Intellectual Property Rights and
the Theory of the Innovating Firm[*]

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Abstract

Stronger intellectual property rights (IPRs) induce specialization and contribute to economic growth. In the United States, a sweeping pro-patent legal reform in 1982 fostered specialization and enhanced firm performance. Around the world, countries experience faster economic growth when their innovating sectors are characterized by a higher level of specialization. An endogenous growth model with endogenous firm boundaries is developed to disentangle the relationship between legal institutions, business scope of the firms, and economic growth. Firm boundaries are identified by the number of intermediate inputs produced in-house. The production technology of every intermediate input is embodied in a patent. To perform R&D, a firm needs both the intermediate inputs based on its own patents and the inputs associated with others' patents. Each firm has two options to access to the inputs based on others' patents: it can buy their products or infringe on their patents by imitating their products. An infringer has to pay a legal settlement if it is sued and loses the lawsuit. To fend off infringement, a firm can expand its business scope and produce more intermediate inputs in-house. With stronger IPRs, the infringing problem becomes less severe, and the firm has weaker incentives to expand its business scope. Hence, stronger IPRs can induce specialization by deterring infringement. The model is matched with stylized facts of firm boundaries and patent litigation. The counterfactual analysis characterizes the optimal strength of IPRs and evaluates the actual patent law enforcement. The pro-patent legal reform in 1982 was welfare-enhancing, but it was too extreme.

Key Words: Firm Boundaries, Growth, Innovation, Intellectual Property Rights, Patent Law Enforcement, Patent Litigation, Specialization

JEL Classification: L21, L25, O31, O32, O34, O41, O43, O47


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1 Introduction

Stronger patent rights induce specialization by deterring infringement. To illustrate, consider the production of smartphone depicted in Figure 1. All the components of smartphone can be produced in one single integrated company. This incurs management costs because the firm must coordinate operations across multiple business lines. Alternatively, each component of smartphone can be produced by one specializing firm. For instance, Apple focuses on designing iPhone and outsources the other tasks to its suppliers. Apple has more than 200 suppliers, e.g., the display of iPhone is outsourced to Samsung and the modem is outsourced to Qualcomm. Every firm specializes in a niche of the market, and they access to each other's technologies through market transactions. However, these firms may infringe on the intellectual property of others. There is a war for patent infringement in the smartphone industry. All major players are involved in high-profile litigations, with hundreds of millions of dollars at stake. From this perspective, there is a trade-off between "infringement costs" in the specialization scenario versus "management costs" in the integration scenario. This is the key trade-off for firms' business scope decisions, and it pins down the firm boundaries in this paper.

FIGURE 1: SPECIALIZATION OR INTEGRATION?
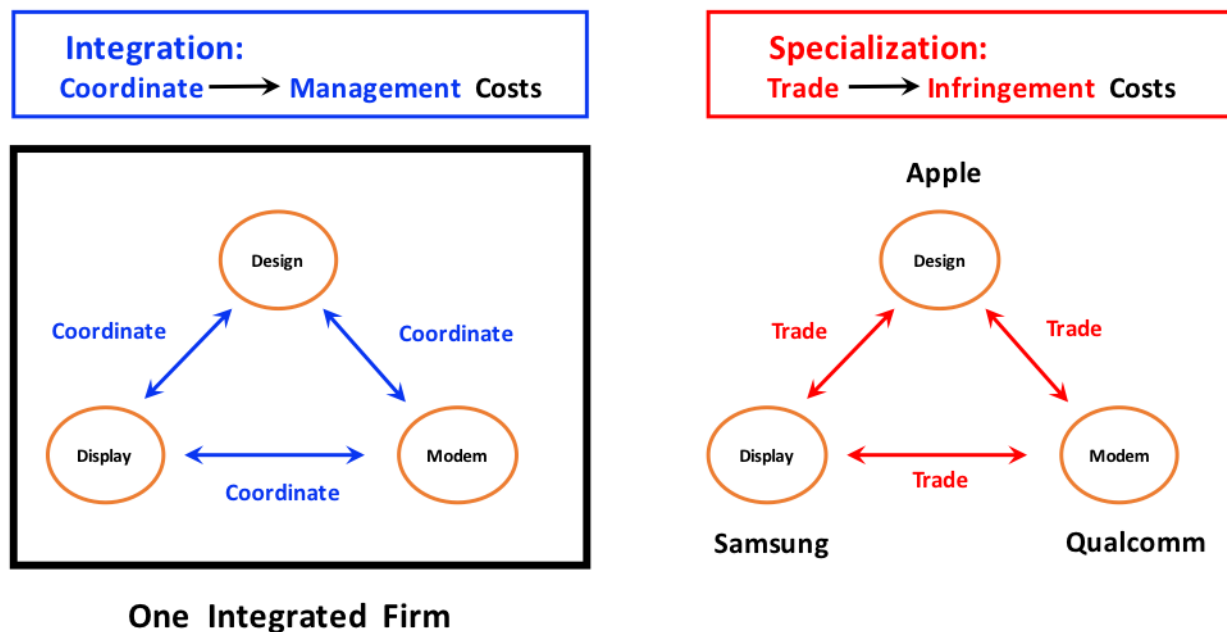
In light of this trade-off, stronger patent rights can induce specialization by deterring infringement. This is because an innovating firm can sue the violator if its intellectual property are infringed in the specialization scenario. Stronger patent rights increase the likelihood this innovating firm can win its lawsuit. Anticipating the costs of infringement, the potential violator can be deterred from infringing, and both firms can specialize in their core competencies.

This thought experiment sheds light on the theory of the firm. Coase (1937) posits some activities can be performed more efficiently within a firm's boundaries, because there will be "transaction costs" if these activities are conducted through market transactions. Hence, the firm exists to internalize these "transaction costs." However, what exactly are these "transaction costs"? From this point of view, the theory of the firm in this paper builds on Coase (1937) by uncovering this black box of "transaction costs," in the specific context of firm innovation. As underscored in this thought experiment, there are "transaction costs" in the innovating sectors because the firms may infringe on each others' intellectual property. In addition, this is a unique problem for the innovating sectors, because the core assets of the innovating firms are intellectual property. These assets are essentially ideas. It can be difficult for courts to verify and enforce the ownership of ideas. In light of this, the infringement problems are substantially more severe for intellectual property than tangible assets. Therefore, the business scope decisions in the innovating sectors require special consideration. To fill this gap, this paper contributes to building a theory of the *innovating* firm.

In addition, this paper also contributes to the literature on the optimal strength of patent rights. As illustrated in Figure 2, there is a classic trade-off for optimal patent rights in the literature: stronger patent rights encourage R&D, but spur monopoly pricing by patent owners. As a contribution to this literature, this paper incorporates the impact of patent rights on firms' business scope decisions. In response to stronger patent rights, firms shrink their scope of business and specialize. This enhances firm performance and constitutes an additional benefit of patent rights. Hence, the optimal patent rights will be stronger when its impact on firm boundaries is taken into account.

