

WHEN ATLAS SHRUGGED: PREEMPTION, COMPLEXITY AND DIVISION OF LABOR  
IN A THEORY OF APPROPRIABILITY

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## ABSTRACT

When Atlas Shrugged: Pre-emption, Complexity and Division of Labor in a Theory of Appropriability

I distinguish between primary appropriability, a firm's ability to profit from a given invention, and generative appropriability, a firm's ability to develop subsequent inventions building on its prior inventions. I identify four determinants of generative appropriability and develop a theoretical model to explain variations in the generative appropriability of firms in the global chemicals industry. I find that technological preemption, control of supporting assets and division of labor enhance generative appropriability while complexity diminishes it.

The resource-based view (RBV) presents a fairly compelling and straightforward explanation of the emergence and sustenance of superior performance. A firm originates a process or product that is both valuable and rare, i.e., valuable in the sense that it satisfies some consumer need and creates value; rare in the sense that it is not possessed by its competitors. If the firm has certain isolating mechanisms that limit its competitors' ability to imitate the firm's invention (Lippman & Rumelt, 1982), then the firm thrives in its relatively uncontested space and generates rents (Hitt, Nixon, Clifford & Coyne, 1999; Liebeskind, 1996).

Yet, the reality of competition suggests that a more complex dynamic is at work in most industries, especially technology intensive ones, on at least two dimensions. First, in most industries, imitation is only one possible threat to sustained super-normal profitability; the other threat that is sometimes even more significant is substitution, the satisfaction of the same need through a different route or product (Hitt, Ireland, Camp & Sexton, 2001; Greenstein & Wade, 1998). For instance, in the pharmaceutical industry, imitation threats to a new drug like Lipitor are temporally distant (i.e. generics) – the isolating mechanism of intellectual property rights in the form of patents provides protection. However, substitution threats in the form of other molecules that reduce cholesterol may be much more immediate. Thus, in a technologically active industry, a more likely dynamic that might emerge is that one firm creates an invention; thereafter, instead of this firm being able to rest on its laurels, it may be faced with a competitor that creates a new invention, one that will reduce the added value, and hence profitability, of its original invention. This second invention thus restarts the cycle of competition. Clearly, in such contexts it is not enough to invent; to be competitive firms need to keep on inventing. From this perspective, technological competition is inherently dynamic: what is important is not just a creating a single invention but ensuring instead, a sequence of inventions (Winter, 2004).

To this more complex picture of the competitive process another layer of complexity gets added on when we consider the possibility that the isolating mechanism that protects the first invention may have a less than benevolent effect on the firm's ability to generate succeeding inventions. The literature on knowledge sometimes presumes that, at least for certain forms of knowledge and in certain industrial contexts, isolating mechanisms such as patents can provide the basis for the firm to appropriate the value it has created through its knowledge. Yet, this assumption, while accurate, may be incomplete. Even in environments in which such protection is available and effective, it does not come without a significant cost. Specifically, while patents may confer a property right on knowledge and protect the firm from imitation, they may also increase the firm's exposure to substitution. This double-edged nature of the patenting benefit comes from the fact that in its most elemental form a patent is a two-sided contract – the state provides the inventor with a right of exclusion to exploit the invention, but along with the right comes the obligation of “enabling disclosure”: the state demands that as a condition of providing the inventor with the legal monopoly on the original invention, the inventor disclose the knowledge required to create that invention to society. The competitive implication of enabling disclosure then is that if an interested party wants to compete in a firm's technology domain, an analysis of the firm's patented efforts can help to educate them and potentially increase their ability to compete with the firm. Indeed, in the context of the technology dynamic described earlier, such an informed competitor could possibly even beat the firm in the race for the next invention.

In a context where inventions occur with some frequency and existing technologies and products are supplanted fairly often, as is the case with many technologically active industries, this situation implies a dilemma for the firm. Obtaining a patent allows the firm to appropriate

value by providing the benefit of reduced competition for the immediate invention. However, it also raises the possibility of failing to appropriate value from the fecundity aspects of the invention by potentially enhancing competition for the (yet unborn) inventions that the current invention may eventually spawn. In this paper I make a distinction between these two aspects of appropriability. I define primary appropriability as a firm's ability to extract rents from its original invention, and secondary (henceforth, generative) appropriability as a firm's ability to capture a large share of the subsequent inventions that are derived from its inventions. I develop a theoretical model to explain what factors influence generative appropriability, and then test the model with longitudinal data on the leading firms in the global chemical industry.<sup>1</sup>

### **THEORY DEVELOPMENT AND HYPOTHESES**

From the time of Arrow and possibly earlier, we have recognized that there are usually at least two facets to any invention (Arrow, 1962). On the one hand, an invention is an artifact, a solution to some techno-economic problem that attempts to enhance utility for some set of potential beneficiaries. However, an invention is also, simultaneously and fundamentally, a concept, an idea that serves to add to our universe of concepts and ideas, and which can itself become a seed for future concepts and ideas (and inventions). Thus, any invention potentially creates value in two ways – it has an intrinsic or inventive value that relates to the problem solving aspect of the invention; it also has a fecundity or generative value which relates to its ability to serve as a springboard or seed for future inventions and ideas (Arrow, 1962; Hopenhayn & Mitchell, 1999).

Ideally, from a strategy standpoint, a firm would like to do both, capture value in the market today by exploiting its invention uncontested, and tightly control the ideas and inventions

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<sup>1</sup> The phrase *When Atlas Shrugged* in the title refers to Ayn Rand's (1957) classic which drew attention to the

that flow from the invention in the future. However, as the double-edged nature of the patenting contract implies, such a favorable (from the firm's perspective) solution is unlikely. To the extent that disclosure is truly enabling, it can entail a trade-off between primary and generative appropriability. The resolution of this trade-off is likely to be contingent on the nature of intellectual property protection provided in a given industry. In some industries where patent protection is unreliable or ineffective it is likely that the benefits of patenting are limited and firms may decide to use other mechanisms such as secrecy to protect their property anyway. However, in industries characterized by strong patent regimes, patenting is likely to be beneficial and hence significant and systematic (Levin, Klevorick, Nelson, Winter, Gilbert, & Griliches, 1987). In such industries, the frequent and comprehensive use of patenting suggests that the trade-off is generally resolved in favor of patenting in such industries. Yet, the underlying tension still remains valid even in these industries, as other things being equal, even after having chosen to patent and benefit from the primary appropriability aspect of the invention, managers would be interested in benefiting from the future generations too, if possible. Correspondingly, in this study I focus on one such industry in which patenting rights are regarded as strong, and assume that after evaluating the benefits of patenting the firm has decided to obtain a patent and accept the attendant enabling disclosure; but that even after accepting the enabling disclosure the firm will have an interest in maximizing generative appropriability. Specifically, I ask the research question, how do firms increase generative appropriability in a regime of enabling disclosure?

