Patent Laws and Innovation Selection in the Global Firm

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PRELIMINARY AND INCOMPLETE

Abstract

This paper provides evidence that offshore patent laws influence global firms' innovation decisions. Within a simple model of multinational production, we find that a novel consequence of imitation risk is that firms innovate selectively, directing investments in product development toward relatively short-lived varieties that are difficult to imitate prior to obsolescence. A key implication of firms' selective product development is that patent reforms tend to increase not only innovation by firms, but also the average economic lifetime of the products they develop—both to extents varying non-monotonically across industries according to rates of underlying technological obsolescence. Using detailed data on U.S. patent grants and citations during 1976–2006 and U.S. multinational firms' affiliate innovation investment during 1982–2009, we find empirical regularities consistent with these hypotheses.

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1 Introduction

Multinational firms account for almost all private U.S. innovation investment and thus hold substantial volumes of intangible assets, including patented intellectual property and trade secrets estimated to be worth several trillion U.S. dollars.[1] However, as large U.S. multinational corporations expand globally, these proprietary trade secrets are increasingly exposed to potential competitors seeking to access leading-edge production technology. As a result, U.S. firms' global expansion is cited as an important contributing factor to rising trade secret theft and its associated economic losses—losses that are particularly acute in offshore markets that lack strong protection for intellectual property.[2]

However, even in such markets, global firms can mitigate the consequences of imitation risk. Consider, for example, a technology intensive firm like Apple. Pressured by low-cost competitors that continually emulate its products and infringe on its intellectual property, the firm responds by pursuing intense innovation investments aimed specifically at ensuring frequent product introductions. The firm states that its competitive success hinges on this strategy of maintaining short product lifecycles, which allow the firm to essentially outpace imitative competitors in the offshore market.[3] Shared by a range of other prominent, technology-intensive multinationals, this view strongly suggests that the rapid pace of product obsolescence within such firms is, in part, a response to imitation risk.[4]

In this paper, we show that this view has novel implications for the effects of offshore patent reforms on the global firm. Within a model in which Northern firms face imitation risk in the South, we find that imperfect patent protection encourages selective innovation, whereby firms develop only shorter-lived products that are relatively difficult to imitate prior to obsolescence. Offshore patent reform expands the range of products firms can develop profitably, increasing not only innovation but also the average product lifecycle length, both to extents that differ across industries according to rates of underlying technological change. To evaluate these implications empirically, we use data on U.S. patents during 1976–2006 and the activity of U.S. multinational firms during 1982–2009. Consistent with the predictions of the model, we find that firm-held technology is shorter-lived on average relative to non-firm technology, that its durability responds to offshore patent reforms non-monotonically across industries—as does the offshore innovation spending by U.S.-based multinational firms.

Taking Bilir (2014) as our point of departure, the model considers Northern firms that locate production in the South, where manufacturing costs are low but patents are only

[1] National Science Board (2014), U.S. Chamber of Commerce (2013).

[2] Estimated economic costs of U.S. firms' trade secret losses are between 1 and 3 percent of U.S. GDP annually. See Yeh (2016).

[3] Based on the SEC 10-K annual report for Apple (2014).

[4] See, e.g., SEC 10-K annual reports for Hewlett-Packard (2014), Western Digital (2014), Intel (2010).

imperfectly protected. Firms nevertheless exercise partial discretion over which available technologies underlying the industry to develop into product innovations; development occurs only if the lifetime expected profits of the potential product exceed the innovation cost. This setup builds from the dual premise that in a range of markets, the product innovations of global firms may be viewed as a proprietary assembly of existing technologies—and that offshoring, even to countries lacking strong patent laws, is broadly an industry standard for the highly productive multinationals responsible for the largest share of innovation spending.

Underlying each industry is a continuum of available technologies that are horizontally differentiated and also distinguished by their economic durability: some are technologically only just removed from currently available products, and face rapid obsolescence; others are positioned well beyond the state of the art, and are viable for a longer period of time. Thus, while all technologies in an industry share a common, exogenous hazard rate of obsolescence, the economic lifetime of a given idea is idiosyncratic. We show that when patent enforcement in the South is perfect, Northern firms optimally develop all available varieties.

However, imperfect intellectual property rights in the South cause firms to restrict innovation effort to include only short-lived ideas with lifetimes falling below a product innovation threshold. This selectivity arises because offshore imitation occurs with a lag: reverse-engineering a new Northern technology in the South is time consuming. A consequence is that a variety faces a higher likelihood of imitation as it matures, so that producing a sequence of short-lived varieties is more profitable in expectation than a sequence of longer-lived varieties. We show that patent reforms increase both innovation and the average lifetime of manufactured products and, importantly, that firms' effort to shorten product lives in the model may thus be viewed as a strategic substitute for formal patent rights.

The model further relates the sensitivity of firms' innovation decisions following reform to the underlying the rate of technological change in each industry. As patent laws are strengthened, firms pursue a margin of more durable ideas—ideas that were previously not profitable. While the measure of affected ideas is strictly positive in every industry, it is highest in sectors with intermediate rates of underlying technology obsolescence near firms' product innovation threshold. For industries in which the average technology is either much longer- or shorter-lived than this innovation threshold, firms' product development response is smaller, reflecting the limited measure of available ideas affected by patent reform. Hence, the magnitude of the increase in firms' innovation and average product lifetime following reform is non-monotonic in industry-specific rates of underlying technology obsolescence.

Evaluating the predictions of the model requires measuring the durability of the technology embedded in specific products, as well as the underlying rate of technological change among ideas within a given industry. For this, we build on the insights of Narin and Olivastro (1993) and Bilir (2014), which propose that proprietary technology is partially observable in patent records, and that the length of time during which a patent continues to be cited by subsequent patents provides a relative indication of the market lifetime of the cited patent's technology: a long average "forward citation lag,"—the time lapse between the cited patent's grant date and a subsequent citation—tends to indicate that the technology exhibits lasting relevance to future innovation. We thus develop an index for the economic lifetime of a patented idea by measuring its average forward citation lag. While conceptually related to the industry-level index in Bilir (2014), our disaggregated index is measured at the patent level, and reveals the salience of within-sector variation in technology lifetimes in the data: only approximately nine percent of the overall variation in patents' technology durability is explained by industry (technology class) differences across patents.

Importantly, a promising technology is often patented even if it is owned by a government or university and is never ultimately embedded in a product. Using our patent-level technology lifetime index and information on patent ownership, we are therefore able to evaluate whether the data support the selective product development that is a key feature of the model. The data suggest that, all else equal, patents granted to firms are on average shorter-lived than otherwise identical patents granted to non-firms including universities, governments, institutes, hospitals, and individuals. If patents by firms more likely protect technology embedded in products, this simple correlation is indeed aligned with the theory.

Our results further indicate that the economic durability of firms' patented technology is shaped systematically by intellectual property rights and the underlying rate of idea obsolescence in the industry; for these results, we consider patents owned both by a U.S. firm and a foreign inventor—technology that is relatively likely to be associated with a global firm. Using proxies for the strength of patent laws by country-year from Ginarte and Park (1997) and Park (2008) and an industry index of the technology obsolescence rate similar to Bilir (2014) but based on non-firm patents, we obtain estimates consistent with the non-monotonicity predicted by the model. Sensitivity to patent laws abroad depends on industries' rate of technological change, reaching its peak effect in an intermediate industry in which the durability of underlying technology is near the median. Intuitively, this arises because industries with underlying obsolescence rates near the product development threshold have the highest density of ideas that are marginal with respect to the patent reform.

Because not all innovation is patented, however, patent-based outcomes leave unobserved a potentially important component of firms' innovation response to intellectual property reforms. Indeed, secrecy and other mechanisms have been established as important methods of protecting intellectual property, particularly where patents are imperfect (e.g. Cohen et al 2000), and the decision to increase the durability of targeted innovations could potentially manifest itself as a response independent of patenting. To permit a broader interpretation of the results above, we therefore consider the innovation investment response by

U.S. firms' manufacturing affiliates using data from the Bureau of Economic Analysis, and confirm a qualitatively identical relationship between patent laws and U.S. firms' innovation abroad. Using variation across firms in U.S. state-level R&D costs from Wilson (2009), we confirm that this affiliate innovation investment response to local intellectual property laws is strongest among multinationals with high U.S. innovation costs.[5] Our results are also consistent with the idea that offshore affiliate imports from the associated U.S. headquarters is an significant channel through which knowledge is shared within the firm.[6]

Our paper is related to a growing literature that empirically examines the effects of intellectual property rights on multinational activity. Javorcik (2004) finds that strengthened patent rights encourage firms in high-technology sectors to establish subsidiaries within Eastern Europe and the former Soviet Union. Relatedly, Branstetter, Fisman, and Foley (2006) find that patent reforms are associated with increased royalty payments and R&D spending by U.S. multinational affiliates, with the largest effects in high-patent firms, and Bilir (2014) finds that strong patent institutions tend to attract multinational affiliates and also expand their sales, assets, and employment levels, particularly in sectors with long product lifecycles. Our paper builds closely on this literature and especially Bilir (2014), yielding additional conclusions. First, we consider the theoretical possibility that firms' technology lifetimes are heterogeneous, even within an industry, and document that such within-industry variation is salient in the data. Second, we endogenize the innovation decision and find that the data are consistent with selective innovation, implying patent reforms abroad shift not only where, but also what is innovated by global firms. Third, we restrict attention in the model to relatively productive firms that dominate innovation spending, but for which there is no theoretical offshoring response to a change in Southern intellectual property rights—and for these firms, we find that the innovation response to patent reforms is important.

Our work contributes to a long-standing debate regarding the link between competition and the rate of innovation (Schumpeter 1942, Arrow 1962). This literature has established that whether a marginal reduction in competition—for example through a policy that strengthens intellectual property rights—increases or decreases innovation depends on economic conditions prevailing prior to the policy change. Indeed, there is an intuitive logic going in both directions (Aghion et al 2005). On the one hand, stronger intellectual property rights lessen the 'escape-competition' motive for product entry (e.g. Qian 2008); on the other, stronger rights expand the effective size of the market for any given product, which can encourage innovation. We show in a simple model that one can partially reconcile these two views: patent reforms increase innovation but also 'slow' the realized rate of product obsolescence; in this, our work also relates to Shapiro (2012).

