade are skewed: 70% of the total gains from trading in inventions accrue to the top 10% of patents, and 25% to the top 1%.

In general, specialization and trade tend to benefit both technology suppliers and downstream producers. However, when downstream assets, rather than technologies, become the scarce resource, technology specialists can experience a significant loss in their bargaining power. This situation can occur when too many technology specialists vie to sell technologies (through licenses or alliances) to too few downstream producers – in such case the latter may be able to reap virtually all the suppliers' rents. Overall, empirical evidence suggests that markets for inventions are more beneficial for firms owning downstream assets than they are for technology specialists. For instance, Arora and Nandkumar (2012), examining the software security industry, find that markets for inventions raise the value of marketing capabilities in ensuring firm survival, but decrease the value of technological capabilities. In the same vein, McGahan and Silverman (2006) use data on publicly traded U.S. firms to show that when 'outsider' firms produce inventions which could be fruitfully commercialized in a focal industry, the market value of companies in this industry generally increases. The reason is that outsiders generally lack control of downstream assets, so the only way they can profit from their inventions is to sell them to incumbent firms in the sector who can market them.

One way in which technology specialists may escape this loss of bargaining power is by developing more general technologies. Discussing this issue, Gambardella and McGahan (2010) explain that the share of returns captured by technology suppliers will depend on their bargaining power vis-à-vis the downstream producers. If the technology suppliers are much smaller than the manufacturers, or if they are relatively many compared to the number of potential buyers, the suppliers' bargaining power will probably be low. However, they also note that, by developing more general technologies, suppliers can move away from depending just on their bargaining power to secure their returns towards something over which they have more control, and is therefore worth investing in. More general technologies can be sold to more different buyers, so the overall returns their technologies can generate in the product market can be raised by increasing the number of applications they can target. As a matter of fact, the development of narrow technologies for well-defined applications constituted a major limitation for biotech specialists in the 1980s, because they could only license their technologies to limited numbers of buyers (Arora et al., 2001; Gambardella & McGahan, 2010). So, in the 1990s, many technology-based firms pursued strategies to invest in technologies with more general applicability that they could then sell to multiple buyers.

Finally, as noted, the market for technology literature sees intellectual property rights as defining the value of inventions, and so encourages suppliers to trade their technologies without fear of their value being expropriated. But recent work by Galasso, Schankerman and Serrano (2011) has identified a new source of profitable specialization along the vertical chain from invention to commercialization. They argue that markets for inventions may produce both private and social welfare gains if firms trade on the basis of their comparative advantage in patent enforcement. This gain stems from the fact that companies which are better at enforcing patent rights tend to resolve disputes without resorting to courts, and thus save on litigation costs (which can be substantial). Empirically, they find that traded patents are less likely to be litigated, which implies that markets for inventions induce firms to trade according to their comparative levels of comparative enforcement advantage.

Innovation

An important stream of literature has emphasized how markets for inventions influence innovation performance by impacting both firms' incentives and capabilities to innovate. First, markets for inventions increase the incentives to innovate of firms which lack downstream capabilities. If there were no such markets, firms that produce inventions could only profit from them by selling products that embody their technologies, or by developing processes that employ them. Thus, companies which did not possess the downstream assets to perform these operations would have little incentive to generate inventions in the first place. So markets for inventions should increase overall innovation rates in the economy.

Second, markets for inventions may also increase firms' incentives to innovate because their R&D capabilities can become a bargaining tool in negotiations. This suggests that, as well as raising technology suppliers' incentives to innovate, markets for inventions also raise the buyers' incentives to invest in R&D capabilities. An incumbent which develops (or retains) some capability to develop a technology internally will have a stronger bargaining position vis-à-vis a start-up technology inventor (Gans & Stern, 2000). So incumbents have an incentive to remain active in R&D to support the outside option of inventing (or part-developing) technologies themselves. The resultant increase in the R&D capacity of the sector should, again, raise overall innovation rates in the whole industry and the economy at large

In addition, markets for inventions may increase the incentives to innovate in sequential innovation contexts, as they encourage (collusive) agreements between initial and subsequent innovators, and thus decrease competition between them (Green & Scotchmer, 1995). However, from the licensee perspective, incentives to invest in R&D might also be reduced by specific contract arrangements such as grant-back clauses, which secure the licensor "the rights to all subsequent technology advances or improvements introduced by the licensee, based on the licensed technology" (Leone & Reichstein, 2012, p. 968), which obviously transfer the incentive to innovate from the licensee to the licensor.

The existence of a technology market may also influence a firm's ability to innovate. Innovation results from the combination of technological skills, so market availability and easier access to new knowledge should have positive effects on a firm's innovative performance (Chesbrough, 2003; von Hippel, 2010). In particular, licensing-in expands the firm's exploration space (Laursen et al., 2010) and favors the quicker generation of new inventions by licensees (Leone & Reichstein, 2012). The innovative advantages of markets for inventions are particularly salient for firms that search more widely and more deeply (Laursen & Salter, 2006), but the positive impact of this type of search on performance is subject to decreasing returns, suggesting there is a point beyond which further search becomes unproductive.

Further, Almirall and Casadesus-Masanell (2010) suggest that an open approach to innovation, which might include markets for inventions, can allow firms to discover new combinations of product features that would be less likely to emerge if R&D efforts were 'closed'. However, this beneficial effect comes with the drawback of reducing the possibility of firms controlling the trajectory of their innovation processes. An 'open' innovation approach also provides firms with the opportunity to allocate parts of their R&D processes to the entities better suited to perform them, whether internal or external to the organization. For instance, Thomke and von Hippel (2002) emphasize how certain product development stages can be performed more effectively and efficiently if they are outsourced to firms' customers.

Finally, several studies have focused on firm innovative performance and tried to assess whether internal R&D and external knowledge acquisitions are complements rather than substitutes, with most finding evidence of complementary relationships between internal and external R&D (Arora & Gambardella, 1990; Cassiman & Veugelers, 2006). However, the evidence is mixed. For instance, Forman, Goldfarb and Greenstein (2008) use data on nearly 90,000 US establishments which have invested in Internet technologies to show that, in large cities where we expect to find a good supply of external technology services, firms substitute internal for external resources, whereas establishments in more rural areas make more significant internal investments instead. In sum, while companies may still want to keep some internal technological capabilities (to strengthen their bargaining positions as buyers in markets for inventions, or to exploit complementarities with external technologies) these markets also have the natural effect of substituting external suppliers' R&D technological capabilities for internal capabilities.

Discussion

Overall, previous research into the implications of markets for inventions has highlighted the existence of two different routes through which these markets may increase firms' economic performance. On the one hand, firms should specialize in the value chain activity where they have a comparative advantage (e.g., technology generation and selling or technology buying and commercialization), and then contract to gain access to other technologies or to downstream assets as needed. So specialization allows firms to generate higher overall value throughout the value chain, as the overall 'pie' firms produce jointly is larger than it would be if they all internalized both research and commercialization activities (Arora et al., 2001).