FIGURE 2: OPTIMAL PATENT RIGHTS: TRADE-OFF
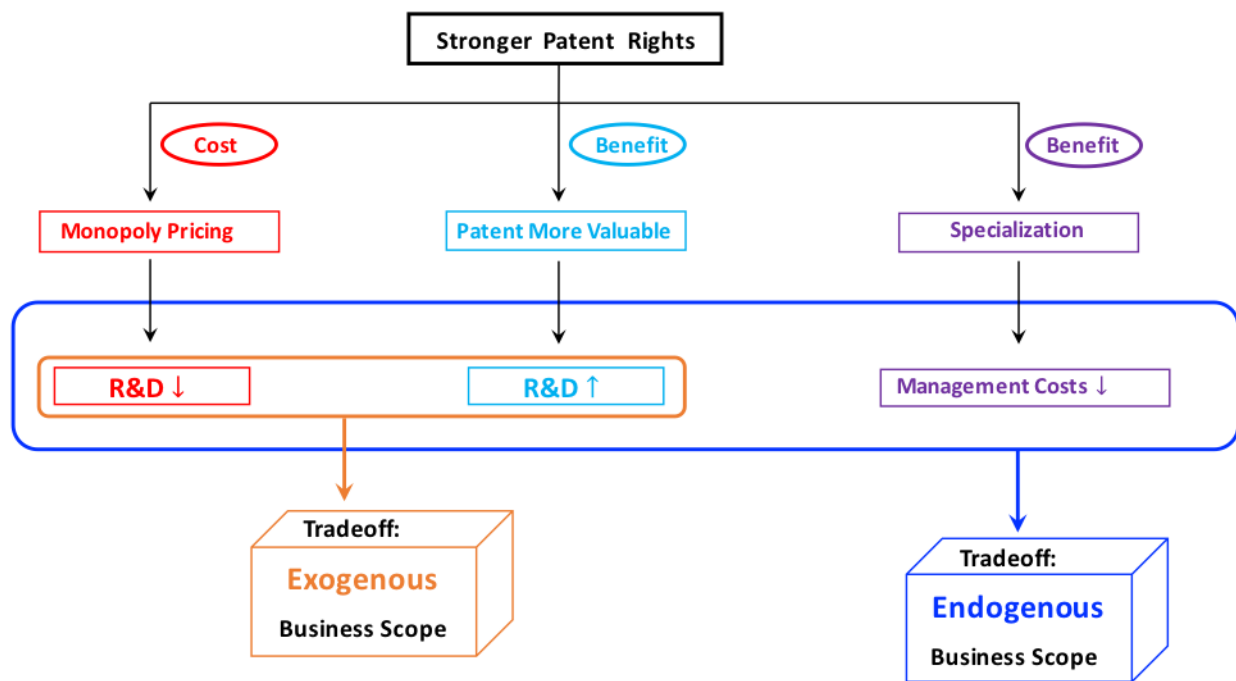
What is the optimal strength of patent rights? To address this issue, an endogenous growth model with endogenous firm boundaries is developed. Firm boundaries are identified by the number of intermediate inputs produced in-house. The production technology of every intermediate input is embodied in a patent. To perform R&D, a firm needs both the intermediate inputs based on its own patents and the inputs associated with others' patents. Each firm has two options to access to the inputs based on others' patents: it can buy their products or infringe on their patents by imitating their products. An infringer has to pay a legal settlement if it is sued and loses the lawsuit. To fend off infringement, a firm can expand its business scope and produce more intermediate inputs in-house. With stronger patent rights, the infringing problem becomes less severe, so the firm has weaker incentives to expand its business scope. The model is matched with stylized facts of firm boundaries and patent litigation, and it delivers three major implications: (1) stronger patent rights induce specialization, (2) specialization enhances firm performance, and (3) specialization contributes to economic growth.

These model implications are supported by the empirical analysis. In the United States, a sweeping pro-patent legal reform in 1982 strengthened patent rights. After this reform, the average

U.S. innovator invents in more closely related technological fields, which implies shrinking business scope and increasing specialization. This legal reform fostered specialization and enhanced firm performance. Around the world, countries experience faster economic growth when their innovating sectors are characterized by higher level of specialization.

To be specific, the empirical findings suggest stronger patent rights can induce specialization. Geographically, the U.S. court system is divided into 12 circuit courts. There is regional variation in the strength of patent rights[1] across circuits. When the patent rights are strengthened in a circuit court, firms located in this circuit tend to innovate in more closely related technological fields. In addition, the impact of patent rights is more pronounced for firms facing higher exposure to patent litigation. This is suggestive evidence that stronger patent rights can induce specialization. The second section of the empirical analysis evaluates how the business scope strategy of a firm affects its performance. When a firm invents in technological fields that are closer to its existing patent portfolio, it will harvest more patents from the same R&D dollar, and its patent stock will have a stronger boost to its TFP and market value. Moreover, this analysis is extended to a cross-country study. At the country level, a nation will experience faster economic growth when its innovators invent in more closely related technological fields. The impact of specialization on growth is economically large. If the level of specialization is enhanced from the Japanese level to the U.S. level, the annual growth rate in Japan would have been higher by 62 basis point. Japan's GDP per capita would have been 13% higher after two decades.

Is the actual patent law enforcement optimal? To address this issue, the optimal strength of patent rights is characterized by quantitative analysis, and it is contrasted with the actual patent law enforcement in practice. Through the lends of the model, the pro-patent legal reform in 1982 was welfare-enhancing, but it was too extreme. Swinging back the legal pendulum and weakening patent rights can improve welfare.

Relationship to the Literature. This paper contributes to two branches of literature: the

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[1] The strength of patent rights is measured by the likelihood for a patent to be invalidated by the court. When a patent is involved in litigation, it can be adjudicated to be valid or invalid by the court. If a patent is less likely to be invalidated, the implied patent rights are stronger.

theory of the firm and the optimal strength of patent rights.

The theory of the firm originates from Coase (1937). In this seminal paper, Coase conceptualizes a trade-off between "transaction costs" and "coordination costs" for the firm boundary decision. Hence, the firms exist to internalize the "transaction costs." Though studies in this field halted for several decades, it was revived by Williamson (1971) and has become a fertile field since then. Williamson (1971) attributes the "transaction costs" to socially inefficient "haggling" for "appropriable quasi-rents." A classic example is the General Motors - Fisher Body relationship, as analyzed by Klein (1988, 2000b). This insight has triggered a large empirical literature on "transaction costs economics," such as Monteverde and Teece (1982), Anderson and Schmittlein (1984), Masten (1984), and Joskow (1985). This literature, however, focuses on the benefits of integration and is largely silent on its costs. In contrast, an alternative approach is taken in the "property-rights theory" pioneered in Grossman and Hart (1986), Hart and Moore (1990), and Hart (1995). In this literature, bargaining is efficient, and, thus, the parties in a contract can share the surplus from their investment via bargaining. A larger share of asset ownership implies larger share of surplus, and, hence, stronger incentive to invest. In this framework, one party in a contract should own all the assets if it is socially optimal to maximize the investment of this party. On the other hand, the assets ownership should be divided if the investment incentives for both parties are important. In both approaches (i.e., the "transaction costs economics" and "property-rights theory"), the source of "transaction costs" is the hold-up problem in various forms. In contrast, the "transaction costs" in this paper is due to the infringement problem (i.e., firms may infringe on each others' intellectual property). This is a unique problem for the innovating sectors, because the core assets of the innovating firms are intellectual property. This insight entails special consideration for the business scope decisions in the innovating sectors.