[5]See, for example, Bilir and Morales (2016).
[6]See Keller and Yeaple (2013).

Finally, our paper contributes to a line of research examining the foreign direct investment response to institutional frictions, including financial development, investor protection laws, and contractual imperfections (Antràs, Desai, and Foley 2009; Manova, Wei, and Zhang 2010; Bernard et al. 2010; Antràs 2003) as responses to corporate tax conditions (Hines 1997). Others have suggested that the effects of these imperfections and firms' ability to transfer earnings across national borders are particularly relevant among innovative firms, particularly those that manufacture cutting-edge technology (Antràs and Helpman 2004, Nunn and Trefler 2008, Davidson and McFetridge 1985). We find evidence that countries' institutions interact to shape the innovation activity of multinational firms. In particular, our results suggest that a patent reform in the South is more effective in attracting innovation by Northern multinationals when firms lack access to generous innovation subsidies in the North.[7] Our results are also in line with the idea that, for global firms, institutional quality in one country can affect firm outcomes in others. Specifically, we find support for the idea that institutional tolerance of imitation in one country affects the products firms manufacture and sell, even to markets with strong patent laws.

2 Model

Building on the simple, partial-equilibrium setup in Bilir (2014), this model considers how Northern firms respond to offshore imitation risk. The framework formalizes the idea that firms facing imitation risk develop products *selectively*, directing innovation effort toward short-lived varieties. Patent reforms reduce the profit consequences of imitation, expanding the range of profitable products toward longer-lived varieties and raising both innovation and the average length of the product lifecycle; these effects differ, however, according to sectors' underlying rates of technology obsolescence. To align the theoretical results with our data and empirical analysis below, the model restricts attention to firms that offshore manufacturing at all points during the product lifecycle.[8]

2.1 Production

Time is continuous, and at every moment, firms in sectors $j = 1, ..., J$ produce horizontally differentiated varieties for consumption in both the North and the South. Each country hosts a monopolistically competitive market of size 1. To produce, a sector-j firm i must cover the cost of developing an available technology into a new variety that is associated with proprietary, product-specific intellectual property (patented and tacit); conditional on doing

[7] See also Bilir and Morales (2016).

[8] Bilir (2014), Section II.G. The data include information on multinationals' offshore affiliate innovation investment only for relatively large Northern firms (see section 3)

so, the firm enjoys a monopoly in variety i until it is either imitated or becomes obsolete. Obsolescence arrives for variety i after a length of time T_{ij}, meaning that once product i reaches a market maturity of T_{ij} years, it becomes obsolete and is of no further economic value. In a departure from Bilir (2014), T_{ij} differs across varieties within industry j.[9]

Producing variety i in sector j requires using product-i technology to combine manufacturing with headquarters services and ongoing innovation investment. Innovating firms locate permanent headquarters in the North and a permanent manufacturing affiliate in the South. We assume that economic conditions favor manufacturing in the South rather than in the North, and that when offshoring, monopolists earn flow profits π^S in each market. To emphasize the innovation response to intellectual property reforms, and to align our analysis with the data, we restrict attention as noted above to relatively productive Northern firms that offshore manufacturing at all product maturities.[10]

A firm's monopoly power may be disrupted by imitation as in Bilir (2014), resulting in profit losses. Specifically, firms competing with an imitator capture only a fraction of the per-period profits π^S. This fraction depends in part on the quality of local patent enforcement, which we summarize with a pair of country-specific indexes ξ_N and ξ_S. Similar to Grossman and Lai (2004), ξ_i is the probability that a country-i patent is enforced at any point in time, but could also be interpreted as the fraction of territory in which patents are enforced. We assume that patents are perfectly enforced in the North, but not in the South, $\xi_N = 1$ and $\xi_S < 1$. Only where a patent fails to be enforced may imitators' products compete directly with innovating firms'. Hence, imitation products may only be sold in the South.

2.2 Imitation

Potential imitators exist in the South and may begin reverse-engineering a product at any time. As in Grossman and Helpman (1991), Glass and Saggi (2002), Bilir (2014), and elsewhere, assume the time to imitation success m is uncertain and arrives at a constant Poisson rate λ. Imitation effort thus may or may not yield an imitation product within the targeted variety's lifetime.

When an imitator successfully enters a market with imperfect patent protection, it engages in Bertrand competition with the innovating firm wherever patents are not enforced until the variety becomes obsolete (Grossman and Helpman 1991). Imitators produce final goods with the same production technology as innovating firms, but as indicated above, are relatively inefficient. As a result, a Northern firm suffers reduced profits when competing with

[9] Our approach is motivated by the evident importance of within sector variation in T_{ij}. Regressing T_{ij} on sector fixed effect indicates industry differences explain less than ten percent of the variation in T_{ij} in the cross section of patents sharing a common grant year.

[10] See note #7.

an imitator. The innovating firm sets a price just below the Southern imitator's marginal cost, deterring sales by the Southern firm, but also reducing its own profit to $\alpha\pi^S < \pi^S$ wherever patents are not enforced.[11]

2.3 Product Development

Under these assumptions, the expected flow profit for a product i with maturity $t \leq T_{ij}$ is

$$\begin{aligned}\pi(t) \equiv E_m[\pi(t; t \leq T_{ij}, \xi_S)] &= 2\pi^S \,\mathrm{P}\{m > t\} + (1 + \widetilde{\xi}_S)\pi^S \,\mathrm{P}\{m \leq t\} \\ &= (1 - \widetilde{\xi}_S)\pi^S \exp(-\lambda t) + (1 + \widetilde{\xi}_S)\pi^S\end{aligned} \tag{1}$$

where $\widetilde{\xi}_S \equiv \xi_S + \alpha\,(1 - \xi_S) < 1$. Accordingly, the expected lifetime profit for variety i is

$$\begin{aligned}E_m[\Pi(T_{ij}, \xi_S)] &= \int_0^{T_{ij}} \pi(t)dt \\ &= (1 + \widetilde{\xi}_S)\pi^S T_{ij} + (1 - \widetilde{\xi}_S)\pi^S[1 - \exp(-\lambda T_{ij})]/\lambda.\end{aligned} \tag{2}$$

Equation (1) reveals the effect of imperfect patent enforcement in the South on profits. Selling to both markets, the firm earns $2\pi^S$ as a monopolist until successful entry by an imitator, which occurs after an *ex ante* uncertain duration of time m. Once imitation has occurred, profit is π^S only where patents are enforced, and is elsewhere reduced to $\alpha\pi^S$ as described above. Notice that because the likelihood of imitation rises as a product matures, the fraction of the product lifetime spent competing with an imitator is, on average, increasing in T_{ij}. Thus, it can be shown that the average per-period profit $E_m[\Pi(T_{ij}, \xi_S)]/T_{ij}$ for i is strictly decreasing in T_{ij}: it is $2\pi^S$ for an infinitesimally-lived variety ($T_{ij} \to 0$) but falls toward $(1 + \widetilde{\xi}_S)\pi^S$ as the product life lengthens ($T_{ij} \to \infty$) as illustrated in Figure 1.

Lemma 1: *Whenever patents are imperfectly protected in the South ($\xi_S < 1$), the expected average profit per period earned by variety i monotonically decreases in T_{ij}, the length of the product-i lifecycle: $\partial[E_m\Pi(T_{ij}, \xi_S)/T_{ij}]/\partial T_{ij} < 0$.*

As a result, Northern firms facing imitation risk and costly product development exercise discretion over T_{ij} when making innovation decisions, and in particular, when choosing which technologies to develop into products. Suppose that there is a continuum of available technologies underlying industry j, and that for each, obsolescence arrives at an exogenous

[11] The parameter α is increasing in the productivity of the Northern firm relative to its imitator. In particular, if country-i firm productivity is summarized by a positive parameter φ_i that affects profits as in Melitz (2003), it can be shown that $\alpha \equiv \alpha(\widetilde{\varphi}, \sigma) = \sigma^\sigma(\sigma - 1)^{-(\sigma-1)}\widetilde{\varphi}^{\sigma-1}(1 - \widetilde{\varphi}) < 1$, where $\widetilde{\varphi} \equiv \varphi_S/\varphi_N < 1$.

Poisson rate that is specific to industry j.[12] The lifetime T_{ij} of any sector-j technology i thus follows an exponential distribution that we denote $\phi_j(T)$. Let T_j be the average lifetime of an industry-j technology implied by this distribution.

Any Northern firm may pay an industry-specific sunk cost to draw an idea i from the distribution ϕ_j. The firm thereby learns T_{ij}, and acquires the right—an exclusive right wherever patents are protected—to sell a sector-j variety based on idea i. To exercise this right, the firm must develop i into a viable product. This requires an applied research and development cost $c(T_{ij}) = cT_{ij}$, where the flow cost c is common across industries and incurred on a per-period basis; to keep things simple in what follows, we assume that the firm producing technology i introduces a non-overlapping sequence of distinct varieties sharing a common lifecycle length T_{ij}. Alternatively, upon learning T_{ij}, the firm may exit at no cost.

Provided that the innovation cost satisfies $(1 + \widetilde{\xi}_S)\pi^S < c < 2\pi^S$, only ideas with sufficiently short lifetimes are attractive targets for product development. A firm, having observed T_{ij}, pays the per-period research and development cost c and produces i only if the lifetime expected profits $E_m[\Pi(T_{ij}, \xi_S)]$ in (2) exceed $c(T_{ij})$. This occurs when T_{ij} is below the threshold value $\overline{T}(\xi_S)$, where $\overline{T}(\xi_S)$ is the unique product lifecycle length T_{ij} satisfying $E_m[\Pi(T_{ij}, \xi_S)]/T_{ij} = c$ (Figure 1), or implicitly,

$$\frac{1 - \exp[-\lambda \overline{T}(\xi_S)]}{\overline{T}(\xi_S)} = \frac{\lambda[c - (1 + \widetilde{\xi}_S)\pi^S]}{(1 - \widetilde{\xi}_S)\pi^S}. \tag{3}$$

Firms thus develop ideas into products *selectively* according to this sector-invariant cutoff $\overline{T}(\xi_S)$. Notice that this cutoff increases in ξ_S, implying innovating firms optimally develop longer-lived varieties when patents are better protected in the South: $\partial\overline{T}(\xi_S)/\partial\xi_S > 0$. Under perfect patent protection ($\xi_S \to 1$), firms develop all ideas into products.