On the other hand, to the extent that selling and buying technologies are complements, and internal R&D and external knowledge acquisitions reinforce each other (e.g., Arora & Gambardella, 1990; Cassiman & Veugelers, 2006) , the optimal strategy would seem to be doing both – selling and buying – rather than specializing in just one activity. This is exactly the conclusion reached by studies of open innovation, defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively" (Chesbrough et al., 2006, p. 1). Research in this area emphasizes that profiting from markets for inventions involves simultaneous inbound and outbound innovation flows (Chesbrough & Crowther, 2006).

Interestingly, this puts the two research streams at odds. The central tenet of the literatures on markets for ideas and markets for technology stresses the vertical specialization of upstream technology suppliers, which only produce and sell inventions, and downstream manufacturing firms, which only buy and market them. In contrast, the main argument of the open innovation literature is that firms should pursue simultaneous inbound and outbound innovation in an 'open' manner. That is, they should use external knowledge internally, on the one hand, but also exploit their internal knowledge by selling or sharing it, on the other (Chesbrough, 2003).

The reason behind these different conclusions probably relates to the different conceptual focus from which these two research streams look at the phenomenon of markets for inventions. Research on markets for technology and markets for ideas, being more economics oriented, analyzes the issue from a more macro perspective. It builds on the central concept of comparative advantage, assuming that small and large firms are naturally endowed with different capabilities in inventing and commercializing and that both types will gain from specializing in the activity in which they are relatively more efficient, and therefore use market trading (e.g. Arora et al. 2001). However, this might only be optimal for small firms in the short term, while they are at their weakest and cannot modify their capabilities, and so the differences in relative advantages persist. If, instead, we take a long-term perspective, restricting their activities on the basis of their innate comparative advantages condemns small firms with low bargaining power to the fate of always only being able to appropriate the smallest slice of the overall pie created in any transaction. Hence, from a dynamic point of view, such small firms should probably try to 'defy' their comparative advantage, and invest in the development or acquisition of downstream assets. This argument is somehow implicit in the open innovation literature, which, taking a firm-level perspective instead, suggests companies should put themselves in a position where they can be active as both technology buyers and sellers (e.g. Chesbrough, 2006).

To make a comparison, the main idea of the research on markets for technology and markets for ideas is that firms should exploit their *comparative advantage*, while the main idea of the research on open innovation is that firms should make decisions on the basis of their *competitive advantage*. According to the open innovation literature, in order to be successful, knowledge-based companies should *both* buy *and* sell technologies. This stream therefore proposes that companies should invest in developing their R&D capabilities, in order to be able to assess the value of external technologies and understand which internally-developed technologies should be sold (e.g. Chesbrough, 2006). At the same time, to the extent that most profits accrue to firms operating in the downstream markets, all firms should acquire the marketing capabilities to commercialize inventions. Overall, given the opposite conclusions reached by these literatures, a key research question concerns the extent to which, and the contingencies under which, specialization is more or less beneficial than an 'ambidextrous' open-innovation approach.

Expanding Research on Markets for Inventions:

Market for Inventions and R&D Allocation Strategies among Technologies

A natural consequence of markets for inventions is that they provide firms with more technologies from which to choose, as the scale of a market is inevitably larger than that of a single firm. In turn, this makes the decision of which technological paths to select and develop for firms' competitive advantage particularly salient. However, previous research on markets for inventions has generally overlooked this topic. Certainly, some relevant prior contributions have investigated how firms' R&D choices are endogenous to the existence of markets for inventions, which might actually influence both the direction and intensity of firms' R&D activities (e.g., Gambardella & McGahan, 2010; Gans & Stern, 2003). But we still lack a fuller understanding of how these markets affect firms' decisions about how best to allocate R&D resources between distinct technologies to maximize their overall returns on their R&D investment.

When confronted with the problem of allocating resources among different technologies, firms can adopt an *extensive* strategy, and invest resources in a wide variety of technologies, or an *intensive* strategy and commit to just one or a few (or even no one). Given the scarcity of firm resources, the decision between these strategies is crucial for knowledge intensive companies, regardless of the existence of markets for inventions, but it becomes more relevant when such markets are developed and well-functioning, and pose both opportunities and threats for companies. On the one hand, information asymmetry and potential opportunistic behavior of market counterparts (e.g., Arora et al. 2001; Arrow, 1962) means the likelihood of investing in poor inventions might increase when they are acquired externally. On the other hand, the division of innovative labor and the rise of a class of suppliers with superior technological capabilities (Arora & Gambardella, 1994a) mean the likelihood of picking extremely valuable inventions also increases.

However, extant research on R&D allocation strategies generally builds on the assumption that the alternative technologies to be evaluated and developed are generated within firm boundaries, which is unrealistic in a world where, increasingly, inventions are traded or even freely shared. To understand the implications of relaxing this assumption, we begin by briefly categorizing and reviewing the main streams of existing research into R&D allocation strategies. We then explore how the existence of markets for inventions changes the scenarios considered by these streams of research and, based on this, we identify and provide some preliminary answers to the emerging research questions.

A categorization of R&D Allocation Strategies

Different streams of research have investigated the R&D allocation problem from different conceptual angles and at different levels of granularity: the economics literature on R&D investments (e.g. Nelson, 1961), multimarket contacts (e.g., Bernheim & Whinston, 1990), and industry structure (Bresnahan & Gambardella, 1998; Sutton, 1998); and the strategy literature on real options (e.g. McGrath, 1997), commitment (e.g. Caves, 1984; Ghemawat, 1991), and incentives (Stern, 2004; Rotenberg & Saloner, 1994). These streams of research have developed separately, reflecting their focus on different theoretical assumptions. To be more precise, we identify two major groups of studies in extant research.

A first group of studies has focused on understanding R&D allocation decisions in scenarios characterized by uncertainty about the value of different technologies. Contributions in this area recognize that a portion of a firm's resources needs to be devoted to technology evaluation to guide its subsequent development investments. So research in this group has investigated the number of technologies that firms should experiment with in order to evaluate them and identify which are worth eventual development, and the literature's overarching research question in this area is: How does uncertainty affect the optimal R&D allocation into technology evaluation?

A second group of studies has focused instead on analyzing firms' R&D allocation decision in scenarios without uncertainty, possibly because firms have already evaluated the available technologies. In such situations, firms (naturally) choose to develop those technologies which promise maximum profitability, so allocation choices are mainly affected by the structure of returns to development investments. This structure is characterized both by the shape of potential returns to investment in any single technology (which can be linear, increasing or decreasing), and the extent of complementarities among multiple technologies. Thus this literature has focused on addressing the research question: How does the structure of investment returns affect the optimal R&D allocation aimed at technology development?