As epitomized in Arrow (1962), there is a classic trade-off for the optimal strength of patent rights: stronger patent rights encourage R&D, but spur monopoly pricing by patent owners. This is reminiscent in Tirole (1988), Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). Based on this trade-off, one branch of this literature studies the optimal length and breadth of patent protection. In Klemperer (1990) and Gilbert and Shapiro (1990), the optimal

patent protection features long duration to encourage R&D, but a narrow breadth to discourage monopoly pricing. Acemoglu and Akcigit (2012) studies the state-dependent policy and proposes a "trickle-down" optimal patent protection: greater protection to technology leaders that are further ahead than those that are close to their followers. A second branch of this literature follows a mechanism design approach for optimal strength of patent rights. As a classic example, Scotchmer (1999) characterized the patent renewal system as an optimal mechanism when the quality and costs of projects are unknown. Llobet, Hopenhayn and Mitchell (2006) studies optimal patent policy with sequential innovation and heterogeneous quality. None of these papers considers the impact of patent rights on firms' business scope decisions. The strength of patent rights is characterized by patent law enforcement. As demonstrated in this paper, firms shrink their scope of business and specialize, in response to stronger patent rights. This enhances firm performance and constitutes an additional benefit of patent rights. Hence, the optimal patent rights will be stronger when its impact on firm boundaries is taken into account.

The rest of the paper is organized as follows. Section 2 reviews the background of patent law enforcement and specialization in the innovating sectors. The model is built in section 3 and matched with the stylized facts in section 4. The implications of the model are derived by the quantitative analysis in section 4, and these implications are tested by the empirical analysis in section 5. The optimal strength of patent rights is characterized in section 6, and it is compared with the actual patent law enforcement in practice. Section 7 concludes.

2 Background

2.1 Patent Law Enforcement

As the first step to investigate the impact of patent law enforcement on specialization, this section outlines the legal background of patent litigation in the U.S., and highlights a major legal reform during the 1980s which creates a more pro-patent legal environment.

2.1.1 Patent Litigation Process

The intellectual property rights of an invention are embodied in a patent, which provides the potential – but not the guarantee – to exclude others from using the patented technology. In the United States, patents are granted at the United States Patent and Trademark Office (USPTO). In contrast, the patent law is interpreted and enforced via the court system, and the court has a final say on the strength of the patent.

FIGURE 3: **Patent Law Enforcement in the U.S.**
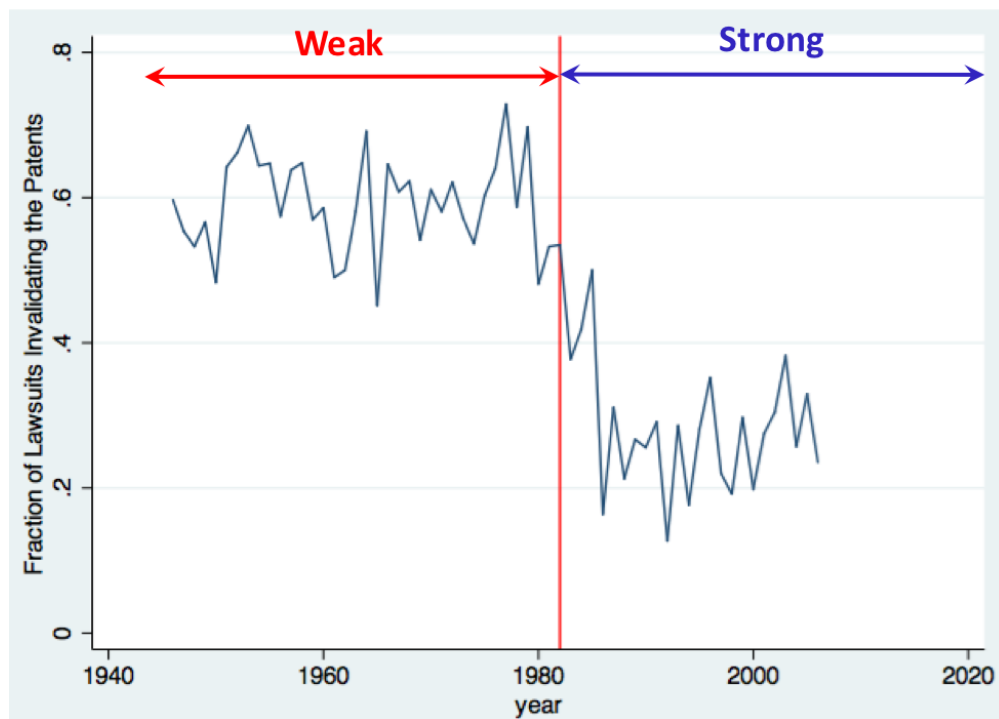
When a patentee identifies a potential infringement, she may bring the alleged violators to the court and sue them for infringement. In response, the defendant will typically counter sue by arguing that the patent is actually not valid in the very first place, and in consequence the patents can be invalidated by the court[2]. Therefore, the fate of the patent eventually depends on

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[2] A patents can be invalidated for a variety of reasons with respect to the legal requirement of novelty and nonobviousness. For instance, Allison, Lemley, and Schwartz (2014) shows that a patent can be invalidated because of no patentable subject matter (success rate: 54%), prior art requirement of section 102 (success rate: 20%), obviousness issue of section 103 (success rate: 20%), indefiniteness issue of section 112 (success rate: 17%), lack of enablement of section 112 (success rate: 13%), inadequate written description of section 112 (success rate: 15%).

the judgment and the attitude of the court. From this perspective, the fraction of cases in which the patents are invalidated can be a proxy of the strength of patent rights. Based on this proxy of patent rights, the evolution of patent law enforcement in the U.S. in the post-war era is illustrated in Figure 3.

2.1.2 Legal Reform In 1982

The vertical axis of Figure 3 is the fraction of cases in which the patents are invalidated by the court, the proxy of the strength of patent rights. As shown in this figure, the patent law enforcement in the U.S. has experienced dramatic changes in the last several decades. While the legal environment in the post-war era used to be fairly stable before 1982, there is a precipitous plummet in the fraction of cases invalidating the patents around 1982. In consequence, patent law enforcement moved to a new legal regime after 1982 with remarkably lower invalidation rate and stronger patent rights.

This changing legal environment is due to a sweeping legal reform on the court system in 1982. Before 1982, all patent-related cases were initiated at one of the ninety-four district courts across the country, and the litigants may further appeal to the regional appellate courts if they disagree with the court decisions. In practice, however, the interpretation and enforcement of the patent law are highly inconsistent across circuit courts before 1982, leading to a regionally fragmented legal system[3].