ASSUMPTION 1: The product development cost c is smaller than initial, pre-imitation profits and larger than post-imitation profits: $(1 + \widetilde{\xi}_S)\pi^S < c < 2\pi^S$.

Lemma 2: *Northern firms facing imitation risk in the South develop ideas into products* selectively. *In any industry j, only varieties with sufficiently short lifecycles $T_{ij} < \overline{T}(\xi_S)$ are developed by innovating firms. The sector-invariant innovation cutoff $\overline{T}(\xi_S)$ is increasing in the quality of Southern patent protection ξ_S, implying firms pursue the development of longer-*

[12] We assume that this distribution of ideas results from a process of basic scientific research in the North that is exogenous to the firms whose product development decisions we consider. In the United States, where the firms we evaluate below are based, the government accounts for approximately one-third of all research and development expenditures, and is also the primary source of basic research funding (National Science Board 2014). This research is performed by university and public-sector research programs for which the firm-level incentives we consider here are unlikely to be an important factor.

lived varieties as offshore intellectual property rights are strengthened: $\partial \overline{T}(\xi_S)/\partial \xi_S > 0$.

In Lemma 2 above, firms' innovation decisions reflect the anticipated cost of future competition with an imitator. Longer-lived ideas are more likely to be imitated before obsolescence, and are thus relatively exposed to this risk; this discourages their development, shifting the industry distribution of manufactured varieties toward the shorter-lived. Intuitively, this selective innovation is a strategy by which firms reduce imitation exposure; in developing only short-lived varieties, firms essentially outpace potential imitators. An important implication is that such efforts to shorten product lives—whether by selective product development or simply faster innovation—can partially offset the costs of imitation risk, thereby serving as a strategic substitute for formal patent protection.[13]

2.4 The Innovation Response to Patent Reform

A Southern patent reform that increases ξ_S also increases $\overline{T}(\xi_S)$, implying that a larger share of available ideas are developed by firms into products within each industry j. As a result, total applied research and development spending in sector j,

$$R_j(\xi_S) = \int_0^{\overline{T}(\xi_S)} c\,\phi_j(t)dt$$

responds for all j, as does the average durability of manufactured varieties in sector j,

$$\widetilde{T}_j(\xi_S) = \int_0^{\overline{T}(\xi_S)} t\phi_j(t)dt.$$

Using the expressions above, it is simple to show that firms' total innovation spending increases in Southern patent rights ξ_S for any industry j, $\partial R_j(\xi_S)/\partial \xi_S > 0$, and that the average product lifetime in any sector j also increases, $\partial \widetilde{T}_j(\xi_S)/\partial \xi_S > 0$. Both changes are intuitive: a Southern patent reform reduces the negative profit consequences of imitation, encouraging firms to pursue the relatively exposed, longer-lived varieties.

Result 1: *An increase in the quality of Southern patent protection* ξ_S *also increases both a) industry-level R&D spending,* $\partial R_j(\xi_S)/\partial \xi_S > 0$*, and b) the average durability of manufactured varieties,* $\partial \widetilde{T}_j(\xi_S)/\partial \xi_S > 0$*, for each sector* j.

However, while a patent reform in the South increases overall innovation spending by Northern firms in all sectors, the magnitude of this increase follows a non-monotonic function

[13] Cohen et al (2000) describes a series of such substitutes, including lead time and secrecy.

across industries in the average durability T_j of underlying ideas, where recall that ideas are on average longer-lived than manufactured varieties in sector j, $T_j > \widetilde{T}_j(\xi_S)$, whenever patent protection is imperfect. In particular, the innovation response $\partial R_j(\xi_S)/\partial \xi_S$ to a change in ξ_S depends on the sector-j rate of technology obsolesce T_j as follows,

$$\frac{\partial^2 R_j(\xi_S)}{\partial \xi_S \partial T_j} = c \, \exp[-\overline{T}(\xi_S)/T_j] \, \overline{T}'(\xi_S) \, (\overline{T}(\xi_S) - T_j)/T_j^3 \tag{4}$$

and is increasing in T_j for $T_j < \overline{T}(\xi_S)$, but decreasing for $T_j > \overline{T}(\xi_S)$.[14] The largest impact of the patent reform occurs in the intermediate industry j for which the average durability of ideas satisfies $T_j = \overline{T}(\xi_S)$. This may be stated as follows:

Result 2: *The innovation response by Northern firms to a Southern patent reform follows a non-monotonic function of underlying idea durabilities T_j. The response is a) increasing in T_j for sectors with short-lived ideas, $\partial^2 R_j(\xi_S)/\partial \xi_S \partial T_j > 0$ if $T_j < \overline{T}(\xi_S)$, b) decreasing in T_j for sectors with long-lived ideas, $\partial^2 R_j(\xi_S)/\partial \xi_S \partial T_j < 0$ if $T_j > \overline{T}(\xi_S)$, and c) reaches its peak in an intermediate industry with $T_j = \overline{T}(\xi_S)$.*

Intuitively, the non-monotonicity described in Result 2 arises because the measure of available technologies that is marginal with respect to the reform-induced increase in $\overline{T}(\xi_S)$ is highest in the industry with the highest density of ideas near the innovation selection threshold $\overline{T}(\xi_S)$. As the distance between $\overline{T}(\xi_S)$ and the industry's average technology durability T_j widens, the measure of sector-j ideas that are affected by the reform declines.[15]

Finally, the increase in the durability of manufactured product varieties following a patent reform in the South also follows a non-monotonic function across industries with different underlying idea durabilities T_j. Like $\partial R_j(\xi_S)/\partial \xi_S$, the increase in product durabilities following the reform is highest in the intermediate industry with $T_j = \overline{T}(\xi_S)$.

Result 3: *The increase in the average lifetime of manufactured varieties following a Southern patent reform follows a non-monotonic function of average underlying idea durabilities T_j. The response is a) increasing in T_j for sectors with short-lived ideas, $\partial^2 \widetilde{T}_j(\xi_S)/\partial \xi_S \partial T_j > 0$ if $T_j < \overline{T}(\xi_S)$, b) decreasing in T_j for sectors with long-lived ideas, $\partial^2 \widetilde{T}_j(\xi_S)/\partial \xi_S \partial T_j < 0$ if $T_j > \overline{T}(\xi_S)$, and c) reaches its peak in an intermediate industry with $T_j = \overline{T}(\xi_S)$.*

[14] See the Appendix for details.

[15] Notice that the innovation mechanism behind the non-monotonicity that arises in this context is distinct from the offshoring mechanism in Bilir (2014). In that paper, Northern firms with durable varieties strategically delay offshoring to postpone imitation. Industries with short T_j do not respond to patent reform in the South, while industries with longer-lived products respond by shifting production to the South. Here, the density of available ideas with durability t in sector j is itself a non-monotonic function of T_j; this determines the measure of *ex ante* available technologies that are developed into new products following a patent reform.

2.5 The Affiliate Innovation Response

Extending the framework above to include an innovation location decision, it is simple to show that patent reforms have a further tendency to increase innovation performed by Southern affiliates. In particular, suppose that product-i flow profits π^S depend on whether innovation is performed in the North or in the South, to an extent that differs across firms. For simplicity, assume that if the Southern affiliate innovates, the firm earns π^S_S; if innovation is instead sourced in the North, the firm earns π^S_{Ni}, which is specific to product i and could be higher or lower than π^S_S depending on i. The product-i profit advantage of sourcing innovation in the North $|\pi^S_{Ni} - \pi^S_S|$ potentially reflects a) innovation subsidies in the North that differ across firms and locations (Wilson 2009), and b) differences in the relative productivity of affiliate innovation, which may depend on complementary investments of the firm as well as local institutions (Bilir and Morales 2016). We assume that the firm producing i always innovates at its preferred location, implying $\pi^S = \max\{\pi^S_S, \pi^S_{Ni}\}$, and that the distribution of π^S_{Ni} implies a sector-invariant probability of sourcing innovation for i in the South, $p_S \equiv P\{\pi^S_{Ni} < \pi^S_S\}$.

In this setting, a qualitatively identical prediction emerges for the impact of patent reform in the South on innovation among offshore affiliates of Northern firms. In particular, innovation spending by affiliates in the South

$$R^S_j(\xi_S) = \int_0^{\overline{T}(\xi_S)} p_S c\, \phi_j(t) dt$$

increases in ξ_S for each sector j, where recall $p_S \equiv P\{\pi^S_{Ni} < \pi^S_S\}$ is the probability that a given sector-j variety is supported by affiliate innovation. In addition, among varieties with $\pi^S_{Ni} < \pi^S_S$, this increase in Southern affiliate innovation follows a non-monotonic function of sectors' underlying idea durabilities T_j, which we state as follows.

Result 4: *Following a patent reform in the South, the innovation response by the Southern affiliates of Northern firms with $\pi^S_{Ni} < \pi^S_S$ follows a non-monotonic function of T_j. The response is a) increasing in T_j for sectors with short-lived ideas, $\partial^2 R^S_j(\xi_S)/\partial\xi_S\partial T_j > 0$ if $T_j < \overline{T}(\xi_S)$, b) decreasing in T_j for sectors with long-lived ideas, $\partial^2 R^S_j(\xi_S)/\partial\xi_S\partial T_j < 0$ if $T_j > \overline{T}(\xi_S)$, and c) reaches its peak in an intermediate industry with $T_j = \overline{T}(\xi_S)$. By contrast, Southern affiliate innovation in firms with $\pi^S_{Ni} > \pi^S_S$ is not responsive to the reform.*

Importantly, if Northern firms are multiproduct firms, Result 4 can be interpreted as having within-firm implications at the affiliate level; in particular, the probability that an affiliate in the South performs R&D increases non-monotonically in T_j as the firm adds new varieties to its portfolio. This affiliate-level response will be most pronounced among firms producing varieties i for which innovation costs tend to be high in the North ($\pi^S_{Ni} < \pi^S_S$).