From a strategy perspective the problem of generative appropriability is important for at both theoretical and practical reasons. From a theoretical standpoint, understanding generative

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importance of appropriability in promoting inventive efforts – a theme that is central to this paper.

appropriability and its determinants has implications for the resource-based view and organizational learning. Within the resource-based view recent work has focused considerably on the issue of imitation threats and how firms can use mechanisms such as complexity and the pre-emption of scarce resources to prevent others from imitating their success (Wernerfelt, 1984; Rivkin, 2001). Yet, the other path to loss of competitive advantage, substitution, has not been as significantly investigated. In this study I raise the possibility that some of the mechanisms that enhance protection from imitation may actually worsen the threat of substitution. As I find, both conceptually and empirically, strategies such as patenting and complexity have somewhat distinct effects when applied to arguments of imitation versus substitution.

The question I ask is also of importance from the perspective of organizational learning. To address the issue of generative appropriability, I focus on the context of how external learning occurs in firms. However, while the inter-organizational learning literature has generally focused on how organizations can learn from each other or transfer knowledge to each other, in the current context I ask, how can organizations *prevent* other organizations from learning from them or deter them from building on their knowledge, even when the blueprints for the organization's knowledge are made public. Thus, I examine a question that is relatively rarely examined in the organizational learning literature.

The issue of generative appropriability is also relevant from a practical standpoint. First, inventions are rarely born fully formed, and the first iterations of any invention are relatively primitive and rudimentary. Subsequent versions of the invention improve significantly, and often have far greater commercial viability than the original invention. If generative appropriability is low, the firm in essence ends up opening paths for others to profit from. Second, even when inventions become commercially viable, the path to staying ahead of

competition often entails being able to create subsequent generations of inventions that are increasingly differentiated for specific uses and market segments or offer better price/performance values (McEvily & Chakravarthi, 2002; Roberts, 1999). Thus, both from the perspective of channelling subsequent generations of technologies into directions that favor the firm's own supporting assets rather than its competitors, and to safeguard against the possibility of being rendered obsolete by improved substitutes that build on the firm's prior efforts, firms need to be concerned with generative appropriability.

Prior strategy research on the context of appropriability has not explicitly made a distinction between primary and generative appropriability. Although, some authors have discussed the related ideas of innovation having two facets (Cohen & Levinthal, 1989) implicitly the substantive focus of much of the prior strategy research has been on primary appropriability. This research has established that firms are able to appropriate value from their inventions to the extent that intellectual property rights are strong (Levin *et. al.*, 1987) or they have strong and proprietary control over the supporting assets required to commercialize the invention (Teece, 1986; Mitchell, 1989). Although both of these insights are extremely useful, they leave unexplored two aspects of the appropriability agenda. First, as noted above, they do not explicitly consider generative appropriability directly. Incorporating and shedding light on this aspect of appropriability is important for the reasons discussed earlier. Second, both the intellectual property rights and the supporting assets arguments are strongest when applied to explaining inter-industry variations in appropriability (as industries may differ in the degree of intellectual property protection provided), or differences in appropriability for industry incumbents versus entrants (as incumbents have access to supporting assets which may be unavailable to entrants) (Mitchell, 1991; Teece, 1986). They are perhaps a shade weaker when

applied to the context of variations in appropriability between competitors within the same industry. In this paper I build on the prior literature in exactly these three ways, a) the studied construct is generative appropriability, b) the focus is entirely on the differences between firms in the same industry (hence the intellectual property regime is the same for all firms), and, c) I move beyond supporting assets to identify additional mechanisms that are relevant in understanding generative appropriability.

Scholars in economics and property rights have also examined the issue of appropriability, albeit in the form of the closely related problem of sequential or cumulative invention (Scotchmer & Green, 1990). Scholars in this tradition have focused on the incentive problem that arises when an invention serves as the basis for several subsequent inventions. Clearly, when the rights of the original inventor are very strong, the incentive for other inventors to enter the technological area of the first invention are weakened, which may not be desirable from a social welfare perspective (Green & Scotchmer, 1995). At the same time if the rights granted to the original inventor are weak, the incentive to invent for the original inventor is itself reduced as the payoff to inventing is low. This quandary has been the main focus of research efforts (Chang, 1995; Matutes, Regibeau, & Rockett, 1996 ). However, the primary solution for this problem from property rights scholars has been in terms of designing an optimal patenting regime or contract i.e. identifying the set of rules in terms of patent duration and patent scope that will balance the incentives of inventors with the goals of society. Thus, using differing protection schemas in terms of the length and breadth of a granted patent, scholars have generally sought to identify or characterize the ideal patent system. How firms could differ in behavior within a given intellectual property regime is not an issue that is studied by these scholars in a direct way.

In my current study, consistent with the strategy rather than public policy focus of the paper, I take a firm-level perspective on the problem. From the standpoint of a firm, the option of reconfiguring the patent system is not really available. The firm needs to operate, at least in the short and medium term, within the constraints of a given patenting system. Thus, I focus on what a firm can do to increase its generative appropriability within the constraints of the existing patent regime. Specifically, I take as given the existing patenting system, and ask if there are strategies that self-seeking firms could pursue to enhance generative appropriability given that they have already decided to patent and thereby obtain primary appropriability and concede the attendant disclosure.

In the following section I identify four potential mechanisms that may enable a firm to capture a larger share of the inventions that build on its prior inventions and thus enhance its generative appropriability. Controlling or obtaining pre-emptive access to key resources has been presented as a fundamental approach to maximize appropriability in a sustained fashion (Ghemawat, 1986; Wernerfelt, 1984). Following this dictum I explore the relationships between generative appropriability and a firm's prior control over two sets of resources that may be relevant to this context – the technologies owned by the firm and the supporting assets that may be required to optimally exploit those technologies. Specifically, I argue that firms can alter the incentives of other firms to come into their technological terrain and build on their inventions by focusing their inventive activities on technologically proximate domains and by maintaining a global infrastructure of supporting assets. Building capabilities that are complex has been argued to be an important mechanism for protecting the firm from imitation (Singh, 1997; Rivkin, 2001). I next investigate its efficacy as a defense against substitution in the context of generative appropriability. Finally, I go to the role of the firm as a repository and recombiner of

unique knowledge (Grant, 1996; Liebeskind, 1996; Szulanski, 1996) and explore a fourth mechanism that may be relevant in understanding generative appropriability – the division of labor within the organization (Liebeskind, 1996).

### **Pre-emption Through Technological Proximity**

Whenever a firm commits resources to the development of a new invention it faces a choice between building close to its existing inventions or creating something at some distance away. Two sets of arguments suggest that, as a firm situates its new inventions in the proximity of its prior inventions, its ability to build on its inventions will increase, and the threat of competitors building on its inventions will decrease. The first set of arguments builds on a spatial pre-emption rationale, while the second set draws upon the literature on local search and absorptive capacity.