To address the issue of inconsistent patent law enforcement across the nation, in 1982 the Congress established a single appellate court to hear all the appeals of patent-related cases: the Court of Appeals of the Federal Circuit (CAFC). After this legal reform, this new court turns out ot hold a salient pro-patent attitude. To see the impact of this legal reform, Table 1 performs a before-and-after comparison. Reported in this table is the fraction of cases invalidating the patents across circuit courts. A revealed in Table 1, there is a decrease in patent invalidation in every circuit court. This indicates stronger patent rights after the legal reform. In addition, there is a decrease in the dispersion, so the litigants are treated more equally around the country. This

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[3] In principle the Supreme Court could step in to ensure legal uniformity across circuit courts. In practice, however, the patent-related cases were rarely heard at the Supreme Court, and, hence, the discrepancy of patent law enforcement across circuits persisted over the years.

implies increasing legal uniformity across the nation.

TABLE 1: **Patent Law Enforcement**

Circuit Headquarter	Fraction of Cases Invalidating the Patents (%)	
	Before 1982	**After 1982**
Boston	0.68	0.22
Chicago	0.56	0.32
Cincinnati	0.60	0.28
Denver	0.42	0.16
New Orleans	0.41	0.23
New York City	0.67	0.26
Philadelphia	0.76	0.29
Richmond	0.54	0.22
San Francisco	0.59	0.29
St. Louis	0.67	0.37

Nevertheless, these changes in patent invalidation rates can be attributed to changing types of cases brought to the court. To address this concern, Table 2 conducts a regression analysis to examine the impact of this legal reform on patent law enforcement, controlling for the characteristics of the patents and the litigants involved in the lawsuits. The unit of observation in this regression are the individual patents reviewed by the court between 1946 and 2006. The dependent variable is a dummy for patent invalidation (which takes the value of one if this patent is invalidated by the court), and the main explanatory variable is a dummy for the legal reform (which takes the value of one if the court decision is made after 1982).

As demonstrated in Table 2, a patent is more likely to be invalidated after the legal reform in 1982, even when controlling for the characteristics of the patents and the litigants involved in the lawsuits[4]. In addition, this regression also uncovers a number of patterns of patent litigation: a

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[4] To be specific, this regression controls for the number of forward citations received by the patent (the truncation issue is addressed following Hall, Jaffe and Trajtenberg (2001)), the age of the patent at the lawsuit, the number of claims of the patent, dummies for the technology class of the patent, dummies for the circuit court where the final court decision is made, whether the patentee is the plaintiff or the defendant, and whether the patentee is U.S. or non-U.S. inventor.

patent is less likely to be invalidated when it constitutes a more important invention (as captured by more forward citations the patent receives), and when the patent has survived more years before being brought to the court. In contrast, it is more likely to be invalidated when the patentee is challenged in the court as the defendant (in contrast to the scenario where the patentee sues for infringement as the plaintiff).

TABLE 2: IMPACT OF THE LEGAL REFORM ON PATENT LAW ENFORCEMENT

	1{ *Patent Invalidated by the Court* }		
	(1)	(2)	(3)
CAFC (= 1 after 1982)	−0.786***	−0.743***	−0.619***
	(0.0851)	(0.105)	(0.139)
ln(num of citations received)			-0.0806**
			(0.0326)
age of patent at the lawsuit		-0.0184***	-0.0358**
		(0.00649)	(0.0151)
patentee as the defendant		0.156**	0.285**
		(0.0738)	(0.127)
ln(num of claims)		-0.0614***	-0.0167
		(0.0173)	(0.0338)
foreign patentee		-0.104***	0.0466
		(0.0376)	(0.0681)
technology class	N	Y	Y
circuit court	N	Y	Y
Observations	5,172	4,043	1,234

NOTES: PROBIT REGRESSION OF PATENT INVALIDATION. THE CONTROL VARIABLES ARE THE NUMBER OF FORWARD CITATIONS RECEIVED BY THE PATENT, THE AGE OF THE PATENT AT THE LAWSUIT, THE NUMBER OF CLAIMS OF THE PATENT, DUMMIES FOR THE TECHNOLOGY CLASS OF THE PATENT, DUMMIES FOR THE CIRCUIT COURT, WHETHER THE PATENTEE IS THE PLAINTIFF OR THE DEFENDANT, AND WHETHER THE PATENTEE IS U.S. OR NON-U.S. INVENTOR. ROBUST STANDARD ERRORS IN PARENTHESES (CLUSTERED AT THE LEVEL OF CIRCUIT COURT). *** DENOTES SIGNIFICANCE AT THE 1 PERCENT LEVEL, ** AT THE 5 PERCENT LEVEL, AND * AT THE 10 PERCENT LEVEL.

The bottom line of this regression is, the same type of patent is less likely to be invalidated after the legal reform. This is suggestive evidence for a more pro-patent legal environment and stronger patent rights after the legal reform.

In light of these dramatic changes in the court system, the next question is, how do the the firms respond to this changing legal environment?

2.2 Specialization In the Innovating Sectors

The dramatic change in the legal environment underlined in the last section has a far-reaching impact on the industrial organizational structures in the innovating sectors. This section develops an empirical measure of innovation specialization based on the technological distance of patent. As shown in this section, there is increasing specialization in the innovating sectors in the U.S. in the recent decades, in the sense that the innovators invent in more closely related technological fields. In addition, as demonstrated in the regression analysis, this increasing innovation specialization is in part due to strengthened patent rights.

To gauge the degree of specialization in the innovating sectors, a metric of technological distance between patents is applied as a measure of firms' business scope with respect their innovating activities. The underlying rationale is, when a firm invents in more closely related technological fields, this signals a more focused business scope strategy and a higher level of innovation specialization.

The measure of technological distance[5] follows the metric developed in Akcigit, Celik, and Greenwood (2016). This distance metric is based on the citation links between the patents. To be specific, the technological distance between two patent classes X and Y is defined as:

$$d(X,Y) = 1 - \frac{\#(X \cap Y)}{\#(X \cup Y)}, \ d(X,Y) \in [0,1].$$

In the expression above, $d(X,Y)$ is the technological distance between two patent classes X and Y, $\#(X \cap Y)$ is the number of patents that cite both X and Y, and $\#(X \cup Y)$ is the number of patents that cite either X or Y. The rationale underlying this distance metric is straightforward:

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[5] In the baseline empirical analysis, technological fields are measured at the level of 3-digit International Patent Classification (IPC).

the more X and Y are cited together, the closer they are. By construction, this measure is always between 0 and 1, and a lower distance implies the patents are closer to each other.