3 Data and Measurement

3.1 Technology Obsolescence Rates

Evaluating the predictions of the model above requires measuring the economic durability of technologies embedded in products, and of technologies or ideas that exist within an industry but ultimately are not embedded into products. It is therefore critical to observe the evolution of technology by industry not only for firms, but also for non-firms. While technology produced by non-firms is by definition unobserved in firm-level datasets, U.S. patent records contain detailed information on technologies developed by both types of agents.

Technology Ownership and Origin

In particular, U.S. patent publications include precise information regarding both technological classification and ownership. Each patent is associated with a three-digit industry class, in addition to a three-digit subclass, allowing for a precise categorization of the technology. For ownership, what is relevant for evaluating the model is to discern whether idea i in sector j is developed into a product by a Northern firm, or whether idea i instead exists but goes undeveloped. The U.S. Patent and Trademark Office data do not explicitly record information about product development, but it is possible to observe whether patent i is owned by a firm, or instead by a non-firm such as a university, government, research institute, hospital, or individual, and whether the owner is domestic or foreign, using the NBER Patent Data Project categorization. In line with the model, we consider a patent that is owned or co-owned by a firm as likely to reflect the intent to develop a product involving the patented idea, and we view patents owned by non-firms as less likely to be developed without further refinement. In addition, to base our Lemma 2 comparison on patents involving a firm in 'the North', we restrict attention to patents with at least one U.S. owner.

Technology Lifecycle Lengths

With this restriction and categorization in hand, we build on the insights in Narin and Olivastro (1993) and Bilir (2014) to construct an index for the economic durability T_{ij} of patented technology i in sector j. The idea behind the T_{ij} index is that the length of time during which a given patent continues to be cited by subsequent patents provides an indication of the market lifetime of the cited patent's technology: a long average "forward citation lag"—the time lapse between the cited patent's grant date and a subsequent citation—tends to indicate that the technology exhibits lasting relevance to future innovation. Our main proxy for T_{ij} is thus the average forward citation lag, analogous to that in Bilir (2014), but is measured not only for each industry j (below) but also for each individual patent i.[16] Importantly, this proxy can be constructed using information in standard datasets (NBER Patent Citations Datafile, Hall, Jaffe, and Trajtenberg 2001). To account for truncation in the citations received by relatively recent patents, we measure T_{ij} using citations occurring within five years of the cited patent's grant date, and to reduce sensitivity to noisy citation dates, we exclude patents receiving fewer than three distinct citations.[17,18] Summary statistics for this T_{ij} index appear in Table 1.

Given the emphasis in the model on within sector-j variation in technology lifetimes T_{ij}, and because considering this within-sector variation is a key novel aspect of our study, it is worth examining whether the distinction between T_{ij} and T_j is meaningful. Evaluating the within-sector variation in the measured index T_{ij}, we find that the data indeed reject the idea that individual technology durabilities are tightly centered around a sector-j average T_j: industry fixed effects account for only nine percent of the total observed variation in T_{ij}, suggesting within-industry variation in technology lifetimes is highly relevant in the data. As in the model above, such variation can nevertheless arise from a process whereby lifetimes T_{ij} are stochastic, but are drawn from a common, industry-j distribution.

As argued in Bilir (2014), this patent-based measurement approach permits a useful flexibility, in that the durability of technology i can span multiple versions of a product over its lifecycle. This flexibility is ruled out by alternative measurement approaches, including proxies based on product turnover rates or patent renewal decisions.[19] It is also straightforward to control for variation in T_{ij} across patents with different grant years, industries, and citations (quality), where the latter is important as it can affect the precision of T_{ij}.

Industry-Average Lifecycle Lengths

[16] An alternative measurement approach would be to consider the maximum citation lag for each patent; while in practice this approach is sensitive to citation outliers, we replicate our results using the 75th-percentile citation lag, which captures variation similar to the maximum while remaining less exposed to noise in the citation data.

[17] Thus, while the patent data span the period 1976–2006, the sample of U.S. patents for which we observe T_{ij} extends only through 2001. In addition, patents may in certain cases be published and also cited prior to the grant date, while still in the application process. Most such citations occur no more than three years prior to the patent grant, around the length of time needed to process the patent application. We thus allow citations within the range of three years prior to, and five years after, the official patent grant date.

[18] That the T_{ij} index is based on citations within five years is guided by the timing of intellectual property reforms. From a U.S. perspective, the most important set of offshore patent reforms during the sample period were the result of the WTO's 1995 TRIPS agreement. Extending the post-grant period to include citations beyond five years has little effect on the cross-patent distribution of T_{ij}, but implies losing post-TRIPS observations: considering citations within ten years implies dropping all patents granted after 1996.

[19] Patent renewal data have been used to measure the asset value of patents (e.g. Pakes 1986); retail turnover data of detailed product varieties are available from Broda and Weinstein (2010).

Results 2, 3, and 4 suggest that the innovation response by firms in sector j to the quality of Southern patent protection is non-monotonic in T_j, the underlying industry-j average lifetime of an idea. To evaluate these results, we thus need a proxy for the industry-average lifetime index T_j and—recognizing that the structure of firms' global operations may differ—information on the country corresponding to 'the South' for each sector-j patent i. We measure T_j using two approaches: the first approach is broad, defining T_j as the industry-j average T_{ij} similar to Bilir (2014); the second approach measures T_j using only U.S. non-firm patents, in line with a strict application of our model assumption that the distribution of ideas results from basic scientific research in the North that is exogenous to firms.[20] This exogeneity also alleviates the potential for a mechanical link between T_{ij} and T_j, and is thus critical to evaluating Result 3 empirically.

Evaluating Results 2 through 4 requires a clear industry definition. For Result 3, which has a patent-based outcome measure, the industry is defined as the three-digit technology class of the patent. Mapping T_{ij} onto data for multinational activity from the BEA, however, involves using a concordance between U.S. patent classes and SIC 3-digit industry codes.[21] In most cases, many patent classes correspond to the same SIC industry. We therefore take an unweighted average $\widehat{T}_j$ index across all patent classes matched to a given SIC code as in Bilir (2014). In all cases, to construct $\widehat{T}_j$, we place no restriction on the patent class of citing patents, to allow for the possibility that a patented technology may have relevance to future innovation not only within its own class, but also for other patent classes.

3.2 Innovation in U.S. Multinational Firms

Results 2 and 4 link Northern multinational firms' innovation investment with intellectual property rights in the offshore manufacturing location. To evaluate these results, we use firm-level panel data on the global operations of U.S.-based multinationals from the Bureau of Economic Analysis (BEA) Survey of U.S. Direct Investment Abroad. These data provide information on U.S. parent companies and each foreign affiliate on an annual basis.[22] Our analysis uses data from benchmark-year surveys, which are the most extensive in both scope

[20] As robustness checks, we replicate the T_j index using a more disaggregated industry definition; also, in case short-T_{ij} patents differ from those with high T_{ij} values for measurement reasons unrelated to the mechanisms of the model, we consider the 75th percentile T_{ij} as an alternative industry proxy.

[21] This concordance can be downloaded from the website of the U.S. Patent and Trademark Office, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/data/sic_conc/2005_diskette/.

[22] Any U.S. person having direct or indirect ownership or control of ten percent or more of the voting securities of an incorporated foreign business enterprise or an equivalent interest in an unincorporated foreign business enterprise at any time during the benchmark fiscal year in question is considered to have a foreign affiliate. However, for very small affiliates that do not own another affiliate, parents are exempt from reporting with the standard survey form. Foreign affiliates are required to report separately unless they are in both the same country and three-digit industry. Each affiliate is considered to be incorporated where its physical assets are located.

and coverage and are available for 1982, 1989, 1994, 1999, 2004, and 2009.[23] Our analysis uses disaggregated information on affiliate-level expenditures on R&D investment, and the location (U.S. state), sales, and innovation investment of associated U.S. parent firms. Given the particular importance of R&D investment measures, we restrict attention to the relatively large firms and affiliates required to report R&D investment in each year.[24] Table 1 provides a summary of multinational activity across the six benchmark years.

3.3 Intellectual Property Rights

A proxy for the strength of patent protection across countries is provided by an index developed in Ginarte and Park (1997), and updated in Park (2008). Because this index is detailed in its construction and provides extensive coverage, it is widely used.[25] The strength of patent rights is documented for five distinct categories: 1) extent of coverage, 2) membership in international patent agreements, 3) provisions for loss of patent protection, 4) enforcement mechanisms, and 5) duration of protection. Each category receives a score between zero and one based on whether prevailing patent laws meet specific, objective criteria.[26] The index itself is the unweighted sum of these five sub-indexes, and so ranges between zero to five, with high values indicating strong protection. The index is available for 122 countries during 1980–2005 in five-year intervals; each benchmark survey year is matched with the closest available index year. Summary statistics appear in Table 1.

While the data on U.S. multinational firms described above allow us to fully observe the global structure of each firm—and to thereby exactly match each offshore manufacturing location with its relevant index of intellectual property protection—our ability to discern the relevant variation for a given patented idea i in industry j is only imperfect. To determine the relevant offshore market for patent i, we consider that a patent co-owned by both U.S. and foreign entities is an idea that is likely to have been developed, at least partially, subject

[23] The BEA's data coverage is nearly complete: in a typical benchmark year, the survey accounts for over 99 percent of affiliate activity. In 1994, for example, participating affiliates accounted for an estimated 99.8 percent of total assets, 99.7 percent of total sales, and 99.9 percent of total U.S. FDI. This reflects the requirement of participation for every U.S. person having a foreign affiliate. However, in certain cases involving missing survey responses, the BEA data may instead report imputed values; these values are coded accordingly and I exclude from my analysis all such observations.