Figure 2 provides a pictorial synthesis of the multiple research streams on R&D allocation strategies, and considers the simplest situation where a firm faces the choice of investing in either or both of two possible technologies, A and B.

Insert Figure 2 about here

In a first scenario (investigated by research on technology evaluation, and shown in the upper part of the figure), firms are confronted with uncertainty about the value either technology could generate if developed. Investing in their development requires solving that uncertainty, but this may be particularly difficult: R&D investments inevitably deal with exploring the unknown (Mowery & Rosenberg, 1982, Rosenberg, 1996). Literature suggests the key contingency determining the choice between extensive and intensive evaluation strategies (i.e. evaluating many or few technologies) is the nature of the uncertainty involved, whether it is endogenous or exogenous (McGrath, 1997).

Endogenous R&D uncertainty refers to uncertainty that can be reduced by firm actions, which tends to lead to pressure to invest immediately. Part of the economics literature on R&D investments focuses on situations characterized by this type of uncertainty and suggests that firms will adopt *extensive* strategies in such cases, making small scale investments in both technologies, aimed at discovering their underlying value (e.g. Loch, Terwiesch & Thomke, 2001; Nelson, 1961). Exogenous R&D uncertainty, in contrast, refers to uncertainty that cannot be reduced by firm action, regardless of the amount of resources invested. Research on real options focuses on this circumstance, suggesting that firms could choose not to invest at all and waiting for the uncertainty to be resolved (e.g. McDonald & Siegel, 1986). As this strategy implies zero spreading of resource investment across multiple technologies, it could be thought of as an extreme example of the *intensive* strategy.

In a second scenario (investigated by research on technology development, and shown in the lower part of the figure), firms know the value of each technology – their problem in this case concerns how many technologies to develop to maximize their overall returns. Under certain circumstances the solution is straightforward and, as such, has not been analyzed by extant literature (and, consequently, not considered in Figure 2). For instance, if only one technology (e.g., A) promises a positive return, a firm will invest all resources in that; or, if investments in technologies A and B seem to offer negative returns, it will choose not to invest at all. Extant research has focused instead on analyzing firms' decisions in the presence of positive marginal returns of multiple technologies: here the optimal investment choice becomes more complex, and may involve investing in single or plural technologies according to the structure of expected returns.

Specifically, firms are likely pursue an *extensive* R&D allocation strategy (i.e. invest in both technologies), in the presence of decreasing returns from investing in each or when they can identify potential complementarities between technologies. Decreasing returns imply that, after a certain level of investment in the most profitable technology, the marginal return will become inferior to that on the second most profitable one. Eventually, a firm will invest in both technologies. A similar outcome will be observed where the technologies are complementary, since developing both technologies simultaneously will be more profitable than developing them separately. But if returns to developing each technology are linear or increasing, or in the presence of diseconomies of scope, firms are likely to pursue an *intensive* allocation strategy, investing all their investment resources in the technology offering the highest marginal returns. The key contingencies determining the structure of returns as identified by prior research include the nature of incentives (e.g., Rotenberg & Saloner, 1994; Stern 2004), of competitive factors (e.g., Bernheim & Whinston, 1990; Ghemawat, 1991), or of the technology itself (e.g., Bresnahan & Gambardella, 1998; Cockburn & Henderson, 1996)

Technology Evaluation

Extensive Strategies for Technology Evaluation

In the face of endogenous uncertainty, firms will generally experiment with multiple technologies, aiming to discover their comparative values. Existing research suggest firms can use two main approaches for this purpose: parallel (e.g. Nelson, 1961) or sequential (e.g. Loch et al., 2001) strategies.

Parallel strategy. A parallel investment strategy (Nelson, 1961) consists of investing a limited amount of resources across multiple technologies, so conducting parallel 'trials', in Nelson's words. Nelson's article focuses on the optimal number of technologies a firm can consider in parallel in order to identify the most valuable. In his model, firms face a choice between different technologies each associated to a different outcome. In the face of uncertainty, even if the overall distribution of different outcomes may be known (i.e., that only a certain percentage of new technologies will turn out to be valuable), they don't know which ones will without conducting trials. In other words, the outcome associated with a certain technology can only be revealed after a certain amount of resources have been invested in testing it. Certainly, the more technologies are tested, the greater is the likelihood that at least one will exceed a critical value level – such as the level above which it is profitable to develop the technology and commercialize the associated innovation.

In the scenario Nelson (1961) describes, one obvious variable determining the optimal number of technologies is the cost of experimenting with each new technology: given the firm's resource constraints, the lower the cost of any trial, the more than can afford to run. Nelson's model also considers the role of statistical interdependency between technologies, that is, whether their outcomes are correlated. Correlation between technologies reduces the number of technologies that need to be tested. For instance, if a given technology is bad, it is more likely that a second similar and so positively correlated technology will also be bad. In contrast, if the technologies are different and so statistically independent, the outcome of the second technology cannot be so predicted.

Several papers, especially over the last decade, have drawn on Nelson's original contribution to develop different angles on the parallel research process. We consider a few. Dahan and Mendelson (2001) generalize Nelson's intuition by studying the underlying properties of outcome distributions in greater detail. Specifically, they study how the optimal number of technologies (which they call "tests") changes according to the distribution's parameters. They find it increases with the variance in the technology value distribution and with the extent to which the distribution has fat tails or a higher upper bound, as they all imply a higher likelihood that any one technology will deliver an extremely high outcome. As the expected value of the best technology increases, the firm is more willing to invest resources in additional technology.

Boudreau, Lacetera and Lakhani (2011) propose a test of the benefits a parallel approach can provide. Specifically, they apply Nelson's (1961) argument in the empirical context of tournament-like contests, and consider the impact on innovation output when a new competitor enters and brings a new alternative technology to the competition. They argue that such an addition might increase the value of the best solution identified, even if the individual effort put in by each contestant decreases in line with the lower probability of being the winner. Interestingly, they also show that, when the competition occurs in an uncertain technological field (which means more variance in the technology value distribution), the increase in the value of the best solution due to the entry of a new competitor is even greater. As a result, they provide empirical evidence that the benefits to a firm of a parallel technology strategy substantially increase with the level of uncertainty.