FIGURE 4:   **Increasing Innovation Specialization In the U.S.**
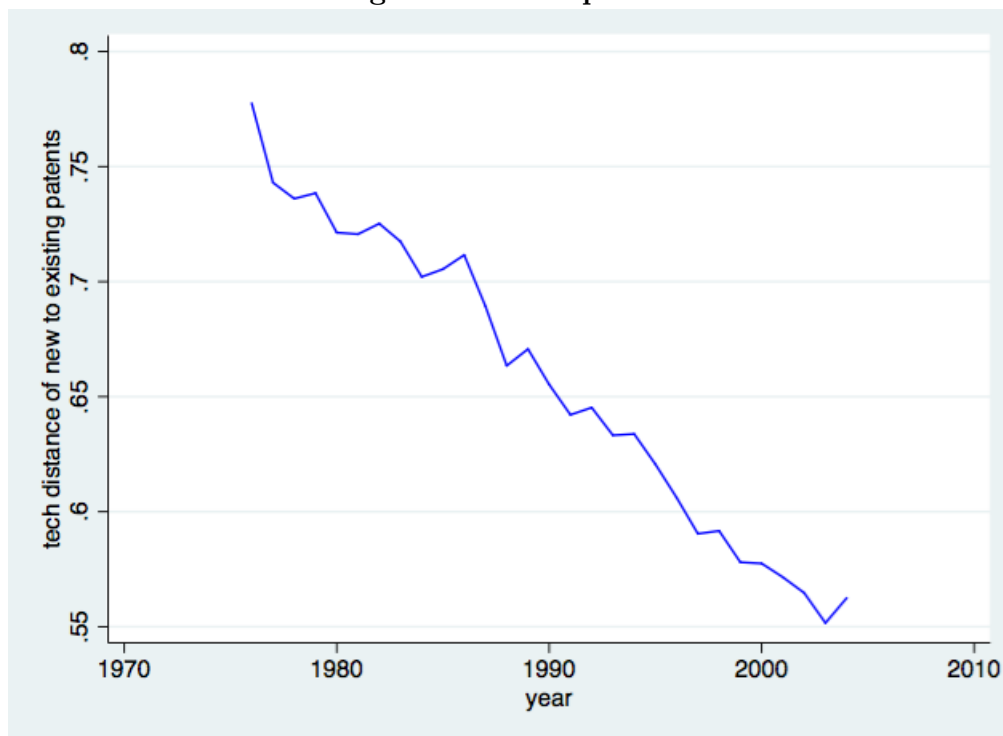
Based on this measure, the evolution of the business scope of the average U.S. innovator is tracked in Figure 4. The vertical axis in Figure 4 is the average technological distance between the new patent and the existing patent portfolio of the innovators[6]. As revealed in Figure 4, the average U.S. innovator is inventing in more closely related technological fields, which implies shrinking business scope and increasing specialization in the recent decades[7].

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[6] To be specific, for each innovator in each year, the technological distance between the new patent it obtains and its existing patent portfolio at the beginning of the year is calculated. The vertical axis is the average technological distance across the innovators in each year.

[7] Echoing these findings, Chesbrough (2006) documented increasing specialization in the semiconductor and life science industry. Back in the 1960s, the semiconductor industry was dominated by only two corporations: IBM and AT&T. Both of them included in their operations the entire production process from design to manufacturing. The landscape of this industry, however, started to change in the 1970s. Intel and Texas Instruments were created and they specialized in the production of chips, ushering in the emerging markets of intermediate inputs for semiconductors. By the 1980s, a revolutionary separation was introduced in the semiconductor industry, leading to a dichotomy of this industry into the "fabs", specializing in the fabrication of semiconductors (e.g., TSMC), and the "fabless", specializing in the design function. The design tools were further stripped in the 1990s, as epitomized by Qualcomm and ARM Holdings. Both of them offered their intellectual property underlying the design tools and effectively created a market for design itself. The specialization in the semiconductor industry was by no means a unique

3 Model

3.1 Environment

Consider an economy where time is discrete. There are 3 types of agents in this economy: the household, the final good producer, and the intermediate goods firms. The final goods are assembled by combining a range of intermediate goods with labor. The intermediate goods are produced by the intermediate goods firms, and there is a constant marginal cost for production. The source of growth in this economy is expanding varieties of intermediate goods a la Romer (1990).

3.1.1 Patent

In this economy, the production technology of every intermediate input is embodied in a patent. In addition, there are 2 types of patents: the active patents and the expired patents. The number of active patents is N, and the owners of the active patents enjoy exclusive rights over their intellectual property. The number of expired patents is $\widetilde{N}$, and everyone has free access to the technologies embodied in these patents. An active patent can expire for 2 reasons. In practice, the term of the patent is limited. This is captured by stochastic survival with probability σ. In addition, the active patents can be involved in litigation, and they can be invalidated by the court. Once they are invalidated, they join the pool of the expired patents. This is a crucial channel for the court system to change the landscape of technology, and the expired patents are introduced to capture the impact of the legal institution.
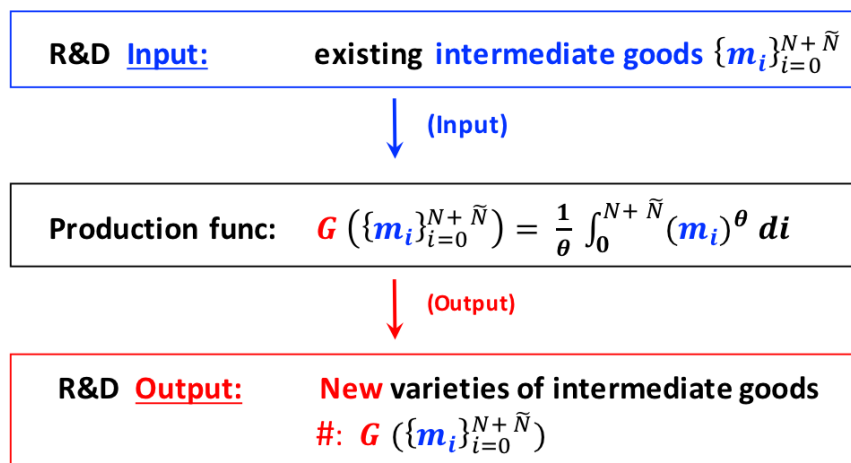
3.1.2 Intermediate Goods Firm

The patents are owned by the intermediate goods firms, and they can produce the intermediate goods associated with the patents they own. The boundaries between these firms can be identified by the range of intermediate goods they produce in house. These intermediate goods are produced

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experience. In the 1970s, pharmaceutical manufacturers, such as Pfizer and Johnson and Johnson, used to keep a whole army of staff, from the R&D team developing new drugs to the marketing division promoting their products. In the 1980s, the development of new drugs began to be led by biotechnology firms specializing in the discovery of new compounds. The pharmaceutical producers acquired the patents of the compounds from these biotech firms, conducted clinical trials and then offered the new drugs to the market. Turning to the 1990s, independent research organizations specializing in performing clinical trials (e.g., Millennium Pharmaceuticals) were created, and they focused on testing the safety and efficacy of the new drugs.

to serve 2 types of customers. They are sold to the final goods producer at price q, and they are used to produce the final goods. They are also sold to other intermediate goods firms at price p, and they are used in the R&D process to discover new varieties of intermediate goods. The prices p and q are different, because the underlying demand functions are different, as will be shown later. There is no resale between these 2 market segments. In addition, the intermediate goods firms can discover new varieties of intermediate goods from R&D, and they file a new patent for every new variety of intermediate good they discover. They can keep the new patents they develop, or they can sell them to other intermediate goods firms. They can also buy new patents, and all patents are traded at their intrinsic value (i.e., the present value of the future payoff).