First, building upon the classical spatial pre-emption argument (Judd, 1985), I suggest that as more of the space in a technological neighborhood is occupied by a firm, the lower are the *incentives* of other firms to enter the remaining space, other things being equal. To place this argument in the current context recall that a patent essentially provides a zone of local monopoly to the inventing firm – an area around the invention from which the firm can rightfully exclude other firms. Consider Figure 1 in which I represent a two-dimensional technological space that is partially covered by patented inventions *a* through *e*. Each of the little circles (*a* through *e*) represents the domain of the eponymous inventions; within each circle the inventing firm can exploit its invention uniquely and any attempt by a competitor to enter this technological space will be considered an infringement leading to legal penalties and costs. Now presume that all of these inventions belong to the focal firm and consider the invention *f*. Will this invention be more attractive to the focal firm or to a competitor? Other things being equal it would appear

that such an invention would be more attractive to the focal firm than it would be to a competitor for at least two reasons. First the zone of local monopoly available to a competitor from this invention is likely to be much smaller than it would be for the focal firm. To see this note that the circle  $f$  represents the largest circle that a competitor could lay claim to – any circle larger than that will infringe on the rights of the focal firm. On the other hand, for the focal firm, the much larger dotted circle  $G$  would be an acceptable domain – it does not have to worry about infringing on itself! Second, to the extent that potential entrants are seeking to maximize their revenue prospects (through the zone of local monopoly) while minimizing their costs (including legal costs), as the expected legal costs of a location increase, the attractiveness of that location on the technological landscape decreases. In the situation where the focal firm owns more of the patents in the neighborhood, if a new firm tries to patent in the same neighborhood, the likelihood that an infringement will occur (or that the focal firm believes an infringement has occurred) on at least one invention will increase, and the probability that litigation (and therefore costs) will result will therefore increase (Somaya, forthcoming 2004).

Note that in the real world, domains of local monopoly may not be so clearly demarcated. However, the same argument would still apply in that instead of there being a deterministic outcome (infringement occurs or does not occur), there would be a probabilistic outcome (a lawsuit is more or less likely) that would have in large measure a similar effect of making entry relatively unattractive. Although the above is but a stylized illustration it does identify two general principles that will drive a firm's potential competitors away from zones wherein the firm is densely established, a) the risk (and hence, expected cost) of litigation is much higher in the neighborhood of the firm's inventions than at more distant spaces and b) for a competitor the

zone of local monopoly is likely to be smaller than it is for the focal firm in this crowded area, thus making the expected return to investments in this area lower.

The second set of arguments that make competitive entry into a densely packed space unattractive comes from the literature on local search and absorptive capacity (Nelson & Winter, 1982; Stuart & Podolny, 1996; Helfat, 1997). This research has established that more experience in an area increases competence in it (Cohen & Levinthal, 1989, 1990). If a firm occupies contiguous spaces in a technological domain increasingly, it limits the spaces available for competitors to occupy. Since technological understanding and knowledge is often cumulative, successive exclusions from a technological area make each subsequent attempt by a new entrant less likely to succeed. Thus, other things being equal, as firms are increasingly deprived of exposure to other close-by locations in a domain, the imperative of experience and local search will reduce the attractiveness of that domain. For both these reasons, I suggest that firms will enjoy greater protection when they house an invention in the proximity of their existing inventions.

*H1: The greater the proximity between a firm's inventions, the higher its level of subsequent generative appropriability.*

### **Preemption Through Supporting Assets**

The ability of a firm to deter competitors from building on its technology and coming up with successive inventions is also likely to hinge upon the focal firm's ownership of the supporting assets necessary to commercialize the stream of inventions. Manufacturing facilities, marketing and sales forces, and a global infrastructure to commercialize an invention are all key for profiting from inventions in general (Teece, 1986). In the context of patenting and its attendant enabling disclosure this general argument also takes a specific form. In a sense,

enabling disclosure starts the clock ticking on the attempts of competitors trying to emulate or supersede the invention. Once the invention is disclosed the quicker a firm can exploit an invention over the broadest possible scope, the better off it is. An established global infrastructure that can translate a given invention into a marketed product or service across the globe in an efficient and effective fashion may be useful not only for converting a given invention to profits, but may also act as a deterrent to other competitors who want to enter that technological niche. Accordingly, I predict:

*H2: The broader the global infrastructure of supporting assets owned by a firm, the greater its generative appropriability.*

Both, blanketing a space with pre-emptive patents, and owning supporting assets, are factors that make it unattractive for other firms to try and build upon the focal firm's technology. I next consider two factors that might provide additional layers of protection to a firm. These factors do not so much make a company's technology unattractive as a domain for building upon, but simply make it difficult to build upon the technology even if a firm was attracted to that technology domain. Thus, unlike the first two factors that focused on the motivation or incentive aspects of knowledge transfer these two factors focus on the characteristics of the knowledge itself and of the context in which it is transferred (Szulanski, 1996). The first of these is the complexity of the technologies developed by the firm. The second is the division of labor in the research effort. I touch upon these in turn.

### **Complexity**

The role of complexity in protecting the firm from imitation is well established (Rivkin, 2001). However, the impact of complexity on substitution or generative appropriability has not been examined. In this section I explore this relationship. Interestingly, the effects of

complexity on generative appropriability are not as one sided as they are in the case of imitation. Specifically, while complexity generally protects firms from imitation, its effect on generative appropriability potentially cuts both ways leading to two competing predictions.

First, one approach suggests that there is a positive relationship between the complexity of the technologies developed by a firm and its generative appropriability. The literature on knowledge and its management suggests that the more complex and interdependent a given set of technologies, the more difficult it is to replicate them, especially for outsiders (Macmillan, McCafferty, & Van Wijk, 1985; McEvily & Chakravarthy, 2002; Rivkin, 2000). Inventions can vary in the number of technological principles they embody or entail. Some inventions work by invoking a single or few technological principles; others involve the manipulation of many parts or distinct principles (Zander & Kogut, 1995; Singh, 1997). Inventions that are complex in the sense that they entail the simultaneous manipulation of many technological principles are likely to be difficult for outsiders to copy relative to technologies that involve the interplay of only a few principles. First, such technologies are likely to be fairly difficult to build on in an absolute sense. By their very nature complex technologies involve higher failure rates (Singh, 1997). Complex systems can suffer tremendous degradation in performance if even a few of the many interdependencies are ignored (Singh, 1997), and hence, getting it “almost right” is not very much better than not getting it at all (Rivkin, 2001). This need to make a whole configuration of decisions work together increases the failure rate for both outsiders and insiders. Second, however, the insider that is trying to replicate such a technology enjoys an informational edge over the outsider – they have access to the tacit knowledge and the original template that was developed (Rivkin, 2001). This enables them to post a better performance than the outsider in

terms of replication of a complex technology. To the extent that substitution can be regarded as a higher version of replication this argument suggests:

*H3a: The more complex the technologies pursued by a firm, the greater the generative appropriability it obtains.*

An alternate argument however suggests that it is important to note that generative appropriability is not the same as replication or imitation. Indeed, generative appropriability goes significantly beyond replication or imitation. Recall that generative appropriability is relevant only when an invention successfully emerges as a novel, non-obvious development or extension of a given invention. Simply replicating the same invention, or even very closely mirroring the original invention will not lead to a patent grant, and will thus not count towards generative appropriability. Viewed from this perspective the tacit knowledge and path dependence of the original inventor could actually be viewed as a liability in the context of generative appropriability. Given the preponderance of local search behaviors in organizations, these characteristics of tacit knowledge and expertise in a given neighborhood or a particular type of solution will focus the original inventor's attention to the same approach or domain as the original invention. With a complex process substituting individual components may not yield a successful outcome, yet local search may constrain the original inventor to search around the edges of "what worked last time". In fact, research finds some evidence of such "familiarity traps" (Ahuja & Lampert, 2001).

On complex landscapes, it is quite likely that peaks are at some distance from each other. This characteristic of such landscapes is in part responsible for the high failure rates of complex technologies in general, for as we noted above, for such technologies copying most attributes may not suffice for a good outcome as getting it "almost right" is not very much better than not

getting it at all. In such a circumstance while the original inventor will be pursuing paths in the neighborhood of the previously successful path, the outsider, cognizant of the novelty and non-obvious extension requirements of patenting is likely to try new approaches and slightly different parts of the landscape. Further, an outsider lacking complete familiarity with the original invention is also more likely to recombine the original idea with a possibly different context or new element that may enhance the likelihood of inventive success relative to the original inventor who is more constrained in their choice set. Consistent with this logic scholars have noted that complexity, whilst making imitation more difficult for other firms, can also make subsequent innovation difficult for the focal firm (Kogut & Zander, 1992; Sanchez & Mahoney, 1996; McEvily & Chakravarthy, 2002). Thus, it appears that outsiders might be better positioned to identify new inventions that build on prior complex inventions than the original inventor. From this perspective the prediction would be:

*H3b: The more complex the technologies pursued by a firm, the lesser the generative appropriability it obtains.*

### **Division Of Labor**

Although complexity in the technologies developed by a firm and the tacit knowledge embodied in them may be a barrier for other firms seeking to build on the focal firm's technology, competitors could turn to a device that provides access to even the tacit elements of knowledge at the focal firm – individual mobility (Liebeskind, 1996; Rosenkopf & Almeida, 2001). Hiring away the scientists that embody the firm's knowledge could be a potent weapon to leapfrog into the next generation of a technology. It is in this context that the firm's role in division of labor and task organization becomes critical.

Scholars have argued that firms' abilities to design tasks represents a key appropriability

advantage for the firm (Liebeskind, 1996). Specifically, through job designs and employee conduct rules firms can limit the degree to which information can leave the firm (Liebeskind, 1996; Grant, 1996). Through the joint mechanisms of specialization at the employee level and integration at the organizational level a firm can simultaneously enhance its capabilities while reducing the danger of knowledge expropriation (Demsetz, 1991, Grant, 1996). Specialist individuals that carry only a small component of the overall knowledge of the company pose less of a threat of knowledge malfeasance. Simultaneously, by developing its capabilities at integrating knowledge the firm can enhance its unique added value (Grant, 1996; Spender, 1992).

Two kinds of routines can be envisaged in terms of the organization of the inventive process a) large teams with individual scientists having a proportionately small role, or b) relatively small teams, but with larger individual roles. When teams are composed so that each project is subdivided among more people three effects come into play. First, such a division of labor ensures that for each project the knowledge available with each individual member is smaller. Second, and concomitantly, the marginal product of each individual team-member declines. The first of these suggests that to reconstruct a given level of knowledge at the original firm the competitor must hire away more people. This is likely to be difficult. The second suggests that to extract the maximal value from their own knowledge, each scientist in the focal firm needs more complementary units of knowledge (other scientists) thus making the departure decision more difficult for each one of them. Thus, from the perspective of the raiding firm this division of labor limits the effectiveness of mobility as an information gathering device; from the perspective of the at-risk-of-departing scientist it reduces the attractiveness of moving. Finally, to the extent that some scientists do move, this task organization limits the disruption to the focal

firm: with routines that are built such that each player has a relatively small role, the departure of a few players will not compromise the firm's ability to develop that technology further. Hence, other things being equal,

•H4: *The larger the size of the average inventive team in a firm, the greater the generative appropriability the firm obtains.*

## METHODS AND MEASURES

### Sample and Data

I tested the hypotheses on a longitudinal data-set drawn from the global chemicals industry over the period 1975 to 1995. The research question requires an industry where patenting is a systematic and commonly used intellectual property rights strategy. The chemicals industry is widely regarded as one where patenting is widely accepted and useful (Levin, *et. al.*, 1987; Arundel & Kabla, 1998). Hence, the core dilemma of this study – how to maximize generative appropriability in a regime of enabling disclosure (fostered by patenting) is extremely relevant here.

I used commercial publications such as Chemical Week and C&E News to identify the leading firms in the chemicals industry. In these published lists of firms subsidiaries were often listed separately from parent firms. From an original sample of approximately 120 firms, after including subsidiaries with parent firms a sample of 107 firms remained. For ten of these firms data could not be reliably obtained and consequently they were dropped from the analysis. The remaining firms include all the key firms in the industry over the study period. The panel is unbalanced as some of the firms were acquired by other firms or restructured in a fashion that made comparison difficult beyond a particular year. The sample is highly varied along a number

of key dimensions such as size, patenting frequency, etc. A full list of the sample firms is available from the author.

I use two primary sources of data. Patent data are used to operationalize the dependent and some of the key independent variables. Financial data are used to create several of the control variables. Financial data for the firms were obtained from Compustat, Worldscope, trade publications, company annual reports, and Japan Company Handbooks and Daiwa Institute Research Guides. For all firms financial data were converted to constant (1985) U.S. \$. Details about the patent data used are provided below.