Sequential strategy. An alternative approach in the face of endogenous uncertainty is to invest in different technologies sequentially. This approach is based on the idea that testing alternative technologies over time, rather than in parallel, provides additional information that guides the direction of subsequent tests. Loch et al. (2001) compare the relative advantages of parallel and sequential testing of alternative technologies. The main benefit of parallel testing over sequential testing is that it reduces the time required to acquire information and thus for discovering the best technology. This aspect might be particularly important in the context of an R&D 'race', where firms aim to be the first to have the patent granted, as the first able to reach the market will capture the lion's share of rents (e.g., Cockburn & Henderson, 1994). But in a parallel testing approach, firms cannot use learning from earlier tests in later ones, a benefit provided by sequential testing (see also Thomke & von Hippel, 2002), so parallel testing tends to involve more tests, and thus greater costs.

Loch et al.'s (2001) model yields some important implications. First, when tests are more expensive, sequential testing is the favored response: but if the trials take time, or if the firm's opportunity costs of time are high, they will prefer parallel testing. Second, trials may vary in their quality, in the sense that there may be a difference between the test outcome and the real value of the design or technology chosen, and firms may be aware of this. The more imperfect the trials are the lower is the appeal of the parallel testing process, because the 'noise' of experimentation makes each test less informative. Third, modularity in the underlying design or technology reduces testing costs, as it reduces the number of configurations that have to be tested. In all, Loch et al.'s (2001) model concludes that the optimal investment solution might involve a combination of parallel and sequential testing, in which batches of multiple designs or technologies are tested sequentially, starting with those with the highest ex-ante probability of success.

Intensive Strategies for Technology Evaluation

When uncertainty is exogenous, firms' actions cannot reduce it. In this case, a dominant strategy is to wait for the resolution of uncertainty. This strategy has been suggested by real option theory, which originated in the context of financial options (Black & Scholes, 1973).

Options to defer and to grow. An option gives its owner the right (but not the obligation) to purchase an underlying asset in the future – an option's value increases with the uncertainty a firm faces, or, more precisely, with the volatility of the expected value of the underlying asset (Dixit & Pindyck, 1994). The key mechanism is that the sunk cost of the option limits the potential losses of the investment, while the potential gains are unlimited, and will increase in line with the uncertainty of the investment returns. In the context of the choice between technologies, a strategy consisting of not investing in any technology can be seen as an "option to defer" investment (Huchzermeier & Loch, 2001; McDonald & Siegel, 1986). The cost of the option is the foregone benefit that the firm would realize had it invested immediately. If this cost is too high, firms might consider the strategy of investing the lowest amount of resources in each technology required not to lose the opportunity to invest in the future: this would constitute a "growth option" (Kulatilaka & Perotti, 1998).

Whether firms facing exogenous uncertainty about the potential future value of a technology should simply defer investment or make very limited investments instead depends, first, on the cumulativeness of R&D – that is, the extent to which future R&D opportunities are contingent on early R&D investments (Malerba & Orsenigo, 1997). Second, this choice may depend on the specific characteristics of the investing firm. A ‘ wait-and-see’ strategy may be more appropriate for fast followers or fast seconds (Markides & Geroski, 2005) who have superior R&D capabilities and thus execute projects faster than competitors, and so can afford to wait longer for uncertainty to be resolved. Third, it might depend on the presence of preemption risks, due, for example, to network effects. When these effects are strong, the growth option value is likely to be greater that the deferral option value (Lin & Kulatilaka, 2007). The choice is also contingent on the level of uncertainty. In particular, Folta and O’Brien (2004) argue that, when uncertainty levels are very high, investing immediately is more valuable than waiting, since the maximum value of an option to defer is bounded, but the maximum value of a growth option is not.

Future Research Directions: Markets for Inventions and R&D Allocation Strategies for Technology Evaluation

The existence of markets for inventions calls for the conclusions reached so far by the literature on technology evaluation to be re-examined, and opens several research avenues. The key research question is how markets for inventions affect the choice between extensive and intensive strategies for technology evaluation in the face of endogenous or exogenous uncertainty. Overall, we suggest that the development of such markets might increase the benefits of waiting strategies for integrated downstream firms, because – even when uncertainty is endogenous - they can shift the burden of its resolution from buyers to technology suppliers. The investment of technology suppliers allows downstream firms in the Silicon Valley computer industry, for instance, to wait until uncertainty is resolved, and then buy the most suitable technology for their purposes (Baldwin & Clark, 2000).

Future research should also attempt to corroborate empirically the suggested relationship, and to clarify the contingencies under which it is stronger or weaker. For instance, in the face of competition, investing earlier and pre-empting competitors may be crucial and the strategic choice of waiting might be less attractive in general. However, waiting might be relatively more attractive for firms who are more likely to secure a contract with suppliers providing the most valuable technologies, because they hold higher reputations or scarce and valuable downstream resources.

Furthermore, firms have an incentive to wait only to the extent that markets for inventions are transparent about the characteristics and potential value of technologies for potential buyers, as is the case in the software industry, where the potential value of the technologies software start-ups produce can be demonstrated relatively simply through demos (Greenberg, 2013). But in other industries (e.g. nanotechnology), where technologies are more complex, companies may not be able to resolve uncertainty until they buy the technology and start experimenting with it. In these cases, they can only resolve uncertainty endogenously, using parallel or sequential approaches. In this regard, another possible research direction would be to explore how the existence of markets for inventions affects investing firms' choices between parallel and sequential strategies. In principle, the development of a market for inventions reduces the cost of any deal, by increasing the supply of technologies, and so lowering the price of inventions, which favors a parallel strategy over a sequential one. And when suppliers in the market are more independent, a parallel approach would also be more effective. These factors suggest that, other things being equal, a parallel approach is more likely to emerge when technology suppliers do not share a common milieu, such as a similar geographic location.

Finally, our reasoning so far builds on the assumption that, in the face of uncertainty, some firms will invest earlier than others and so become technology suppliers. But this raises another question about which firms have the superior risk bearing ability that would allow them (in the face of uncertainty) to invest and generate technologies to sell on the market in the first place. For instance, those firms with a superior ability to evaluate uncertainty – or to influence its resolution – even when such uncertainty is exogenous for other firms in the industry might be more likely to develop and trade new technologies. Future research might usefully investigate the issues to find empirical support for them.

Technology Development

Extensive Strategies for Technology Development

When there is no uncertainty about the value of different technologies, firms do not need to engage in their evaluation. The literature identifying R&D investment strategies in the absence of uncertainty again falls into two groups according to the choice between extensive and intensive investment strategies. The first group focuses on contingencies that make it convenient for firms to invest and develop multiple technologies simultaneously – that is, to choose more extensive forms of R&D allocation.

R&D complementarities. A primary reason to invest in multiple technologies is the existence of R&D complementarities between those technologies, which often follows from the nature of the knowledge field(s) in which firms operate. For instance, Cockburn and Henderson (1996) show that, in the pharmaceutical sector, knowledge developed in a specific therapeutic area can be usefully applied in another area, because human body systems do not usually operate in isolation. Complementarities may also be firm-specific, and some organizations are better equipped with organizational practices and routines aimed at combining and redeploying knowledge (Hargadon & Sutton, 1997).