3.1.3   R&D: Input and Output

The R&D process in this economy is illustrated in Figure 5.

FIGURE 5: R&D: SETUP

> **R&D Input:**   existing **intermediate goods** $\{m_i\}_{i=0}^{N+\widetilde{N}}$
>
> ↓ (Input)
>
> **Production func:** $G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right) = \frac{1}{\theta} \int_0^{N+\widetilde{N}} (m_i)^\theta\, di$
>
> ↓ (Output)
>
> **R&D Output:**   **New** varieties of intermediate goods
> #: $G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right)$

The input of R&D is a basket of the existing intermediate goods. These inputs are used in the corporate lab to discover new varieties of intermediate goods. By investing a basket of intermediate goods $\{m_i\}_{i=0}^{N+\widetilde{N}}$, an intermediate goods firm can discover new varieties of intermediate goods in the amount of $G(\{m_i\}_{i=0}^{N+\widetilde{N}}) = \frac{1}{\theta} \int_0^{N+\widetilde{N}} (m_i)^\theta di$.

These new varieties of intermediate goods are the output of R&D. They can be the blue prints of new semiconductors, or they can be the chemical structure of new drugs and medicine. The

intermediate goods firms file a patent for each new variety of the intermediate goods they discover. This is how technology advances in this economy.

3.1.4   R&D Inputs: Sources and Costs

Where do the R&D inputs come from? They come from 3 sources, as depicted in Figure 6.
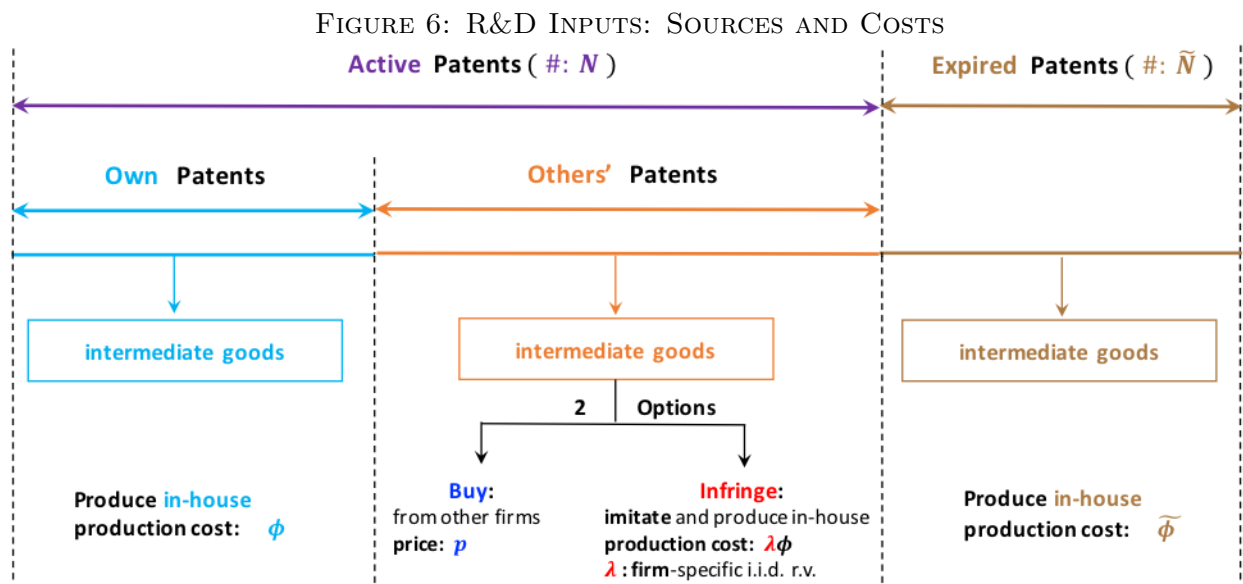
FIGURE 6: R&D INPUTS: SOURCES AND COSTS

For some of the intermediate goods, the underlying production technology is embodied in the expired patents. Everyone has free access to these inputs, and they can produce them in house at the cost $\widetilde{\phi}$. In contrast, for some of the intermediate goods, the underlying production technology is embodied in the active patents. These patents have owners. For instance, a semiconductor has many components. Some of these components are associated with the patents owned by Intel, and some components are based on the patents of Texas Instruments. To develop a new semiconductor, Intel needs to combine the components based on its own patents, with the components patented by Texas Instruments. For the first type of the components, Intel can simply produce in house, and there's a production cost, ϕ. In contrast, to obtain the components based on the patents of Texas Instruments, Intel has 2 options. He can buy these components from Texas Instruments, and he needs to pay the price p. Alternatively, Intel can infringe on the patents of Texas Instruments, by imitating its product and producing in house. That is to day, Intel can produce the same

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component of Texas Instruments, but their production cost can be different. The production cost of Texas Instruments is ϕ, and the cost of Intel, the imitator (or the infringer), is $\lambda\phi$. λ is firm-specific random variable, and it captures heterogeneous firm capabilities to imitate. In addition, λ is uniformly distributed on $[0, \bar{\lambda}]$, and it is independently and identically distributed across firms and across periods.

3.1.5 Legal Institution

The legal institution to resolve the disputes are outlined in Figure 5. When the patent of an intermediate goods firm is infringed by other firms, it can sue them in the court. In response, the alleged infringers will challenge the validity of the patent, and the court will make a decision on whether this patent is valid or invalid. If the patent is adjudicated to be valid, the patent owner will receive a legal settlement. If the patent is adjudicated to be invalid, this patent will expire. In addition, a patent is more likely to be invalidated when more firms challenge the validity of this patent in the court. In order to invalidate a patent, the number of firms needed to challenge the patent follows an exponential distribution with parameter τ. That is to say, when a patent is challenged by f firms, this patent will be invalidated with probability $1 - e^{-\tau f}$.

FIGURE 7: LEGAL INSTITUTION
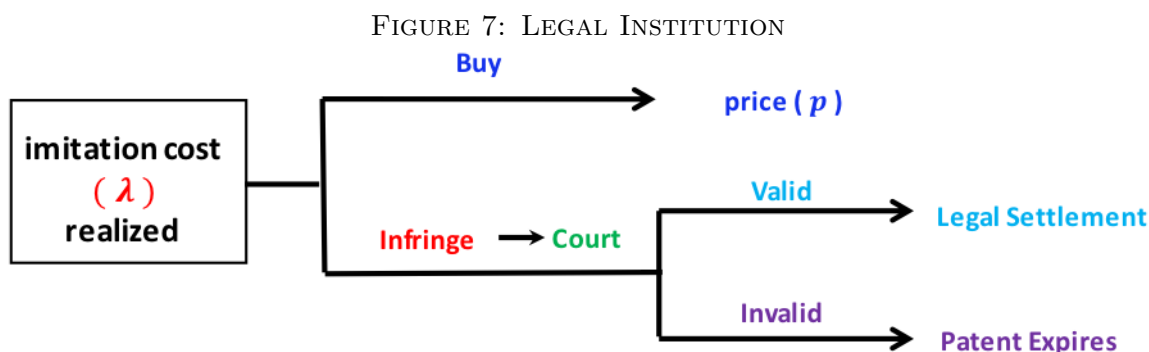
3.1.6 Measure of Specialization

In this economy, the production technology of every intermediate good is embodied in a patent. The number of patents a firm has determines the range of intermediate goods that it produces

in house, in contrast to the intermediate goods purchased from the external market. The model features representative firm and every firm holds the same number of patents: s. Hence, the number of intermediate goods a firm produces in house is also s. The business scope of the firm can be captured by s, because s pins down the boundary between the intermediate goods produced in house, and the intermediate goods purchased from the external market.