[24] While the size threshold for affiliate R&D reporting is relatively low in early benchmark years, it rises to $90 million by 2009; affiliates for which sales, assets, and net income fall below this value are not required to report, and are therefore excluded from the analysis below. For this reason, the model in section 2 considers only relatively productive firms for which the decision to offshore is theoretically insensitive to intellectual property rights.

[25] See, for example, Bilir (2014), Qian (2007), Branstetter, Fisman, and Foley (2006), Javorcik (2004), McCalman (2004), and Yang and Maskus (2001).

[26] For example, the enforcement mechanisms category was scored by adding binary indicators corresponding to the availability of a) preliminary injunctions, b) contributory infringement pleadings, and c) burden-of-proof reversals. A country with laws meeting all three criteria would receive a value of 1 for this category.

to the influence of innovation incentives in the foreign country; we therefore associate each such co-owned patent with the country of the foreign inventor.[27]

4 Econometric Framework

The model in section 2 has implications linking the volume and composition of Northern firms' innovation with the quality of Southern patent institutions. In this section, we describe the estimation approach used to evaluate the data.

4.1 Estimating Equations

Lemma 2 indicates that firms facing imitation risk are selective in deciding whether to develop a given idea i into a product. This selection favors shorter-lived ideas, implying T_{ij} is, on average, shorter among patents owned by firms. Conversely, if the owning firm is primarily operating in markets for which patents are well-protected, the strength of this selection motive is decreased. To assess these predicted correlations, we use the full set of U.S.-owned patents for which we observe the ownership type as well as the location of the owner, and evaluate the following specification

$$T_{ij} = \alpha \, \mathrm{Firm}_i + \beta \, \mathrm{IPR}_n + \eta_j + \eta_t + \eta_c + \varepsilon_{ij} \qquad (5)$$

where T_{ij} is the measured durability of idea i, Firm_i indicates whether i is owned or partially-owned by a U.S. firm, and IPR_n captures the intellectual property rights for the country n the owner of i in 1975, just prior to the first patent observation in 1976. Equation (5) includes industry fixed effects corresponding to the three-digit technology class j of patent i, its grant year t, and the number of subsequent citations i receives within five years of t. Finding that $\alpha < 0$ and $\beta > 0$ would be in line with the selection described by Lemma 2.

Our specification for Result 3 builds on that above, but relies on additional sources of variation and is evaluated on a narrower sample of U.S. patents. In particular, Result 3 states that firms' selectivity across ideas i relaxes as patent laws are strengthened, implying firms' average T_{ij} increases in patent laws to an extent that is non-monotonic in industries' T_j, the mean of the underlying distribution of industry-j ideas. To align our estimates with the prediction, our evaluation restricts attention to the set of patents owned by a U.S. firm and a foreign co-inventor, and is based on following equation

$$T_{ij} = \beta_1 \, \mathrm{IPR}_{nt} \times T_j + \beta_2 \, \mathrm{IPR}_{nt} \times T_j^2 + \eta_j + \eta_{nt} + \eta_c + X_{njt} + \varepsilon_{ij} \qquad (6)$$

[27] If there are multiple foreign inventors on a patent with a U.S. co-owner, which occurs in a small minority of cases, we include separate observations for each patent-country pair rather than to take a stand on how to weight the institutional quality across the various countries involved.

where IPR_{nt} corresponds to the foreign country n of a patent-i co-owner in i's grant year t, T_j is the time-invariant technology durability index in i's industry j, η_{nt} is a country-grant year fixed effect, and all other variables are as in (5) above. The strong non-monotonicity prediction of Result 3 would be consistent with $\beta_1 > 0$, $\beta_2 < 0$, a positive marginal effect $\beta_1 + \beta_2 T_j$ for all observed T_j, and a peak effect $T^p = -\beta_1/2\beta_2$ falling within the range of industry-level idea durabilities T_j observed in the data. An important advantage of (6) relative to (5) is our ability to separately identify the influence of patent laws from unobserved country characteristics, such as general levels of economic development, that may evolve as a country strengthens its patent institutions. To address the further possibility that such characteristics interact with T_j, for example through changes in demand conditions, we extend (6) by adding interactions between GDP per capita and T_j.

Results 2, 3, and 4 are symmetric, distinguished only by the outcome variable: Results 2 and 4 are predictions for the innovation investment of a Northern firm facing imitation risk abroad, and are therefore evaluating using data on U.S.-based multinational firms' foreign affiliate operations. In particular, we consider the specification

$$R_{int} = \beta_1 \, \text{IPR}_{nt} \times T_j + \beta_2 \, \text{IPR}_{nt} \times T_j^2 + \eta_j + \eta_{nt} + \eta_i + X_{njt} + X_{it} + \varepsilon_{int}, \tag{7}$$

resembling (6), but in which R_{int} measures the innovation investment for the country-n affiliate of firm i in year t. Because a firm i is observed for multiple time periods, the equation includes firm i fixed effects as well as X_{it}, the R&D spending and sales revenues of the firm-i U.S. parent at t. All other variables are as defined above. Finding that $\beta_1 > 0$, $\beta_2 < 0$ would again be consistent with Results 2 and 4, as would a peak implied effect $T^p = -\beta_1/2\beta_2$ falling within the range of industry-level durabilities T_j observed in the data. In addition, Result 4 suggests that these effects should be observed only among the Southern affiliates of Northern firms with $\pi^S_{Nij} < \pi^S_S$—that is, Northern firms with a clear innovation cost *disadvantage* in the North. To assess this, each firm i is categorized according to the observed R&D user cost corresponding to the U.S. parent state and year, from Wilson (2009), and the specification above is then reevaluated separately for firms with high or low U.S. innovation costs.

4.2 Identification

In (6) and (7), identification of the main coefficients of interest β_1 and β_2 is based on within-'country-year' variation across industries in the underlying rate of technology obsolescence. An important advantage of this empirical approach is that it helps mitigate the challenge posed by policy changes that are concurrent to patent reforms. Improvements to intellectual property rights often occur alongside more general institutional or economic reforms—

reforms that also influence the location of multinational activity.[28] Countries joining the WTO, for example, not only align patent protection with the standards in TRIPS, but also make substantial changes to domestic policies, including trade and investment barriers. Because such factors affect multinationals' innovation decisions, the coefficients resulting from a simple regression of R_{int} or T_{ij} on IPR_{it} would lack a clear interpretation, as in Bilir (2014); it is therefore empirically challenging to evaluate Result 1 directly.

By contrast, through the model developed in section 2 above, the coefficients β_1 and β_2 have a clear interpretation (Results 2, 3, and 4). This is because variation in the average lifetime T_j of an underlying industry-j technology indexes variation in the measure of available ideas that are just above the innovation threshold $\overline{T}(\xi_S)$ and thereby affected by a small increase in ξ_S. Multinationals' innovation sensitivity with respect to formal patent laws is thus captured by T_j, while firms' sensitivity to general institutions and development levels is theoretically independent of T_j. Using cross-industry variation in T_j, we are therefore able to estimate the effect of patent laws on firms' innovation decisions separately from the effects of general institutions and development, even for cases in which all change simultaneously.

5 Main Results

5.1 Patent Ownership and Origin

We begin by evaluating the predicted correlation of Lemma 2 that, all else equal, technologies developed into products are on average shorter-lived than technologies that remain undeveloped—particularly if the firms responsible for product development face imitation risk in the destination market. This prediction is assessed using (5) and relying on the observed distinction between U.S. firm-owned patents and U.S.-owned non-firm patents, as argued above. Resulting correlations for U.S.-owned patents granted during 1976–2001 appear in Table 2, and are aligned with Lemma 2: it is apparent that T_{ij} is on average shorter for patents owned by U.S. firms relative to U.S.-owned patents granted to non-firms, regardless of whether or not controls for the industry, grant year, and quality of patent i are included. In particular, the coefficient α is negative and highly significant across all columns, indicating U.S. firm-owned technologies are approximately 2.2 percent shorter lived relative to technologies introduced by the U.S. government, U.S. universities, and so on (column 8).

The estimated correlations in Table 2 further suggest that, among U.S. patents, those owned by a U.S. inventor or co-owned by both U.S. and foreign inventors have lifetimes that

[28] The literature has documented substantial correlations between patent laws and general institutions, including economic development and market openness (Acemoglu, Johnson, and Robinson 2005), legal origin (Lerner 2009), and economic growth (Evenson 1990). The data used in this analysis reveal a persistent correlation across countries between GDP per capita and the IPR index of between 60 and 70 percent.

increase systematically in the strength of intellectual property rights in the inventor country, on average. Although only a small minority of patents are co-owned by both U.S. and foreign inventors, the coefficient β in Table 2 is positive and precisely estimated, indicating that a patent owned by a U.S. inventor (highest patent index, $\text{IPR}_{US,1975} = 3.83$) is approximately 12 percent longer lived than a patent co-owned by U.S. and Venezuelan inventors (lowest patent index, $\text{IPR}_{Ven,1975} = 0.92$) (column 8).

5.2 Technology Obsolescence in U.S. Firms

Estimates of (6) appear in Table 3, and correspond to the predictions of Results 1 and 3 that patent reforms encourage firms to pursue longer-lived varieties, increasing (non-monotonically) the realized length of product lifecycles depending on industries' rates of underlying technological change. The key coefficients β_1 and β_2 are on the interactions between patent rights IPR and industry-average technology durability T_j in columns 3–6. Patents included as observations in Table 3 are those jointly owned by a U.S. firm and at least one foreign co-inventor, and the industry-level index T_j is measured based either on all U.S. patents (Panel A) or on only U.S.-owned non-firm patents (Panel B). In Panel B, patents included as observations are thus *excluded* from the T_j index.