Competitive considerations. From a competitive standpoint, the returns to pursuing multiple technologies targeted to different markets increase due to weaker competition: multimarket competition literature (Karnani & Wernerfelt, 1985; Porter, 1980; 1985) suggests that companies can benefit from competing with rivals across several markets because this reduces the intensity of rivalry, improving all firms' profitability (for a review see Chen & Miller, 2012). The structure of competitive relationships may be stabilized by a "live-and-let-live" policy (Bernheim & Whinston 1990; Scherer, 1980), so that rivalry extending across multiple markets leads to mutual forbearance, and markets whose participants compete simultaneously in other markets can mutually agree to set higher prices and thus all achieve greater profitability (Gimeno & Woo, 1996; 1999). These findings confirm the idea that firms might find it valuable to enter several markets to gain interdependencies with their rivals. However, as a firm's multimarket contacts grow, the losses that can be expected from the possible retaliation by a competitor who interprets the entry of a focal firm as an aggressive move will also increase (Baum & Korn, 1996).

Incentives. The design of employees' incentives may also lead firms to pursue multiple technologies. Scientists and researchers enjoy having autonomy to develop any technology they are interested in, and may even accept lower remuneration to retain that creative autonomy, increasing firm profitability (Stern, 2004). At the same time, firms where individual employees are given the latitude to develop new technologies are likely to purse more extensive R&D allocation strategies than firms where a single decision-maker picks which technologies are to be developed. As a result, individual scientists' preference for autonomy may indirectly create economies of scope. By allowing employees to retain their autonomy, firms generate multiple diverse technologies and wage costs are reduced (Stern, 2004).

Intensive Strategies for Technology Development

A second group of studies focuses on those factors that make returns on investing in few technologies (or even one) more convenient, in other words, where firms adopt more intensive strategies. The most immediate reason concerns the existence of linear or increasing returns to investment in a single technology.

Economies of scale at the R&D level. In the simplest case, such linear or increasing returns are due to the nature of the technology itself. For instance, cumulative investment in a specific technology may increase firm performance due to its specialized learning over time (Ghemawat, 1984; Spence, 1979). Especially when the technology is radically new, its development might require a great amount of managerial attention (Ocasio, 1997). Major investment in a unique technology can serve as a valuable mechanism for focusing managerial attention, which previous research has shown to be quite a valuable resource for the company (Eggers, 2012). On the other hand, as Sutton (1998) and Bresnahan and Gambardella (1998) point out, some technologies might produce multiple applications at a zero or low marginal cost, which creates incentives to concentrate resources on their development, and to reutilize them in multiple submarkets, rather than spreading resources across several technologies each dedicated to a specific submarket.

Competitive considerations. The dynamics of competition may also explain increasing returns from investing resources into a single technology. Literature on commitment has suggested that 'locking-in' a large amount of resources into the development of one, market-specific, technology can reduce rivalry from competitors, mainly due to resource pre-emption and the consequent creation of entry barriers (e.g. Caves, 1984; Ghemawat, 1991; Katz &

Shapiro, 1994). And certain technologies are characterized by network effects, such that individuals' utility from using them increases with the numbers of other users. Thus, consumers prefer to adopt the technology they believe will be adopted by the majority of other consumers. In such cases, a major investment in a technology can be a signal of strong commitment and create favorable expectations about its future market size, staring a 'virtuous circle' of user growth.

Incentives. Commitment may also be important for providing firms' scientists with the right incentives to increase their productivity. Rotenberg and Saloner (1994) argue that pursuing multiple technologies create diseconomies of scope in R&D by reducing employees' motivation. The basic intuition is that returns generated by a firm's R&D investment depend, among other factors, on the effort exerted by individuals within the organization, and the level of those efforts may depend on the expectations that they will be well rewarded. But this will only occur if those ideas are implemented, which is less likely where many technologies compete for a limited amount of firm resources. So, in order to convince employees to exert more effort and increase productivity, firms should only commit to investing in a limited number of technologies.

Future Research Directions: Markets for Inventions and R&D Allocation Strategies for Technology Development

As we have noted, once uncertainty is resolved, firms should choose an intensive or an extensive R&D allocation strategy for developing a technology according to various factors, including the existence of increasing returns to scale and complementarities among technologies, competitive considerations and optimal internal incentive design. Hence, the question is: How do markets for inventions affect this decision?

As far as R&D complementarities are concerned, markets for inventions allow firms to access a broader range of different 'pieces' of knowledge, which can be fruitfully recombined to increase innovative performance (e.g. Chesbrough, 2003; 2006; Leiponen & Helfat, 2011). The opportunities for knowledge recombination and cross-fertilization that markets can produce are likely to be higher than when R&D is just conducted internally. Path dependency means that firms tend to continue to invest in the same or related technological trajectories (Cohen & Levinthal, 1989; Nelson & Winter, 1982), so solutions generated within a firm are likely resemble one another, and there is little room for recombination. In contrast, technologies pursued by distinct firms are likely to differ (Cohen & Malerba, 2001). However, an important question unaddressed by previous research concerns the extent to which firms may be able to recombine external as opposed to internal technologies, or to accurately assess the existence of synergies – or of diseconomies of scope – in managing multiple technologies in whose development that have not been closely involved. We suggest that, to evaluate the opportunities markets for inventions offer for technology development, future research should investigate more closely the extent to which the benefits from diversity exceed the costs.

As for competitive considerations, we argue that markets for inventions can facilitate the acquisition of different technologies targeted at specific markets, or even of general technologies applicable to multiple markets, and thus provide firms with opportunities to manipulate the degree of their competitive interdependence with rivals more quickly, through a multi-market contact strategy (e.g., Bernheim & Whinston, 1990). This provides an interesting starting point, from both a theoretical and empirical standpoint, for future research. The existence of markets for inventions might also affect the design of firms' R&D incentive structures. As mentioned above, Rotenberg and Saloner (1994) point out that committing to allocate resources to a limited number of technological areas improves R&D

employees’ incentives to invent, by increasing the likelihood that each employee’s ideas will be adopted, and the employee rewarded accordingly. But when internally generated ideas compete to be adopted with external ones, such an incentive strategy may not be credible enough to employees to be effective. Consequently, an interesting question for future research concerns how markets for inventions might affect the levels and types of incentives technology firms offer their scientists to innovate.

Conclusions

In this paper, we have provided a unifying framework for understanding the existence and growth of ‘markets for inventions’, where knowledge elements which are disembodied from individuals, organizations and products are traded. In order to do so, we have brought together various streams of literature, which, due to their different assumptions, have focused on different aspects of the phenomenon. Furthermore, we pointed out that extant literature in this area has generally neglected the implication of invention markets for firms’ decision about how to allocate resources among different technologies. Given the lack of research on the topic, we started to establish and explore the link between markets for inventions and firms’ R&D allocation strategies, and to identify a research agenda in this domain.