In addition, the level of integration of the firm is captured by $\frac{s}{N}$, the fraction of intermediate goods the firm produces in house. An increase in $\frac{s}{N}$ implies a higher level of integration, and a lower level of specialization. s is a key choice of the firm[8], and the number of the firms, F, is pinned down by $\frac{N}{s}$. The number of the firms will settle down along the balanced growth path.

3.1.7 Management Costs

It is costly to manage the business in this economy. To be specific, the management cost for a firm is $\Omega(\frac{s}{N}, w) = \frac{1}{\xi+1} \left(\frac{s}{N}\right)^{\xi+1} w$. The management cost is increasing in the wage rate, w. Imagine every firm needs to hire managers to run the business. In addition, another key factor in the management cost is $\frac{s}{N}$, the fraction of intermediate goods the firm produces in house. The management cost is increasing and convex in $\frac{s}{N}$. Imagine the management monitoring is subject to diminishing return to scope. The convexity of Ω implies scope diseconomies and benefits of specialization. When a firm pursues a more focused business strategy with lower $\frac{s}{N}$, the firm can enhance its management efficiency because of the convexity of the management cost function. The degree of scope diseconomies and the benefit of specialization is governed by the magnitude of the convexity (ξ).

3.1.8 Timing of Events

As bird view of the major decisions of the intermediate goods firms, the timing of events is illustrated in Figure 8. At the beginning of the period, the production cost under imitation (λ) is realized. Based on their λ, the firms will decide whether to buy the intermediate goods from other firms or infringe on their patents. Then the firms will produce the intermediate goods, and decides how

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[8] More precisely speaking, s is a key state variable of the firm. Every firm starts with s at the beginning of the period, and it chooses s' for the next period.

much to spend in R&D. The legal disputes will be settled in the court, and the firms will make payment to each other based on the court decisions. If the patents of a firm is infringed and it wins the lawsuit, this firm will receive legal settlement from the violator. Meanwhile, if a firm infringes on others' patent and loses the case, it will have to pay the compensation to the patentee. Lastly, the firms can trade patents before the end of the period, so that every firm can adjust its business scope to any level as it desires.

Based on this setup, the decisions of the agents are delineated as follows.

FIGURE 8: TIMING OF EVENTS
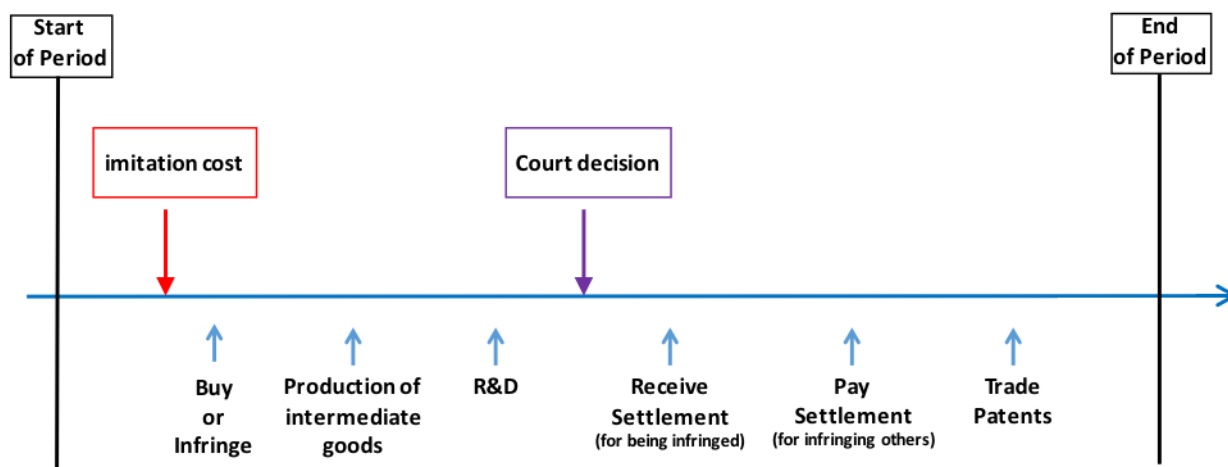
3.2 Households

There is a representative household in this economy. The household is endowed with one unit of labor and the labor supply is inelastic. The household owns all the firms and earns income from wages and the dividends collected from the firms. The objective of the household is to maximize the lifetime utility with discount rate β for future. The preference of the household is characterized by CRRA utility with momentary utility function: $U(c) = \frac{c^{1-\epsilon}}{1-\epsilon}$, where c refers to current consumption and ϵ is the coefficient of relative risk aversion. Since this setup is entirely standard, the household problem is not explicitly delineated.

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3.3   Final Goods Producer

The final goods in this economy are assembled by combining labor with a range of intermediate inputs. To be specific, the final goods are produced under the following production technology:

$$Y = \frac{1}{\alpha} \int_0^{N+\widetilde{N}} x_i^\alpha di \ L^{1-\alpha}$$

In this production function, L is the labor input and $1 - \alpha$ is the share of labor. x_i is the quantity of intermediate input i, and the intermediate inputs are ranging from $[0, N + \widetilde{N}]$. Recall N and $\widetilde{N}$ are the number of active and expired patents, respectively, and $N + \widetilde{N}$ is the total number of intermediate inputs (or patents). There is a constant marginal production cost $\widetilde{\phi}$ for the intermediate inputs based on the expired patents (i.e., $i \in [0, \widetilde{N}]$). For the intermediate inputs associated with the active patents (i.e., $i \in [0, N]$), the final goods producer is facing a price q charged by the owner of the active patents. Therefore, the final goods producer is facing the problem:

$$\max_{\{\{x_i\}_0^{N+\widetilde{N}}, \ L\}} \frac{1}{\alpha} \int_0^{N+\widetilde{N}} x_i^\alpha di \ L^{1-\alpha} - \int_0^N q \ x_i di - \int_N^{N+\widetilde{N}} \widetilde{\phi} \ x_i di - wL$$

The first term in the problem of the final goods producer is the output, the second term is the expenditures on the intermediate inputs associated with active patents, the third term is the production cost for intermediate inputs associated with expired patents, and the last term is the labor cost. The problem of the final goods producer delivers the demand function $q(x_i)$ for the intermediate input associated with active patent i and the wage rate of labor[9].

3.4   Intermediate Goods Firms

The intermediate goods firms are the core players in this economy, and their decisions are delineated in this section.

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[9] Recall there is inelastic supply of labor with one unit.