### **Variable Definition and Operationalization**

*Dependent variable.* The core construct of **Generative Appropriability** refers to the degree to which a firm is able to build on its own technologies relative to others building on its technologies. I use patent citation data to measure this variable. Specifically, I measure generative appropriability as the ratio of self citations / total citations to a firm's patents in year  $t$ . To compute this variable for year  $t$  I first identify the firm's patents in periods  $t-1$  through  $t-6$  (a six year window). I then identify all citations to this set of patents in year  $t$  and then identify those citations to these patents that are made by the firm itself. Illustratively, to calculate generative appropriability for firm  $i$  for the year 1981, I first identify all the patents created by the firm in the years 1975-1980. I then examine all patents for 1981 and identify the citations these 1981 patents make to the set of 1975-80 patents. Assume that of all the patents applied for in 1981 150 cited the firm's patents in 1975 through 1980. Of these 150 citations 50 were made by the focal firm. Then the value of generative appropriability for the focal firm for the year 1981 is  $50/150$  or 0.33. Note that with this approach, I cannot compute values of generative appropriability for years before 1981 (as I only have patent data from 1975 onwards). The last

year that I use for measuring appropriability is 1988. In the sample that I have, the data end in 1995. For reliable measurement of citation patterns, the patents should have been available for citing for some period of time. For the last few years of patents, the 'at-risk-of-being-cited' period is relatively low and so I exclude these from the data. This exclusion still leaves appropriability data for 1982-1988 thus making possible a 7 year panel. My choice of 6 years for the patent base on which appropriability is to be calculated is based on prior work in the technology and R&D depreciation arena that has used a 5 or 6 year period as the relevant life of a technology (Griliches, 1984; Stuart & Podolny, 1996). For robustness, I also computed the appropriability measure using a 5 year window – it was correlated with the variable using a six year window at  $r=0.97$ .

I used patent data from the US Patents Database for all firms including firms that are headquartered outside the US. This was necessary to maintain consistency, reliability, and comparability, as patenting systems across nations differ in their application of standards, system of granting patents, and value of protection granted (Basberg, 1987; Griliches, 1990). The US represents one of the largest markets for chemicals, and firms desirous of commercializing their inventions would most likely patent in the United States if they were to patent anywhere at all. Prior research using patent data on international samples has followed a similar strategy of using US patent data for international firms (Patel & Pavitt, 1997; Stuart & Podolny, 1996). Prior studies of the global chemicals industry have also used US patent data for all firms, including international firms (Achilladelis, Schwarzkopf, & Cines, 1990).

To identify citations and self citations the patent portfolio of each firm in the sample has to be identified. To accomplish this I used the following procedure. First, for each firm in the sample a list of all its divisions, subsidiaries, and joint ventures was prepared using WHO

OWNS WHOM (United States, United Kingdom and Ireland, Continental Europe and Asia editions) and The Directory of Corporate Affiliations. Thereafter, each firm's history was traced through the study period to account for any name changes and reorganizations and to obtain information on the timings of events such as the founding and dissolution of joint ventures. This master list of firm names was used to identify all patents issued to the sample firms. The list of chemicals patents owned by these firms was derived from the above master list using the technology class information on the patents. The US patent system classifies the technology domain into four hundred broad classes and several hundred thousand sub-classes nested within the classes. Each patent is assigned to a primary technology class by patent examiners. The Patent Manual was used to identify the technology classes corresponding to chemicals. Using the identified technology classes the chemicals patents of the sample firms were separated from other patents obtained by them.

***Independent Variables.*** Measuring closeness between a firm's inventions to reflect the kind of argument made in Hypothesis 1 is a fairly challenging task in the context of large sample data. To accomplish this I created a variable, **Technological Proximity**, based on the citations made *by* the firm's patents in the previous 6 years. Note that these citations are distinct and different from the ones that the dependent variable is based upon. Illustratively speaking, the dependent variable is based upon the citations made by all 1981 patents in the USPTO *to* the focal firm's patents in 1975-1980. The independent variables are based on the citations made *by* the focal firm's 1975-1980 patents. The actual measure of proximity in a firm's inventions is the ratio of the number of total citations in a firm's patents for the prior 6 years divided by the number of unique citations in the same patents.

To develop an intuitive feel for how this measure captures the proximity between a firm's inventions consider the following hypothetical illustration of two firms that both have a patent portfolio of 5 patents. Both firms have also cited 4 patents in each of their 5 patents. Hence, the total number of citations in their patents is 20 for both firms. However, the actual patents cited by the 2 firms are different. Firm 1 in its 5 patents has cited the same 4 patents in each case - patents a, b, c, and d. Firm 2 on the other hand has cited patents a, b, c, d, in Patent 1, patents e, f, g, h, in Patent 2, patents i, j, k, l, in Patent 3, patents m, n, o, p in Patent 4, and patents q, r, s, t in Patent 5. Now we see that even though the two firms had cited an identical number of patents in total, the number of unique patents cited by the firm is different. Firm 1 has cited only 4 unique patents. Firm 2 has cited 20 unique patents. Thus the value of the technological proximity variable for firm 1 is 5 ( $20/4$ ) while that value of the same variable for firm 2 is 1 ( $20/20$ ). The basic logic for this measure is that firms that have inventions that are very close to each other are going to cite the same prior art. The higher the overlap between the citations in a firm's patents, the closer are the firm's inventions to each other, and the higher is the value of this measure.

To obtain a measure of **Supporting Assets** that taps into the construct of a global infrastructure I used the number of nations in which a firm has a subsidiary or affiliate as an indicator of its ability to simultaneously exploit an invention over the broadest geographic scope. Who Owns Whom (annual editions) provide details of the nation by nation subsidiary and affiliate network for each firm.

To measure **Complexity** in the technologies developed by a firm I used the information on technological classes of the cited patents. The patent system is divided into approximately 400 distinct technology classes. The patents in a given technology class belong to the same

technological domain and represent closely related technologies and principles. Patents in different technology classes represent different technological domains and principles. When a patent cites another patent as prior art it essentially builds on that prior art patent. If the patents of a firm on average cite many different technological classes they can be regarded as having combined many relatively disparate technologies successfully in their patents. This ability to combine many disparate technologies successfully ties closely to the notion of complexity used in the arguments earlier. Hence, I use the Blau Index (1-Herfindahl) of patent classes cited by the firm in its patents of the previous 6 years as my measure of complexity (Hall, Jaffe & Trajtenberg, 2001). Firms that consistently combine elements of distinct technological classes in their patents can be regarded as having more complex technologies. For instance, for one firm a patent on average may cite only 2 technology classes while for another firm a patent on average may cite 5 technology classes. The latter firm is combining the knowledge from 5 different technology classes in its average patent and can therefore be regarded as producing more complex technology (see also Zander & Kogut, 1995).

Some of the citations in the patents are to patents that are from the pre-1975 period. For these citations it is not possible to identify what technological classes these citations were from because that data is not available from the USPTO. To control for that I include the variable **Citation Availability** which provides the average proportion of citations for which the data were available for a given firm year.

To measure **Division of Labor** I use the average number of inventors listed on each patent for the firm for the previous 6 years. Firms can vary considerably in the number of inventors that are involved in the invention effort for any given technology. Some firms may entail many people working on a project while others may entail a lesser degree of task

partitioning and may have only a few scientists assigned to each project. The USPTO lists the inventors on a given patent. I use this information to calculate the average number of inventors per patent for the firm.