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TABLE 1
Summary of Selected Papers on the Definition of Markets for Inventions

Author(s), publication year	**Key dimensions considered in connection with markets for inventions**	**Method**	**Key findings**
Arora, Fosfuri & Gambardella, 2001	Invention price	Theoretical model & Quantitative analysis	Knowledge-based companies increasingly use markets for technology, arms-length transactions that involve the exchange of technology in disembodied form for a price
Chesbrough & Appleyard, 2007	Invention price	Theoretical model	Firms might adopt a partial free revealing approach, such that only one part of the invention is free but the other part needs to be bought
Chesbrough, 2003; Chesbrough, Vanhaverbeke &West, 2006	Invention price	Theoretical model & Quantitative analysis	Firms and industries experiment with novel business models based on open innovation, which include forms of knowledge sharing occurring both within and outside markets
Gans & Stern, 2003	Invention price	Theoretical model	Start-ups innovator can compete indirectly in the product market by using a “cooperation” strategy, based on selling their inventions to other firms—usually incumbents—who operate as "conduits" for technology commercialization in the product market
von Hippel, 2010	Invention price	Theoretical model	Individual users often freely reveal their knowledge because they want gain reputation among their peers or because they would like to see their ideas transformed into innovations
Arora & Gambardella, 1994a	Knowledge Codification & Division of Innovative Labor	Theoretical model	The production of general and abstract knowledge, due to advancements in theoretical understanding of problems, instrumentation, and computational capability, increases the possibility of division of innovative labor among firms
Kogut & Zander,	Knowledge Codification & Division of Innovative Labor	Theoretical Model	Tacit knowledge is shared and transferred more effectively within firms than across markets
Nonaka, 1991	Knowledge Codification & Division of Innovative Labor	Theoretical model	Tacit knowledge can typically be transmitted through social interactions occurring within the boundaries of a given organization, where individuals can easily interact face-to-face, and share common “languages”
Winter, 1987	Knowledge Codification & Division of Innovative Labor	Theoretical Model	Firms can choose strategically the extent of knowledge codification, based on the opportunities they have to collaborate with unaffiliated entities
Baldwin & Clark, 2000	Knowledge Codification & Division of Innovative Labor	Theoretical model	Firms shifting toward a more modular system may take advantage of modular innovations produced by many independent suppliers
Baldwin & von Hippel,	Knowledge Codification	Theoretical model	Modular design architecture are an important element to facilitate collaboration. Modularity

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
2011	& Division of Innovative Labor		tends to affect design and coordination costs
Brusoni & Prencipe, 2001	Knowledge Codification & Division of Innovative Labor	Theoretical model	Firms are heterogeneous in their ability to explore and experiment alternative patterns of problem decomposition
Langlois, 2002	Knowledge Codification & Division of Innovative Labor	Theoretical model	Modularity constitutes a way of managing complexity. Organizations reflect non-modular structures and decision rights, rights of alienation, and residual claims to income reside among different firms
Sanchez & Mahoney, 1996	Knowledge Codification & Division of Innovative Labor	Theoretical model	Modular systems allow a form of coordination which is alternative to authority, i.e. embedded coordination. Embedded coordination is a form of system coordination based on standardized components and organizational interfaces, that creates information structures. Modularity requires codification of architectural knowledge about component interactions
Schilling, 2000	Knowledge Codification & Division of Innovative Labor	Theoretical model	Modularity is a continuum describing "the degree to which a system's component can be separated and recombined, and it refers both to the tightness of coupling between components and the degree to which the "rules" ol the system architecture enable (or prohibit) the mixing and matching of components"

TABLE 2
Summary of Selected Papers on the Determinants of Markets for Inventions

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
Aggarwal & Hsu, 2009	Institutions	Quantitative analysis	The frequency and intensity of prior relationships contribute to build trust between partners and can exert a positive effect on the likelihood that they engage in further transactions
Anand & Khanna, 2000	Institutions	Quantitative analysis	There exist robust cross-industry differences on several contractual features (exclusivity, cross-licensing, ex ante vs. ex post technology transfers, licensing to unrelated vs. related parties)
Arora, 1995	Institutions	Theoretical model & Quantitative analysis	The provision of technical service (i.e., tacit knowledge) can increase the enforceability of technology licensing contracts
Arora, 1996	Institutions	Theoretical model & Quantitative analysis	Bundling complementary inputs with know-how in a technology package can overcome the problems in contracting for know-how
Arora & Ceccagnoli, 2006	Institutions	Quantitative analysis	Increases in the effectiveness of patent protection increase licensing propensity, but only when the firm lacks specialized complementary assets required to commercialize new technologies
Arora, Fosfuri & Gambardella, 2001	Institutions	Theoretical model & Quantitative analysis	Markets for technology are more likely to be observed in environments characterized by strong IPR regimes
Arrow, 1962	Institutions	Theoretical model	Indivisibility, appropriability and uncertainty constitute sources of market for knowledge failures
Berkovitz & Feldman, 2008	Institutions	Quantitative analysis	Knowledge transfer decisions are affected by norms. Individuals tend to adhere to norms to which they have been exposed in the past, but are also influenced by the local work environment
Caves, Crookel & Killing, 1983	Institutions	Quantitative analysis	Markets for intangible knowledge are subject to market failures deriving from: small-numbers bargaining, appropriability problems, uncertainty, transaction costs, and impacted information coupled with opportunism
Chesbrough, 2003; Chesbrough, Vanhaverbeke &West, 2006	Institutions	Theoretical model & Quantitative analysis	Open innovation occurs also in contexts beyond the ones in which formal intellectual property rights are relevant