In line with Result 3, the estimated coefficient β_1 on the linear interaction IPR $\times$ T is positive, while the estimated β_2 on the quadratic interaction IPR $\times$ T^2 is negative. These coefficients imply a concave curve indicating initially increasing sensitivity to patent laws as T_j rises, then reaching a peak and subsequently decreasing in T_j. The magnitudes indicate a peak effect in the industry with $T_j = 2.23$, just below the average, and in line with the theory, the marginal effect $\beta_1 + \beta_2 T_j$ is positive for the full range of observed T_j values. Recall that non-monotonicity arises in the model because industries with T_j near the product development threshold $\overline{T}(\xi_S)$ have the highest density of ideas that are marginal with respect to an increase in ξ_S. As the average lifetime of an idea diverges from the threshold $\overline{T}(\xi_S)$, toward either shorter- or longer-lived ideas, a declining measure of ideas responds.

Columns 1 and 2 consider the simple correlation between the durability of patented idea i and patent rights in the inventor origin country. The estimated coefficient on the patent rights index is positive in both columns, in line with Result 1, but unsurprisingly, is not precisely estimated; as in Bilir (2014), this reveals the potential limitations of an identification strategy that relies only on within-country time-series variation in patent laws.

All specifications include industry fixed effects that capture relevant sectoral differences in R&D intensity and competitiveness, as well as the industry-average durability of available ideas T_j. Columns 1 and 2 further include country and year fixed effects and time-varying country GDP per capita, to control for levels of economic development that may change concurrently with patent laws. Columns 3–6 replace these with a set of country-year fixed effects, which capture not only the patent index and GDP per capita, but any other country characteristic that is dynamic and that impacts innovation. Because countries could differ in demand or inputs necessary for production in sector j, columns 4 and 6 include interactions between GDP per capita and T_j. Finally, to control for patent quality, even-numbered columns include the number of citations received within five years of the grant date.

5.3 Innovation in U.S. Firm Affiliates Abroad

A limitation to interpreting the patent-level results above is that not all innovation is patented, leaving unobserved a potentially important component of firms' innovation response to intellectual property reforms. Indeed, secrecy and other mechanisms have been established as important methods of protecting intellectual property, particularly where patents are imperfect (e.g. Cohen et al 2000), and the decision to increase the durability of targeted innovations could potentially manifest itself as a response independent of patenting. To permit a broader interpretation of the results above, we therefore consider the innovation response in U.S. firms' manufacturing affiliates abroad.

For this, it must be recognized that the model features an industry in which all firms and affiliates are accounted for. In the data, however, only relatively large affiliates report R&D investment, implying truncation at the industry level as well as at the multinational firm level.[29] At these aggregate levels, it is difficult to translate Results 2 and 4 into clear empirical analogs; at the affiliate level, however, this is possible in certain cases. In particular, if multinationals are multiproduct firms, then the model predicts that the firm adds new products—relatively durable ones—to the portfolio of its country-n manufacturing affiliate following a patent reform in n. Adding a product requires funding the stream of R&D investment at cost c per period, which is performed by the affiliate with probability p_S. Thus, one way to interpret Result 4 is that the affiliate-level R&D propensity should increase in local patent rights, again non-montonically as a function of T_j. Notice that this is not because imitation is facilitated by affiliate R&D investment, which therefore responds to a change in imitation costs—instead, it is because patent reforms prompt increased innovation and the entry of longer-lived products.

The estimates in Tables 4 and 5 evaluate whether this interpretation of Result 4 is consistent with the data. Although some variation in T_j is lost in the match from patents to firms' SIC industry codes—going from 472 unique classes, to roughly 30 SIC industries—the results in Table 4 are nevertheless revealing. The propensity for an affiliate to perform R&D is indeed increasing in patent rights, and non-monotonically so, according to T_j. And, even though the index is aggregated relative to that in Tables 2 and 3, the peak effect implied

[29] In 2009, for example, only affiliates with above \$80 million in sales, assets, or net income are required to report R&D investment.

by the estimates in Table 4 is still around the industry with the average T_j, similar to the patent-level results above.

All columns in Table 4 include industry fixed effects and either country and year effects (column 1), or country-year fixed effects (column 2–6). To control for potential differences across firms in scale, productivity, and R&D intensity, all columns include firm-specific U.S. parent R&D investment and sales. Firm fixed effects (column 6) capture any other firm characteristics relevant to the affiliate innovation decision (e.g. the number of products).

U.S. Parent Innovation Costs

Result 4 suggests that the affiliate-level innovation response in Table 4 should be relatively pronounced among firms for whom it is relatively profitable to source innovation in the South. One way to identify such firms is to consider differences across U.S. headquarters locations in the generosity of innovation subsidies such as state-level R&D tax credits. To evaluate this, Table 5 takes a split-sample approach, categorizing multinationals' U.S. headquarters innovation costs as either high or low using observed variation in firms' U.S. user cost of R&D. The measured user cost of R&D for all state-year pairs during 1963–2006 is from Wilson (2009); the measure reflects primarily changes in state-level R&D tax credits, but also accounts for corporate tax rates and capital rates of return. We simply categorize a U.S. parent as a high-cost innovator (for which π^S_{Ni} likely falls below π^S) if its U.S. user cost of R&D falls above the median value.

The split-sample results are in Table 5: estimates for U.S. parents with low U.S. R&D costs are in columns 1–3, and those for high-cost parents are in columns 4–6. It is apparent across these six columns that regardless of whether GDP per capita $\times$ T interactions and firm fixed effects are included, there is a strong response among high-cost U.S. parents, while among low-cost parents the affiliate response is statistically indistinguishable from zero. This is consistent with the idea that, in multinational firms sourcing product innovation at the U.S. headquarters for cost reasons, offshore affiliates do not increase innovation in response to a local patent reform. It is instead firms facing high U.S. innovation costs for which R&D sourcing decisions are sensitive to the reform. These results highlight an important interaction between home and host country institutions that, in this case, shape the innovation response to patent reforms.[30]

[30] Bilir and Morales (2016) relies on this source of variation to identify the impact of U.S. firms' foreign affiliate R&D on subsequent firm performance.

6 Robustness

We perform a series of additional specifications aimed at evaluating the stability of the results. First, we replicate the results using alternative indexes of industry and patent level technology obsolescence rates. We find nearly identical results using the 75^{th} percentile of patent citations instead of our main measures of T_{ij} and T_j in Table 6. This ensures that our industry-level index of idea obsolescence is not driven by unsuccessful innovations that receive few citations, and also helps ensure that variation in the patent-level index reflects the timing of relatively informative citations that occur later in the product life. Separately, we use the patent subclass to construct a more detailed T_j index that varies across four-digit industries in Table 7; although the industry fixed effects we include limit the sample size under this alternative T_j definition, relative to Table 3, the results are essentially unchanged in magnitude and remain strongly significant.

The results above indicate that affiliate innovation spending is more sensitive to local patent laws when U.S. parent innovation costs are relatively high. That affiliates' innovation is sensitive only in this case strongly suggests that U.S. parent innovation can serve as a substitute for affiliate innovation. While this is in line with Bilir and Morales (2016), which finds that both parent and affiliate innovation investment contribute to growth in affiliate performance, it raises the question of how knowledge resulting from R&D investment is transferred across borders from parent to affiliate. To shed light on potential transfer mechanisms, Table 8 replicates Table 5 using observed intrafirm import propensity by an affiliate from its corresponding U.S. parent. The results indicate strong sensitivity in affiliate import propensity with respect to patent laws in the host country, but primarily among multinationals with low U.S. innovation costs—firms likely to source innovation at the U.S. parent rather than offshore. By contrast, affiliate imports from the U.S. parent are unresponsive in multinational firms facing high headquarters innovation costs. Consistent with Keller and Yeaple (2013), these results support the idea that tangible intrafirm trade is one channel through which innovation output is shared within firm boundaries.

7 Discussion

This paper provides evidence that offshore patent laws influence global firms' innovation decisions. Within a simple global production model, we find that a novel consequence of imitation risk is that firms innovate selectively, directing investments in product development toward relatively short-lived varieties that are difficult to imitate prior to obsolescence. A key implication of firms' selective product development is that patent reforms tend to increase not only firms' overall innovation, but also the average economic lifetime of the products they develop—both to extents varying non-monotonically across industries according to underlying rates of technological change. Using detailed data on U.S. patent grants and citations during 1976–2006 and U.S. multinational firms' affiliate innovation investment during 1982–2009, we find robust evidence consistent with these hypotheses.

Our results speak to an ongoing debate regarding the relationship between competition and the rate of innovation. While strong patent rights can encourage innovation (Schumpeter 1942), the incentive to escape competition can also be an important motive (e.g. Qian 2008, Aghion et al 2005); indeed, the reward to certain forms of innovation may be lower for an incumbent monopolist than for a competitive firm (Arrow 1962), suggesting stronger patent rights could *reduce* innovation. Our results suggest offshore patent reforms do increase innovation, but also encourage reductions in the rate of product turnover ('slower' innovation), and are thus—to a certain extent—consistent with all of these views.[31]

The selective innovation mechanism we emphasize is conceptually related to Melitz (2003), but our model emphasizes a specific microfoundation for productivity. In our model, products share identical productivities *ex ante* but differ *ex post* due to imitation that, while random in incidence, nevertheless impacts the lifetime profitability of a variety to an extent that increases, on average, in the length of its economic life. Imitation thus induces forward-looking firms to innovate selectively—and patent reforms lessen this selectivity. In considering imitation and intellectual property rights as factors shaping firms' productivity, our model yields an important and distinct set of policy implications, as imitation effectively transfers surplus away from foreign multinationals and toward local consumers by reducing prices. A global economy dominated by large, technology-intensive multinational firms may thus be one in which intellectual property enforcement serves as an influential border instrument that countries may exercise strategically alongside traditional tariff policies.