***Control variables.*** I also included a number of control variables that may be relevant in affecting generative appropriability. I include a measure of the firm's **Assets** in the chemicals business as an indicator of its size. To compute **Assets** I multiply the assets owned by the firm by the proportion of its total sales turnover that was drawn from the chemicals business.

The nature of technology that firms are active in may limit or encourage in their technologies by other firms. For instance, older technologies may be less attractive for other firms to enter. Accordingly, I include a control for the **Average age** of the patents cited by the firm in the previous 6 years. Similarly, patents may differ in their general applicability with some being more basic than others and opening up broader domains than other patents. To control for this I used the **Generality** variable (Hall, Jaffe & Trajtenberg, 2001). For instance, if a firm's patents receive citations from many different technology classes they can be regarded as more general or basic patents. The generality variable is essentially the Blau Index (1-Herfindahl) for each firm's patent portfolio using the technology classes of the patents that cite the focal firm's patents. **R&D Intensity** measures the ratio of research and development expenditures to sales for these firms. More research intensive firms might be more likely to better protect their own technology. **Debt/equity** measures the leverage characteristics of a firm and controls for the focal firm's financial condition – highly leveraged firms might be regarded as being “in trouble” and therefore easier prey for attack on their technology. **Current Ratio**, measuring the ratio of current assets to current liabilities, measures another aspect of financial condition (financial liquidity or solvency), and **Return on assets** are also included as controls

for a similar reason. **Diversification** is included as a control for the possible effects of diversification. On the one hand diversified firms may be able to use more of their internally developed technology than less diversified firms because they are present in more product markets, and therefore have higher rates of generative appropriability. Alternately, diversification in product markets may drive diversification in technology and firms may tend to focus on very broad and varied areas. The following formula for the entropy measure was used to calculate **Diversification** =  $\sum P_j \times \ln(1/P_j)$ , where  $P_j$  is defined as the percentage of firm sales in segment  $j$  and  $\ln(1/P)$  is the weight for each segment  $j$  (Palepu, 1985). Firms may differ in the intrinsic value of technology that they create. Firms creating more valuable technologies may be more susceptible to other firms building on their inventions while firms with relatively less valuable technology may be left alone to pursue future generations of inventions on their technologies. In some part the econometric specification controls for such effects as the panel estimator that I use explicitly accounts for unobserved “firm” effects. However, as a further control I directly model this into the estimation by including the variable **Claims**. **Claims** measures the aggregate number of claims associated with the focal firms patents for the previous 6 years. The claims in a patent are correlated with patent value (Lanjouw & Schankerman, 1999). Firms with few claims may be producing technology that is in some senses less valuable. By using this measure I proxy for the total value of the inventions that are at risk of being built upon for a given firm. All these control variables were lagged by one year as is customary (Stuart, 1998). I also included 6 year dummies (1982 is the omitted/base year) and regional dummies for European and Japanese firms (USA is the omitted/base nation) in all models to account for any period specific or geographic influences. I do not make any formal predictions on the effects of the control variables.

## Model Estimation and Econometric Issues

I used a Two Sided Panel Tobit regression approach to test the above hypotheses. The dependent variable, generative appropriability, is a proportion variable that can take any continuous value between 0 and 1. The tobit model is appropriate for such a limited dependent variable. Since the range of the Generative Appropriability variable has both a lower limit, 0, and an upper limit, 1, I used the two-sided version of tobit. In the two sided tobit the likelihood function is modified to account for the fact that the dependent variable cannot drop below a certain threshold (the lower limit) or exceed another value (the higher limit). Finally, to account for possibilities of systematic heteroskedasticity, serial correlation and unobserved heterogeneity, I used the panel version of Tobit that explicitly models firm effects rather than a simple Tobit.

## RESULTS

Table 1 presents descriptive statistics and correlations for all key variables in the study. As the descriptive statistics indicate, the sample is characterized by significant variance in terms of the important variables. For instance, the smallest firm in the sample is only 1/1000<sup>th</sup> the size of the largest firm in the sample on the basis of Assets. Table 2 presents the results of the panel Tobit regression analysis. Model 1 presents the base model and includes only the control variables. Model 2 includes the Technological Proximity variable and Model 3 adds the Supporting Assets variable. Model 4 and Model 5 bring in the last two hypothesized effect variables, Complexity and Division of Labor, respectively, completing the model. I use the full model (Model 5) to interpret the results. The results in Model 5 provide support for Hypotheses 1, 2, and 4, and support Hypothesis 3b. Hypothesis 3a is rejected. Specifically, in Hypothesis 1 I predicted a positive relationship between a firm's Generative Appropriability and its creation of

inventions in technological proximity to each other. This hypothesis was supported as the coefficient on Technological Proximity was positive and significant. In Hypothesis 2 I predicted a positive relationship between a firm's generative appropriability and the breadth of its global infrastructure of supporting assets. This hypothesis was also supported as the coefficient on Supporting Assets was positive and significant. In Hypothesis 3 I predicted two competing effects of complexity on generative appropriability. The coefficient on the Complexity variable was negative and statistically significant supporting the interpretation that complexity lessens generative appropriability. In Hypothesis 4 I predicted a positive relationship between generative appropriability and larger sized research teams. This hypothesis was also supported as the Division of Labor variable was positive and significant.

To test the robustness of the results I ran several additional models. I tested the sensitivity of these results to the inclusion of additional control variables and alternate construction of the hypothesized effect variables. The results were robust to all these variations. For instance, variation in firm activity across technology classes could be a source of variations in their generative appropriability. To ensure that my results were robust to this alternative explanation I created dummy variables for the 83 technology classes that were represented in the data and thus redid the analysis on a "within technology class basis". Model 6 presents the results of this estimation. These results are consistent with the results in Model 5 suggesting that the identified effects are robust to this alternative explanation.

## **DISCUSSION AND CONCLUSIONS**

In this paper I sought to draw the attention of strategy scholars to the distinction between two corresponding notions of appropriability and explain the determinants of the less studied one, generative appropriability. To this end I developed a theoretical framework to explain

variations in generative appropriability and tested the arguments with longitudinal data. The resultant empirics provide at least some support to the core arguments of the study. Specifically, it appears that placing inventions in technological proximity of existing inventions, control of supporting assets, and division of labor are all strategic means through which firms can limit the degree to which other firms build on their technologies. Although, theoretically, complexity is yet another path to achieve this outcome, that argument was not corroborated by these data. Rather, the opposite argument was confirmed. Complexity while being a good barrier to imitation as established in past research, may also limit the firm's generative appropriability. These concepts and associated results have significant implications for theory in at least three domains, organizational learning and knowledge management, the resource-based view, and the literature on breakthrough inventions. I touch upon each of these briefly.