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
Dyer & Singh, 1998	Institutions	Theoretical model	Firms can substitute or complement contract design mechanisms with relational ones in order to avoid market failures due to opportunism. Such relational mechanisms are self-enforcing agreements that do not require a third party to enforce them
Fauchart & von Hippel, 2008	Institutions	Qualitative and Quantitative Analysis	Norms-based intellectual property (IP) systems are a complement to or substitute for law-based IP system
Gans & Stern, 2003	Institutions	Theoretical model	Firms' choice of their technology commercialization strategy depends on the level of excludability of the environment
Gans, Hsu & Stern, 2008	Institutions	Quantitative analysis	From the buyer's perspective, reductions in uncertainty surrounding the scope and extent of IP rights may facilitate trade in the market for ideas
Hall & Ziedonis, 2001	Institutions	Quantitative analysis	Strengthening of patent rights induces "patent portfolio races" among capital-intensive firms and facilitates entry by specialized design firms
Kulatilaka & Lin, 2006	Institutions	Theoretical model	Due to cash-constraints issues, small firms might prefer to be paid with a fixed sum rather than with royalty rates
Pisano, 1990	Institutions	Quantitative analysis	Small-number bargaining problem might lead firms to internalize R&D. Hence pharmaceutical companies are more likely to internalize R&D in those biotechnology product areas in which R&D capabilities are concentrated in fewer R&D supplier
Shane, 2002	Institutions	Quantitative analysis	University inventions are more likely to be licensed when patents are effective. Patent effectiveness also increases the royalties earned for inventions licensed to non-inventors, as it reduces the risk of opportunistic behaviors
Somaya, Kim & Vonortas, 2010	Institutions	Quantitative analysis	Exclusivity is used as a contractual hostage to safeguard licensees' investments in complementary assets and to enable contracting over early stage technologies
Teece, 1998	Institutions	Theoretical model	Profits from knowledge assets depend on interplay between the strength of the appropriability regime and firm dynamic capabilities
Arora, Fosfuri & Gambardella, 2001	Firm Characteristics	Theoretical model & Quantitative analysis	Markets for technology foster the division of innovative labor between small and large firms
Arora & Gambardella, 1994b	Firm Characteristics	Theoretical model & Quantitative analysis	Firms with a greater ability to utilize demand more external technologies (i.e., are more likely to license in new technologies). However, firms with a higher ability to evaluate may acquire fewer external technologies
Arora, Fosfuri & Roende, 2013	Firm Characteristics	Theoretical model	When licensing decisions are decentralized to business units, rather than centralized at headquarters, firms are less likely to license, because top managers reward divisions less for

Author(s), publication year	**Key dimensions considered in connection with markets for inventions**	**Method**	**Key findings**
			their licensing profits than for their (more easily observed) production profits
Ceccagnoli & Jiang, 2013	Firm Characteristics	Quantitative analysis	The buyers' cost of integrating a licensed technology is affected by suppliers' knowledge transfer capabilities, buyers' absorptive capacity, and the co-specialization between R&D and downstream activities in the buyers' industries
Chesbrough, 2003; Chesbrough, Vanhaverbeke &West, 2006	Firm Characteristics	Theoretical model & Quantitative analysis	Organizational practices may foster knowledge exchange
Dodgson, Gann, Salter, 2006	Firm Characteristics	Case study analysis	Firms' external search processes are fostered by their possession of relevant information technologies capabilities
Fosfuri, 2006	Firm characteristics	Quantitative analysis	The licensing-out of technology entails a trade-off: licensing payments net of transaction costs (revenue effect) must be balanced against the lower price–cost margin and/or reduced market share implied by increased competition (profit dissipation effect) from the licensee. Firms with a small market share are more likely to license out than larger firms because they suffer a smaller loss in profits from the increase in rivalry
Gambardella, Giuri & Luzzi, 2007	Firm Characteristics	Quantitative analysis	The most important determinant of patent licensing is firm size. Other factors (patent value, breadth, protection) have an impact, but not as important
Henkel, 2006	Firm Characteristics	Quantitative analysis	Firms balance openness and protection of intellectual property by revealing knowledge selectively. Revealing policies are strongly heterogeneous across firms
Laursen, Leone & Torrisi, 2010	Firm Characteristics	Quantitative analysis	Firm assimilation capacity and monitoring ability affects the decision to explore distant technologies through licensing-in
Rivette & Kline, 2000	Firm Characteristics	Theoretical model	Companies increasingly use patents for making revenues (with licensing out) or blocking competitors. Large companies may use licensing for making profits out of relatively unused inventions
Sakkab, 2002	Firm Characteristics	Case study analysis	Maintaining effective connections requires an information management strategy based on knowledge sharing reporting systems
Sine, Shane & Di Gregorio, 2003	Firm Characteristics	Quantitative analysis	Institutional prestige and reputation increases the licensing rate of the university, as they tend to solve market imperfections
Anton & Yao, 1994	Industry Structure	Theoretical model	In the absence of legal property right protection, an inventor with little wealth can expect to appropriate sizable share of the market value of the invention by fully disclosing information about the invention value
Arora, Fosfuri &	Industry Structure	Theoretical model	Development of specialized upstream technology suppliers in leading countries improves

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
Gambardella, 2000		& Quantitative analysis	technology access and lowers investment costs for downstream firms in follower countries
Bresnahan & Gambardella, 1998	Industry Structure	Theoretical Model	As market breadth increases, technology specialists will produce general technologies supplied to the downstream producers that operate in different segments of the final market. By contrast, as depth increases, downstream firms are more likely to integrate backward and produce dedicated technologies for their business
Fosfuri, 2006	Industry Structure	Quantitative analysis	The licensing-out of technology entails a trade-off: licensing payments net of transaction costs(revenue effect) must be balanced against the lower price–cost margin and/or reduced market share implied by increased competition (profit dissipation effect) from the licensee. In product markets with more incumbent competitors, both the rent dissipation from the creation of a new competitor, and the revenue from licensing decrease
Gallini, 1984	Industry Structure	Theoretical model	An incumbent firm may license its own technology to reduce the incentive of a new entrant to produce its own, possibly better, technology
Gambardella & Giarratana, 2013	Industry Structure	Quantitative analysis	When product markets are fragmented, innovators can identify potential licensees in market niches in which they do not compete directly. This possibility requires the licensor to develop general technologies that can support distant applications
Gambardella & McGahan, 2010	Industry Structure	Theoretical Model	The development of general purpose technology to be licensed to downstream specialists is an increasingly adopted business model. By developing more general technologies the suppliers can move away their source of returns from bargaining power, to something that they can invest in and control
Grindley & Teece, 1997	Industry Structure	Theoretical model.	Licensing and cross-licensing are increasingly adopted by companies in semiconductors and electronics, as a mean to prevent litigation and soften the cost of competition
Rockett, 1990	Industry Structure	Theoretical model	For an incumbent, licensing agreements can be a mean for ‘choosing’ relatively weak competitors
Scotchmer, 1991	Industry Structure	Theoretical model	In cases where early innovations constitute a foundation for later innovations, the first innovator should be given some claim on the profits of the later innovators, so that the first has enough incentive to invest.. This is possible through increasing patent breadth or allowing (collusive) licensing among patent holders