Given this, however, it is important to recognize that the enforcement of intellectual property rights permits considerable local discretion across firms and technologies. If patent infringement litigation is resolved based on the opinion of local judges and juries, it may also be subject to local bias, thereby facilitating implicit protectionism (e.g. Love, Helmers, and Eberhardt 2016). This essential concern forms the basis for major international intellectual property treaties including the Paris Convention of 1883 and the more recent 1995 TRIPS agreement (Bilir, Moser, and Talis 2012), but it is unclear that these agreements are sufficient, as countries including the United States are seeking substantially deeper integration in current regional trade agreement negotiations (U.S. Chamber of Commerce 2013). In light of these observations, understanding the strategic importance of intellectual property policy in the modern global economy is an important area for future work.

[31]See also Shapiro (2012).

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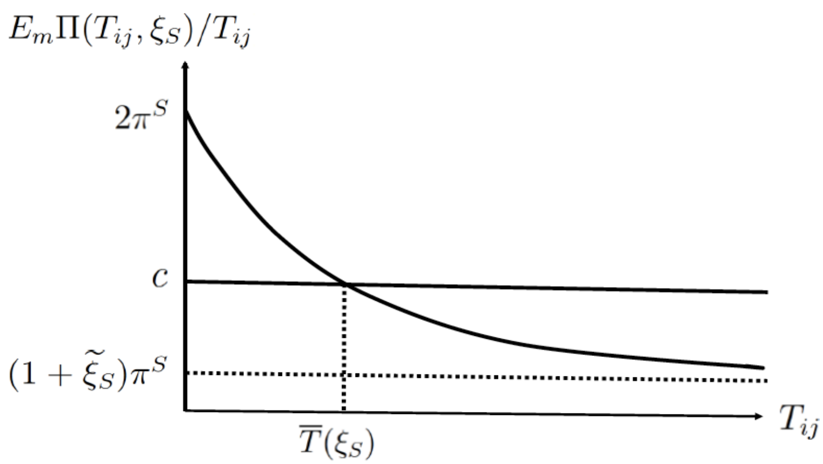
Figure 1: Imitation and Innovation Selection



Notes: This figure describes the determination of the innovation selection cutoff as the product lifecycle length corresponding to the intersection between the product development flow cost *c* and average expected profits per period, which declines in the length of the product lifecycle because in expectation, a longer-lived variety spends a greater fraction of the lifecycle competing with an imitator and earning reduced profits.

Table 1: Regression Summary Statistics

Variable	Mean	St Dev	Min	Max
Affiliate-Year Level:				
Indicator for Positive R&D Investment	0.312	0.463		
log R&D Investment, Conditional on Positive	6.431	2.009		
log Sales	10.450	2.097		
log Number of Employees	4.913	1.614		
log U.S. Parent Sales	14.950	0.132		
log U.S. Parent R&D	10.886	3.305		
U.S. Parent R&D Intensity (R&D/Sales)	0.053	0.411		
Intellectual Property Rights Index (IPR)	3.695	1.020	0	4.680
log GDP per capita	9.851	0.746	5	11.345
U.S. Parent R&D User Cost	1.225	0.079	1.043	1.499
Industry Average Patent Citation Lag (years)	8.571	0.486	7	11
Patent Level:				
Average Patent Citation Lag (years), Index ≤ 5	2.355	1.251	-3	5
Number of Citations, Forward Lag ≤ 5 years	7.687	11.367	1	296
Indicator for U.S. Firm Ownership	0.933	0.249	0	1
Indicator for U.S. Firm Ownership with Non-U.S. Inventor	0.004	0.066	0	1
General:				
Number of Affiliates	14926			
Number of Firms	1702			
Number of U.S. Patents	916245			

Notes: This table summarizes the data on U.S. multinational firms and U.S. patents used in the analysis. Firm statistics correspond to U.S. multinational firms and their majority-owned foreign affiliates that are large and thus required to report innovation spending during the period 1982-2009. Patent statistics correspond to U.S. patents assigned to U.S. entities and granted during 1976-2006. The Intellectual Property Rights Index (IPR) is from Ginarte and Park (1997) and Park (2008); this and GDP per capita, from the Penn World Table, correspond to the affiliate country during year t. The U.S. Parent R&D User Cost is from Wilson (2009) and corresponds to the firm-i U.S. parent location during the year t. The Average Patent Citation lag is measured at the SIC three-digit industry level and is from Bilir (2014). This index is also measured at the patent level; to maximize the patent sample while minimizing truncation effects, the index is based on citations occuring within either five or ten years after the patent grant date. These measures and the indicators for U.S. firm-owned patents, with either domestic or foreign inventors, are from the NBER Patent Citations Datafile (Hall, Jaffe, and Trajtenberg 2001).

Table 2: Patent Laws, Firms, and Technology Obsolescence, U.S. Patents 1976—2006

Dependent Variable:	Technology durability index, patent *i* in sector *j*							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	U.S. patents granted 1976—2001, index ≤ 5							
U.S. Firm-Owned $_i$	-0.0535***	-0.0540***	-0.0726***	-0.0727***	-0.0454***	-0.0454***	-0.0519***	-0.0519***
	0.0056	0.0056	0.0057	0.0057	0.0053	0.0053	0.0053	0.0053
IPR $_i$		0.4098***		0.3027***		0.0908***		0.0904***
		0.0191		0.0178		0.0152		0.0152
Industry FE	N	N	Y	Y	Y	Y	Y	Y
Year FE	N	N	N	N	Y	Y	Y	Y
Citations FE	N	N	N	N	N	N	Y	Y
Observations	916245	916245	916245	916245	916245	916245	916245	916245
R^2	0.0001	0.0007	0.0533	0.0536	0.2036	0.2036	0.2080	0.2080

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for (3) and several variants thereof. The dependent variable captures the durabilty of sector-*j* patent *i* and is the average forward citation lag across citations occuring within five years of the grant date. The sample includes all patents assigned to U.S. entities. To ensure that citations are observed for a uniform period across patents, the sample includes only patents granted by December 2001. U.S. Firm-Owned indicates that the ultimate owner of the patent is a U.S. corporation; this variable and all patent information is from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in 1975. Specifications include industry fixed effects (columns 3-8), grant year fixed effects (columns 5-8), and citation volume fixed effects (columns 7 and 8). Robust standard errors clustered by inventor country appear below each point estimate.

Table 3: Technology Obsolescence in U.S. Firms, Reponse to Patent Laws Abroad, 1976—2001

Dependent Variable:	Technology durability index, patent *i* in sector *j*					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A	Industry T_j measured using all U.S. patents					
IPR	0.1254*	0.1296**				
	0.0640	0.0581				
IPR x T			2.8517***	3.6275***	2.8322***	3.5610***
			0.6763	1.1034	0.6921	1.1699
IPR x T^2			-0.7008***	-0.9380***	-0.6945***	-0.9199***
			0.1740	0.2914	0.1823	0.3142
R^2	0.5514	0.5583	0.5825	0.5828	0.5894	0.5897
Panel B	Industry T_j measured using U.S.-owned non-firm patents					
IPR x T			3.8471***	3.4253**	3.8492***	3.3477**
			0.9659	1.5318	0.9761	1.5604
IPR x T^2			-0.8652***	-0.7934*	-0.8629***	-0.7737*
			0.2435	0.3819	0.2507	0.3965
R^2			0.5828	0.5832	0.5898	0.5902
Industry FE	Y	Y	Y	Y	Y	Y
log GDP per capita	Y	Y	N	N	N	N
Country FE, Year FE	Y	Y	N	N	N	N
Country-Year FE	N	N	Y	Y	Y	Y
log GDP per capita x T, T^2	N	N	Y	Y	Y	Y
Citations FE	N	Y	N	N	Y	Y
Observations	2921	2921	2921	2921	2921	2921

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for (4) and several variants thereof. The dependent variable captures the durabilty of sector-*j* patent *i* and is the average forward citation lag across citations occuring within five years of the patent-*i* grant date. The sample includes all patents owned by U.S. firms and at least one foreign inventor; for the minority of such patents with multiple foreign inventors, the sample includes a separate entry per patent-country pair. Because the dependent variable T_i is sensitive at low citation volumes, the sample excludes the approximately 25 percent of patents receiving three or fewer citations. IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-*i* grant year; GDP per capita is from the Penn World Table. T is the time-invariant average patent citation lag in sector *j* across all U.S. patents assigned to that sector; both this and the dependent variable are measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). All specifications include industry fixed effects, country and year (columns 1 and 2) or country-year fixed effects (columns 3-6), and patent citation volume fixed effects (columns 7 and 8). Robust standard errors clustered by inventor country appear below each point estimate.

Table 4: Affiliate Innovation in U.S. Firms, Reponse to Patent Laws Abroad, 1982—2009

Dependent Variable:	Indicator for affiliate R&D investment, firm *i* in country *n* in year *t*					
	(1)	(2)	(3)	(4)	(5)	(6)
IPR	0.0032					
	0.0079					
IPR x T		0.2190***	0.5163***	0.2188***	0.5158***	0.2841*
		0.0698	0.1237	0.0700	0.1240	0.1510
IPR x T^2		-0.0113***	-0.0274***	-0.0113***	-0.0274***	-0.0149*
		0.0037	0.0066	0.0037	0.0066	0.0083
log GDP per capita	0.0075					
	0.0318					
log GDP per capita x T			-0.5795***		-0.5795***	-0.4913**
			0.2099		0.2099	0.2034
log GDP per capita x T^2			0.0312***		0.0312***	0.0266**
			0.0111		0.0111	0.0111
IPR x R&D Intensity				0.0040	0.0034	0.0645**
				0.0220	0.0220	0.0293
IPR x R&D Intensity^2				0.0000	0.0000	-0.0615*
				0.0003	0.0003	0.0369
Industry FE	Y	Y	Y	Y	Y	Y
Parent Sales, Parent R&D	Y	Y	Y	Y	Y	Y
Country FE, Year FE	Y	N	N	N	N	N
Country-Year FE	N	Y	Y	Y	Y	Y
Firm FE	N	N	N	N	N	Y
Observations	24300	24300	24300	24300	24300	24300
R^2	0.2364	0.2461	0.2464	0.2461	0.2464	0.3783

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for (5) and several variants thereof. The dependent indicates whether multinational firm *i*'s country-*n* affiliate performs R&D investment activity in year *t* during the period 1982-2009. IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-i grant year; GDP per capita is from the Penn World Table. T is the time-invariant average patent citation lag in the firm-*i* sector *j* across all U.S. patents assigned to that sector, and is measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). R&D Intensity corresponds to the firm-*i* U.S. parent, and is the ratio of R&D to sales. All specifications include industry fixed effects, parent R&D investment, and parent sales. All firm-specific data are from the Bureau of Economic Analysis. Column 1 includes country and year effects; columns 3-7 include country-year fixed effects, and column 7 includes firm-*i* fixed effects. Robust standard errors clustered by inventor country appear below each point estimate.