First, the notion of generative appropriability that I developed in this paper is of importance from both strategy and organization theory and public policy perspectives. From a strategy / organization theory standpoint this concept draws attention to a facet of organization learning and knowledge that has generally been underdeveloped in the literature. Much of the knowledge literature has focused on the identification of factors and routines that enhance inter-organizational learning and facilitate knowledge transfer (Grandori & Kogut, 2002). Yet as scholars have noted (Cohen & Levinthal, 1990; Grandori & Kogut, 2002) there are two aspects to learning. Learning is not just about knowledge and its sharing, it is also about competition and incentives: firms will invest in knowledge and learning depending on the degree of competition and imitation. More commonly, the learning literature focuses on how firms can learn from other firms. This paper drew attention to a context in which the incentives of firms were in the opposite direction – how can they prevent others from learning from them?

Although prima facie that appears socially undesirable, a more nuanced consideration of the problem draws our attention to an insight similar to the one provided by Ayn Rand in her work that lends its name to this paper – in a ‘for profit’ world, activities that don’t yield returns to the actor, are eventually not undertaken. In that sense, the strategies reflected here, while appearing undesirable may still be better than the alternative. Theoretically, this paper represents a call to integrate more closely, the consideration of incentives and competition into the literature on learning.

The concept of generative appropriability also provides a similar insight for public policy. There is a considerable literature, largely in economics, that has discussed the notion of patent thickets, in largely pejorative terms. In this paper I raise the possibility that pre-emptive patenting of this type may not necessarily be ‘evil’. In some situations, such behavior could reflect rational firm responses that correct incentive deficiencies in the patenting system, and are thus efficiency enhancing. Specifically, in regimes in which patent breadth and scope are not optimally specified, strategic behavior by firms may partly compensate for the incentive misalignment. Note though, that my arguments only raise this *possibility* of a socially beneficial role for pre-emptive patenting, they do not provide any direct theoretical or empirical support to assert that such behavior is indeed, on balance, beneficial for society at large. However, they do represent a departure from extant work and suggest that understanding the relative benefits and costs of such behavior may be useful rather than necessarily presuming that it is undesirable. In future research important questions exploring the relationship between generative appropriability and the rate and direction of overall technical change could be addressed. For instance, how do high levels of generative appropriability impact the rate of technological development? Do they reduce or increase the actual quality of the inventions?

Most fundamentally, the ideas of this paper also have important implications for the resource-based view of the firm. The identification of task organization and division of labor as the mechanisms by which firms enhance appropriability suggests broad and far reaching implications for rent preservation and the theory of the firm (Grant, 1996; Rajan & Zingales, 2001; Liebeskind, 1996). Resources can in general be classified into two forms – those on which property rights are available such as patents and manufacturing assets, and those for which such property rights are inherently unavailable, such as human assets. As more of value creation relies on knowledge and intellectual assets the importance of the second class of resources is likely to grow. However, from a value appropriation standpoint the growing importance of such assets highlights the problem of organizational embeddedness – how do you tie such resources to a firm? The division of labor argument presents an important take-away in this regard. Reducing the marginal product of individual actors and tying it in to complementarities within the firm (human or otherwise) may be ways to embed such resources into the fabric of the firm. Indeed these approaches can be applied to many forms of human capital, not just scientists.

Equally importantly, the notion of generative appropriability raises some interesting questions about the role of complexity in sustaining superior performance. The existing literature has described in some detail the benefits of complexity in terms of protecting the firm from threats of imitation (Reed & DeFillippi, 1990). However, the negative result here raises the possibility that perhaps the effects of complexity operate differently with respect to the two threats to sustainable performance, imitation and substitution. Specifically, while complexity may be helpful in deterring imitation, this paper draws attention to the possibility that complexity may actually hinder the ability to innovate and thus combat substitution threats (see also Sanchez & Mahoney, 1996; McEvily & Chakravarthi, 2002). The generative

appropriability construct draws attention to the fact that in dynamic technological environments you have to keep solving problems, not settle on a one time solution – in this it differs from exploitation wherein one solution is applied again and again. Perhaps it is the case that when a problem has to be solved only once and the system is fairly static, then a complex assemblage may indeed convey a competitive advantage by making imitation difficult. However, when the problem has to be solved again and again, as is the case with many substitution threats, it may no longer be easy to come up with ever improved solutions after starting from a complex base. Thus, complexity while protecting the firm from imitation may be leaving it more vulnerable to substitution.

The last set of implications from this paper relates to the literature on innovation and invention in general and also identifies a significant caveat with respect to some of the strategies identified in this paper. The generative appropriability enhancing strategies identified in this paper can entail significant trade-offs vis-à-vis other desirable organizational outcomes. The trade-off between primary and generative appropriability has already been described. The strategies of pre-emption and division of labor also entail significant trade-offs. First, generative appropriability favors depth in technological expertise, when a firm faces a choice between exploring a new dimension of knowledge and blanketing an existing one more deeply, generative appropriability argues for the latter. Yet, the most dramatic inventions may lie on the path of exploration of new ideas. Thus, firms that focus on enhancing generative appropriability may run the risk of lowered possibilities of breakthrough inventions. Similarly, high levels of task decomposition may enhance appropriability but may also lead to higher integration costs and possibly lower rates of inventive success. Understanding how firms make these trade-offs

between primary and generative appropriability, and between appropriability and these other innovation related outcomes may present rich opportunities for future research.

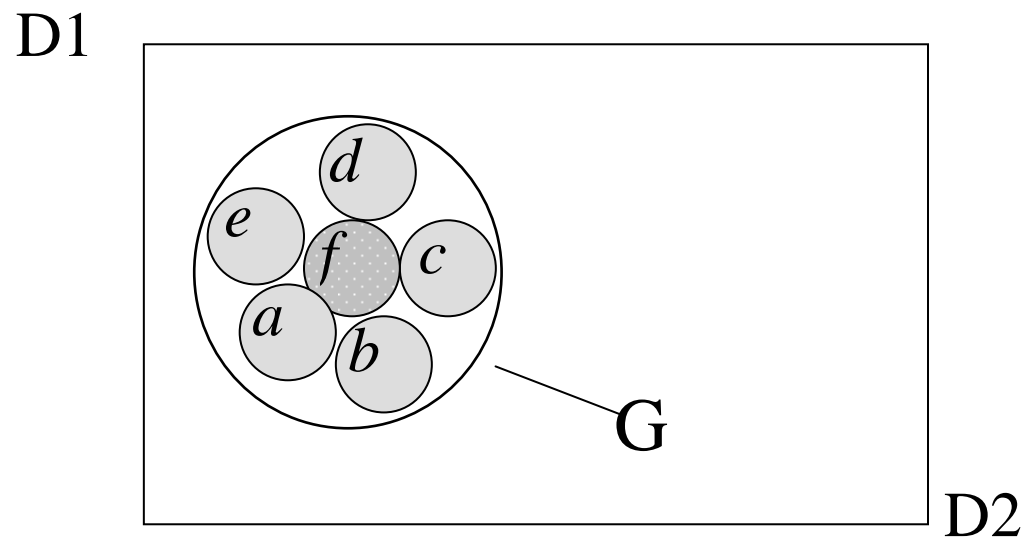
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**Figure 1**  
**Technological Pre-emption**