TABLE 3
Summary of Selected Papers on the Implications of Markets for Inventions

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
Arora & Nandkumar, 2012	Specialization and Trade	Quantitative analysis	A greater supply of technology diminishes the importance of technical ability as a source of competitive advantage, but enhances the impact of marketing capability on performance
Arora, Fosfuri & Gambardella, 2001	Specialization and Trade	Theoretical model & Quantitative analysis	At the firm level, markets for technology increase the strategy space; at the industry level, they lower barriers to entry and increase competition
Chesbrough & Rosenbloom 2002	Specialization and Trade	Theoretical model	Capturing value from early stage technology requires appropriate business models
Galasso, 2011	Specialization and Trade	Theoretical model & Quantitative analysis	Markets for inventions may induce firms' specialization according to their comparative advantage in enforcing intellectual property
Gans & Stern, 2003	Specialization and Trade	Theoretical model	Under certain conditions, markets for ideas allow small firms to avoid knowledge expropriation and appropriate the economics returns from innovation
Gans, Hsu & Stern, 2002	Specialization and Trade	Quantitative analysis	Returns to specialization and cooperation vis a vis competition in the downstream market are increasing in control over IPRs, low transaction costs, sunk cost for market entry
Holmstrom, 1989	Specialization and Trade	Theoretical model	Different organizational structures have diverse advantages in performing innovative activities vis-à-vis more routine activities, like, for example, development and commercialization
Serrano, 2011; Serrano 2010	Specialization and Trade	Quantitative analysis	Gains from specialization and trade exist
Teece, 1986	Specialization and Trade	Theoretical model	When imitation is easy, the profits from innovation may accrue to the owners of complementary assets, rather than to the developers of the intellectual property. Innovators may access these assets through licensing agreements
Almirall & Casadesus-Masanell, 2010	Innovation	Theoretical model	Open approaches to innovation allow firms to discover combinations of product features that would hardly emerge under integration. However this beneficial effect comes with the drawback of reducing firms' possibility of individual firms to take control over the innovation process and in particular over the trajectory taken by such process
Arora, Fosfuri & Gambardella, 2001	Innovation	Theoretical model & Quantitative analysis	By fostering the division of inventive labor, markets for technology increase innovation performance
Chesbrough, 2003; Chesbrough, Vanhaverbeke &West,	Innovation	Theoretical model & Quantitative analysis	Access to internal and external knowledge and simultaneous inbound and outbound of knowledge increase firms' innovative performance

Author(s), publication year	Key dimensions considered in connection with markets for inventions	Method	Key findings
2006			
Chesbrough & Crowther, 2006	Innovation	Theoretical model	Open innovation does not occur only in high-tech industries but also in more established and mature ones. It involves simultaneous inbound and outbound of knowledge
Forman, Goldfarb & Greenstein, 2008	Innovation	Quantitative analysis	In large cities, where we expect to observe a good supply of external technology services, firms substitute internal for external resources. By contrast, establishments make more significant internal investments in professional internet services in more rural areas
Gans & Stern, 2000	Innovation	Theoretical model	When the expected licensing fee is high, incumbents have an incentive to remain active in R&D to feed the outside option of making the technology themselves
Green & Scotchmer, 1995	Innovation	Theoretical model	Markets for inventions may increase the incentive to innovate in sequential innovation contexts, as they encourage cooperative agreements between initial and subsequent innovators decreasing the level of competition among them
Leone & Reichstein, 2012	Innovation	Quantitative analysis	Licensees are faster to invent than non-licensees, but this effect disappears if the licensing contract includes a grant-back clause
Thomke & von Hippel, 2002	Innovation	Theoretical model	Certain stages of product development can be performed more effectively and efficiently if they are outsourced to a firm's customers
West, 2003	Innovation	Theoretical model	There exist a trade-off between strategies maximizing innovation and those maximizing appropriability

FIGURE 1
Structure of the Existing Literature on Markets for Inventions

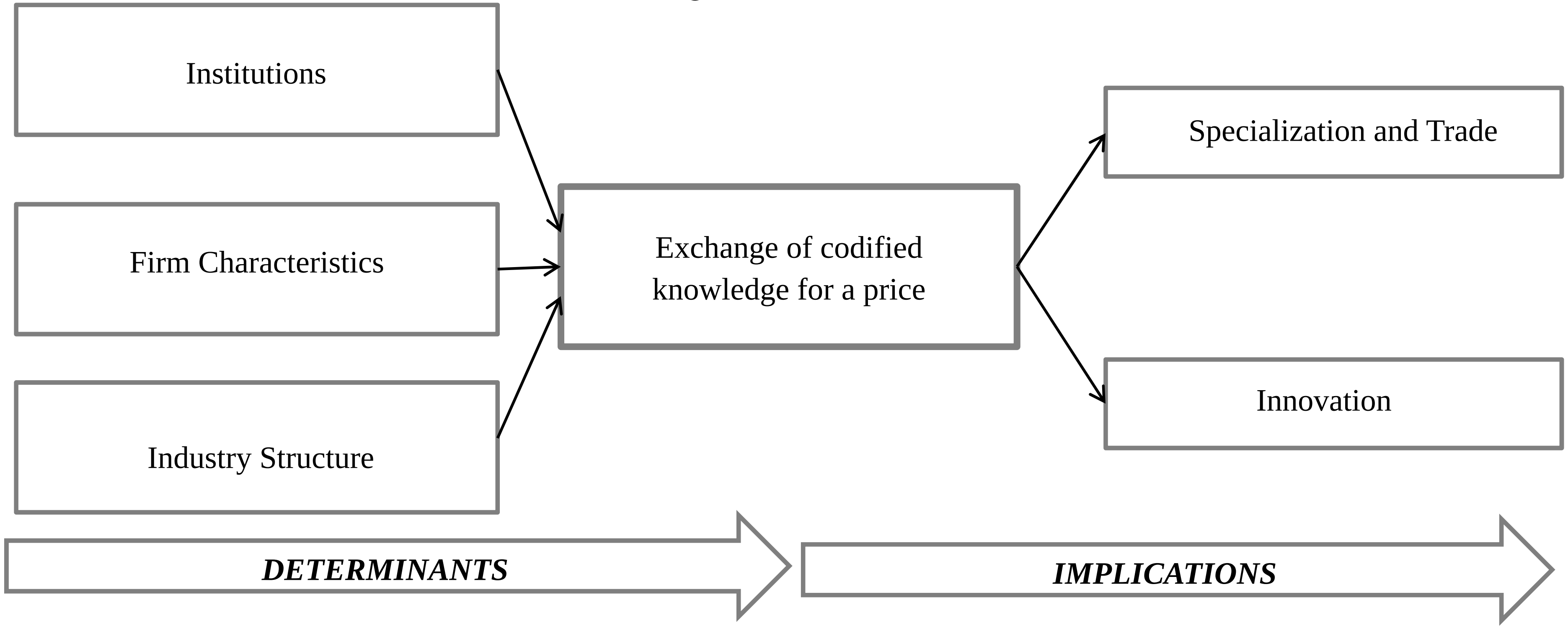

FIGURE 2
Structure of the Existing Literature on R&D Allocation Strategies