Table 5: Affiliate Innovation in U.S. Firms, Heterogeneous Reponse to Patent Laws Abroad, 1982—2009

Dependent Variable:	Indicator for affiliate R&D investment, firm *i* in country *n* in year *t*					
	Low U.S. R&D Cost			High U.S. R&D Cost		
	(1)	(2)	(3)	(4)	(5)	(6)
IPR x *T*	-0.0440	0.1416	0.0494	0.4468***	0.9675***	0.6599**
	0.1380	0.2936	0.2681	0.1088	0.1849	0.2694
IPR x T^2	0.0027	-0.0073	-0.2717	-0.0236***	-0.0524***	-0.0354**
	0.0072	0.0155	0.2806	0.0059	0.0101	0.0152
log GDP per capita x *T*		-0.2573	-0.5795		-1.1271***	-1.1068**
		0.4008	0.2099		0.3211	0.4450
log GDP per capita x T^2		0.0139	0.0148		0.0619***	0.0611**
		0.0209	0.0152		0.0175	0.0250
Industry FE	Y	Y	N	Y	Y	N
Parent Sales, Parent R&D	Y	Y	Y	Y	Y	Y
Country-Year FE	Y	Y	Y	Y	Y	Y
Firm FE	N	N	Y	N	N	Y
Observations	12386	12386	12386	11464	11464	11464
R^2	0.1216	0.1217	0.2881	0.3678	0.3688	0.5124

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. This table provides least-squares estimates for a variant of (5) that permits differences across firms *i* in the cost of U.S. parent innovation relative to affiliate innovation. The dependent indicates whether multinational firm *i*'s country-*n* affiliate performs R&D investment activity in year *t* during the period 1982-2009. Each affiliate is categorized as having either low (columns 1-3) or high (columsn 4-6) U.S. parent R&D costs based on the user cost of R&D reported in Wilson (2009). IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-*i* grant year; GDP per capita is from the Penn World Table. *T* is the time-invariant average patent citation lag in the firm-*i* sector *j* across all U.S. patents assigned to that sector, and is measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). All firm-specific data are from the Bureau of Economic Analysis. Specifications include industry fixed effects (columns 1-2, 4-5) or firm-*i* fixed effects (columns 3 and 6), as well as parent R&D investment, parent sales, and country-year fixed effects (all columns). Robust standard errors clustered by affiliate country appear below each point estimate.

Table 6: Patent Laws and Technology Obsolescence in U.S. Firms, 75th-Percentile Citation Lag, 1976—2001

Dependent Variable:	Technology durability index, patent *i* in sector *j*					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A	Industry T_j measured using all U.S. patents					
IPR	0.1948**	0.2001***				
	0.0720	0.0647				
IPR x T			5.3462***	5.7131***	5.2282***	5.8786***
			1.0501	1.6596	1.0395	1.7439
IPR x T^2			-0.8727***	-0.9539***	-0.8575***	-0.9908***
			0.206	0.3117	0.1999	0.3209
R^2	0.4983	0.5135	0.5313	0.5314	0.5459	0.546
Panel B	Industry T_j measured using U.S.-owned non-firm patents					
IPR x T			5.6557***	3.9793**	5.1254***	3.7973**
			1.6344	1.7574	1.556	1.6817
IPR x T^2			-0.8474**	-0.5608*	-0.7588**	-0.5342*
			0.2989	0.3164	0.2843	0.3011
R^2			0.5311	0.5313	0.5458	0.5459
Industry FE	Y	Y	Y	Y	Y	Y
log GDP per capita	Y	Y	N	N	N	N
Country FE, Year FE	Y	Y	N	N	N	N
Country-Year FE	N	N	Y	Y	Y	Y
log GDP per capita x T, T^2	N	N	Y	Y	Y	Y
Citations FE	N	Y	N	N	Y	Y
Observations	2921	2921	2921	2921	2921	2921

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for (4) and several variants thereof. The dependent variable captures the durabilty of sector-*j* patent *i* and is the average forward citation lag across citations occuring within five years of the patent-*i* grant date. The sample includes all patents owned by U.S. firms and at least one foreign inventor; for the minority of such patents with multiple foreign inventors, the sample includes a separate entry per patent-country pair. Because the dependent variable T_i is sensitive at low citation volumes, the sample excludes the approximately 25 percent of patents receiving three or fewer citations. IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-*i* grant year; GDP per capita is from the Penn World Table. T is the time-invariant average patent citation lag in sector *j* across all U.S. patents assigned to that sector; both this and the dependent variable are measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). All specifications include industry fixed effects, country and year (columns 1 and 2) or country-year fixed effects (columns 3-6), and patent citation volume fixed effects (columns 7 and 8). Robust standard errors clustered by inventor country appear below each point estimate.

Table 7: Patent Laws and Technology Obsolescence in U.S. Firms, Disaggregated Industries, 1976—2001

Dependent Variable:	Technology durability index, patent *i* in sector *j*					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A	Industry T_j measured using all U.S. patents					
IPR	0.2323***	0.2424***				
	0.0709	0.0676				
IPR x T			2.6635**	3.6343**	2.5540**	3.4388**
			1.1653	1.4294	1.1305	1.4568
IPR x T^2			-0.6162*	-0.9030**	-0.5811*	-0.8452**
			0.3037	0.3701	0.2963	0.381
R^2	0.6379	0.6468	0.6697	0.6700	0.6792	0.6794
Panel B	Industry T_j measured using U.S.-owned non-firm patents					
IPR x T			4.0442***	4.2121***	3.8764***	3.9154**
			1.1116	1.3449	1.0425	1.4168
IPR x T^2			-0.8223***	-0.8635**	-0.7787***	-0.7882**
			0.2798	0.3502	0.2617	0.364
R^2			0.6698	0.6698	0.6785	0.6785
Industry FE	Y	Y	Y	Y	Y	Y
log GDP per capita	Y	Y	N	N	N	N
Country FE, Year FE	Y	Y	N	N	N	N
Country-Year FE	N	N	Y	Y	Y	Y
log GDP per capita x T, T^2	N	N	Y	Y	Y	Y
Citations FE	N	Y	N	N	Y	Y
Observations	2361	2361	2361	2361	2361	2361

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for (4) and several variants thereof. The dependent variable captures the durabilty of sector-*j* patent *i* and is the average forward citation lag across citations occuring within five years of the patent-*i* grant date. The sample includes all patents owned by U.S. firms and at least one foreign inventor; for the minority of such patents with multiple foreign inventors, the sample includes a separate entry per patent-country pair. Because the dependent variable T_i is sensitive at low citation volumes, the sample excludes the approximately 25 percent of patents receiving three or fewer citations. IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-*i* grant year; GDP per capita is from the Penn World Table. T is the time-invariant average patent citation lag in sector *j* across all U.S. patents assigned to that sector; both this and the dependent variable are measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). All specifications include industry fixed effects, country and year (columns 1 and 2) or country-year fixed effects (columns 3-6), and patent citation volume fixed effects (columns 7 and 8). Robust standard errors clustered by inventor country appear below each point estimate.

Table 8: Affiliate Imports from U.S. Parent, Patent Laws, 1982—2009

Dependent Variable:	Indicator for affiliate imports from U.S. parent, firm *i* in country *n* in year *t*			
	Low U.S. R&D Cost		High U.S. R&D Cost	
	(1)	(2)	(3)	(4)
IPR x T	0.6985**	0.7312**	-0.4093*	0.0313
	0.2926	0.2981	0.2143	0.2480
IPR x T^2	-0.0374**	-0.0394**	0.0240*	-0.001
	0.0159	0.0163	0.0120	0.0140
log GDP per capita x T	-0.6209**	-0.8717***	1.2135***	0.3341
	0.2879	0.2879	0.3733	0.4117
log GDP per capita x T^2	0.0314**	0.0457***	-0.0690***	-0.0195
	0.0156	0.0157	0.0209	0.0232
Industry FE	Y	N	Y	N
Parent Sales, Parent R&D	Y	Y	Y	Y
Country-Year FE	Y	Y	Y	Y
Firm FE	N	Y	N	Y
Observations	10976	10976	14014	14014
R^2	0.3805	0.4893	0.2519	0.4080

Notes: * p < 0.10, ** p < 0.05, *** p < 0.01. This table provides least-squares estimates for a variant of (5) that permits differences across firms *i* in the cost of U.S. parent innovation relative to affiliate innovation. The dependent indicates whether multinational firm *i*'s country-*n* affiliate imports from its U.S. parent in year *t* during the period 1982-2009. Each affiliate is categorized as having either low (columns 1-3) or high (columsn 4-6) U.S. parent R&D costs based on the user cost of R&D reported in Wilson (2009). IPR is the Ginarte and Park (1997) and Park (2008) index of intellectual property rights corresponding to the inventor country in the patent-*i* grant year; GDP per capita is from the Penn World Table. *T* is the time-invariant average patent citation lag in the firm-*i* sector *j* across all U.S. patents assigned to that sector, and is measured using information from the NBER Patent Citation Datafile (Hall, Jaffe, and Trajtenberg 2001). All firm-specific data are from the Bureau of Economic Analysis. Specifications include industry fixed effects (columns 1-2, 4-5) or firm-*i* fixed effects (columns 3 and 6), as well as parent R&D investment, parent sales, and country-year fixed effects (all columns). Robust standard errors clustered by affiliate country appear below each point estimate.