D1 = Technological Dimension 1

D2 = Technological Dimension 2

**Table 1: Descriptive Statistics and Correlations**

	Observation s	Mean	Std. Dev.	1	2	3	4	5	6	7	8
Generative Appropriability	659	0.17	0.15	1.00							
Technological Proximity	658	1.23	0.18	0.34	1.00						
Supporting Assets	653	18.27	16.36	0.18	0.33	1.00					
Complexity	658	0.36	0.07	-0.01	0.39	0.17	1.00				
Division of Labor	655	2.59	0.78	-0.02	-0.36	-0.52	-0.32	1.00			
Assets	659	2296.47	3391.23	0.20	0.25	0.58	0.13	-0.20	1.00		
Average Age	655	11.38	2.32	0.01	0.11	0.20	0.16	-0.40	-0.01	1.00	
Citation Available	659	0.85	0.07	0.00	-0.08	-0.13	-0.00	0.37	0.09	-0.80	1.00
Generality	658	0.43	0.08	-0.10	0.06	-0.11	0.63	-0.02	-0.07	-0.07	0.12
Claims	659	2837.47	4381.30	0.33	0.44	0.65	0.17	-0.23	0.79	-0.04	0.07
R&D Intensity	659	0.03	0.02	0.11	0.18	0.24	0.07	-0.09	0.19	0.12	-0.05
Debt/Equity Ratio	659	3.58	4.34	-0.09	-0.18	-0.25	-0.13	0.26	-0.09	0.09	-0.20
Current Ratio	659	1.56	0.61	0.14	0.26	0.32	0.11	-0.42	0.12	0.22	-0.19
Return on Assets	659	0.03	0.03	0.12	0.30	0.25	0.18	-0.39	0.09	0.12	0.00
Diversified	659	1.30	0.33	0.02	-0.02	0.38	-0.04	0.01	0.40	-0.05	0.08
European	659	0.33	0.47	-0.09	-0.11	0.46	-0.21	-0.27	0.15	0.39	-0.37
Japanese	659	0.41	0.49	-0.10	-0.32	-0.66	-0.18	0.77	-0.27	-0.46	0.43

**Table 1: Descriptive Statistics and Correlations, Continued**

	9	10	11	12	13	14	15	16	17
Generality	1.00								
Claims	-0.06	1.00							
R&D	-0.19	0.30	1.00						
Intensity									
Debt/Equity	-0.03	-0.20	-0.11	1.00					
Ratio									
Current	-0.07	0.22	0.20	-0.33	1.00				
Ratio									
Return on	-0.02	0.16	0.17	-0.45	0.41	1.00			
Assets									
Diversified	-0.10	0.36	0.12	-0.01	0.01	-0.09	1.00		
European	-0.29	0.06	0.18	0.12	0.30	0.02	0.25	1.00	
Japanese	0.18	-0.32	-0.20	0.16	-0.57	-0.37	-0.13	-0.59	1.00

**Table 2: Two-Sided Panel Tobit Regressions Predicting Generative Appropriability**

	1 <sup>a</sup>	2	3	4
Technological Proximity		0.15* (.06)	0.15* (0.07)	0.18** (0.07)
Supporting Assets			0.00 (0.00)	0.00 (.00)
Complexity				-0.47** (0.18)
Div of Labor				
Assets	-0.00 (0.01)	0.00 (0.00)	-0.00 (0.01)	-0.00 (0.00)
Average Age	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.02* (0.01)
Citation Available	0.14 (0.27)	-0.16 (0.27)	0.16 (0.27)	0.31 (0.27)
Generality	-0.03 (0.13)	-0.08 (0.12)	-0.07 (0.13)	0.13 (0.15)
Claims	0.00** (0.00)	0.00* (0.00)	0.00* (0.00)	0.00* (0.00)
R&D Intensity	0.30 (0.51)	0.25 (0.49)	0.29 (0.49)	0.42 (0.48)
Debt/Equity	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)
Current Ratio	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)
ROA	-0.12 (0.25)	-0.13 (0.25)	-0.17 (0.26)	-0.19 (0.25)
Diversified	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.03)
European Firm	-0.08* (0.03)	-0.05 (0.03)	-0.06 (0.04)	-0.08* (0.04)
Japanese Firm	0.01 (0.04)	0.03 (0.04)	0.04 (0.04)	0.02 (0.04)
Intercept	-0.11(0.29)	-0.28(0.30)	-0.30(0.30)	-0.44(0.31)
Observations	655	655	649	649
Log-Likelihood	144.87	147.33	146.22	149.74
Rho	.39 (.06)	.35 (.06)	.35 (.06)	.33 (.05)
Wald ChiSquare (df)	39.34**(18)	44.59*** (19)	43.2**(20)	51.77*** (21)

All hypotheses are single-tailed

All controls are two-tailed

Standard Errors in parentheses

+ =10%; \* = 5%; \*\* = 1%

**Table 2, Continued**

	5	6 <sup>b</sup>
Technological Proximity	0.19** (0.06)	0.17** (0.07)
Supporting Assets	0.00+ (0.00)	0.00* (0.00)
Complexity	-0.41** (0.18)	-0.48** (0.19)
Div of Labor	0.09** (0.02)	0.08** (0.02)
Assets	-0.00 (0.00)	-0.00 (0.00)
Average Age	0.016* (0.01)	0.02* (0.01)
Citation Available	0.17 (0.28)	0.11 (0.28)
Generality	0.16 (0.15)	0.28 (0.15)
Claims	0.00 (0.00)	0.00 (0.00)
R&D Intensity	0.34 (0.48)	-0.23 (0.50)
Debt/Equity Ratio	-0.00 (0.00)	0.00 (0.00)
Current Ratio	0.01 (0.02)	0.02 (0.02)
Return on Assets	-0.15 (0.25)	-0.16 (0.26)
Diversified	-0.02 (0.03)	-0.04 (0.03)
European Firm	-0.12** (0.04)	-0.08 (0.04)
Japanese Firm	-0.09 (0.05)	-0.02 (0.05)
Intercept	-0.52(0.31)	-0.56(0.31)
Observations	646	646
Log-Likelihood	158.81	203.85
Rho	0.33 (0.05)	0.25 (0.07)
Wald ChiSquare	69.76***(22)	185.1***(105)

All hypotheses are single-tailed

All controls are two-tailed

Standard Errors in parentheses

+ =10%; \* = 5%; \*\* = 1%

<sup>a</sup>Models 1-6 all include 6 year dummies whose coefficients are not reported

<sup>b</sup>Model 6 includes 83 technology class dummies whose coefficients are not reported