3.4.1 Buy or Infringe?

The first decision an intermediate goods firm faces is: o obtain the intermediate goods associated with others' patents, should he buy their products or infringe on their patents? The key determinant for the decisions to buy or infringe is the firm's production cost under imitation (λ). A firm can enjoy lower R&D cost if it decides to infringe on others' patent, because it can imitate their product and produce in house, instead of buying their product from the market. On the other hand, an infringer may lose the lawsuit when being sued in the court. In consequence, the infringer will have to pay the legal settlement. From this perspective, an infringer is facing the trade-off between lower R&D cost versus paying legal settlement when losing the lawsuit. In equilibrium the firms will follow a cutoff strategy to infringe (i.e., a firm will infringe if and only if its imitation cost λ is below a threshold)[10]. This threshold for the infringement decision will be precisely pinned down later in the section of equilibrium characterization.

3.4.2 Operating Profits

An intermediate goods firm can produce the intermediate goods associated with its patent, and sell them to both the final goods producer and other intermediate goods.

To be specific, the price an intermediate goods firm sets for the final goods producer is determined in the following problem:

$$\pi^X = \max_{\{q,\ x\}} (q - \phi)\, X(q)$$

$$\text{s.t. } X(q): \text{ demand of final goods producers}$$

An intermediate goods firm seeks to maximize the profits obtained from the final goods producer, and the equilibrium operating profit is denoted by π^X. There is a constant marginal production cost ϕ for the intermediate inputs based on the active patents (i.e., $i \in [0, N]$). q is the price the intermediate goods firm chooses to charge the final goods producer, $X(q)$ is the quantity demanded by the final goods producer given the price q.

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[10] Recall the imitation cost λ is a firm-specific variable. Hence, when a firm decides to infringe, it infringes on everything outside her own patent portfolio.

In addition, the intermediate goods firms also need the products of each other, because these intermediate inputs will be used for R&D. Each firm has two options to access to the inputs based on others' patents: it can buy their products, or infringe on their patents by imitating their products. The decisions of other firms to buy or infringe depend on the price charged by the the intermediate goods firm. To be specific, the price p a patent holder charges other patent holders is determined as follows:

$$\pi^M = \max_{\{p,\ m\}} (p - \phi) \times M(p) \times (1 - \widetilde{\lambda})F$$

$$\text{s.t. } M(p) : \text{ demand of other patent holder}$$

$$\text{s.t. } \widetilde{\lambda}(p,) : \text{ fraction of firms that infringes}$$

An intermediate goods firm seeks to maximize the the profits obtained from other intermediate goods firms, and the equilibrium operating profit is denoted by π^M. In the expression above, p is the price the intermediate goods firm charges, and $M(p)$ is the quantity demanded given the price p. The demand function $M(p)$ hinges on the return from R&D. Given the price p set by an intermediate goods firm, a fraction $1 - \widetilde{\lambda}$ of the firms will buy her products, and a fraction $\widetilde{\lambda}$ of the firms will infringe on her patent. Hence, the number of buyers is $(1 - \widetilde{\lambda})F$, where F is the total number of intermediate goods firms in this economy. As will be shown later, $\widetilde{\lambda}$ is increasing in p, the price charged by the intermediate goods firm. Hence, when a firm charges a lower price, more people will decide to buy her products instead of infringing. In addition, $\widetilde{\lambda}$ is increasing in τ, the odds for the patent to be invalidated by the court. When the the patents are more likely to be invalidated, more firms will decide to infringe instead of buying. This is a crucial channel for the court system to change the firm decisions.

3.4.3 Patent Survival Rate

In this economy, a patent may expire for two reasons. First, the term of the patent is limited and this is captured by stochastic survival with probability σ[11]. In addition, a patent can be involved

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[11] In the quantitative analysis, σ will be specified to match the term of the patent in practice.

in litigation when it is infringed, and the patent may be invalidated when being challenged in the court. The number of alleged infringers challenging the patent is $\widetilde{\lambda}F$, so the patent will be adjudicated to be valid with probability $e^{-\tau\widetilde{\lambda}F}$.[12] Hence, the survival rate of patent is $\eta = \sigma e^{-\tau\widetilde{\lambda}F}$.

3.4.4 Legal Settlement Received

Though the intermediate goods firm does not receive any payment from the infringers, it can bring them to the court and sue them for infringement. In each lawsuit, the patent owner can win and receive the legal settlement with probability $e^{-\tau\widetilde{\lambda}F}$.. The amount of the settlement upon victory is a fraction μ of the price of the patent, P.[13] However, it is costly to sue people, and the cost of litigation is a fraction ψ of the price of the patent, P. Hence, the net legal settlement received by an intermediate good firm is $z \times s = (e^{-\tau\widetilde{\lambda}F}\mu P - \psi P) \times \widetilde{\lambda}F \times s$.

3.4.5 Patent Trading

At the end of the period, all firms can adjust their business scope to any level as they desire, and this can be achieved by trading their patents with each other. There is a centralized market for patent trading, where every patent can be traded at the intrinsic value (i.e., the present value of the future payoff). To be specific, the price of the patent is:

$$P_t = \sum_{j=0}^{\infty} \frac{\eta^j \left(\pi_{t+j} + z_{t+j}\right)}{R^j}$$

The price of a patent at period t is denoted by P_t.[14] The price of a patent is the present value of the expected payoff in future, and the future payoffs of a patent is discounted by the gross interest rate, R. In each period, the patent can survive with probability η. Conditional on survival, there are two sources of income for a patent: operating profits collected from the buyers (π) and legal settlement received from the infringers (z).

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[12] In order to invalidate a patent, the number of firms needed to challenge the patent follows an exponential distribution with parameter τ. That is to say, when a patent is challenged by f firms, this patent will be invalidated with probability $1 - e^{-\tau f}$.

[13] The value of the patent (P) will be delineated momentarily in the next section.

[14] The price of patent will settle down along the balanced growth path.

Given the price P', every firm chooses the number of patents to trade, h, and its expenditure on patent purchase (or revenue from patent sale) is $H = hP'$. A positive choice of h implies patent purchase, and a negative choice of h implies patent sale.

3.4.6 Value Function

Combining the payoffs of the patent holders delineated in the previous sections, the value function of the intermediate goods firm is characterized as follows:

$$V(s; N, \widetilde{N}; \lambda) = \max_{\{ \text{ Buy (B), Infringe (I) } \}} \{V^B(s; N, \widetilde{N}), V^I(s; N, \widetilde{N}; \lambda)\}$$

There are four state variables for the intermediate goods firm: the number of patents she owns (s), her production cost under imitation (λ), the total number of active patents (N), and the total number of expired patents ($\widetilde{N}$). In addition, every intermediate goods firm is facing two states of the world: she can be a buyer if she decides to buy the products of other intermediate goods firms, or she can be an infringer if she infringes on others' patent by imitating their products and producing in house.

If an intermediate goods firm decides to buy the products of other firms, its value function is characterized as follows:

$$V^B(s; N, \widetilde{N}) = \max_{\left\{q,\, p,\, \{m_i\}_{i=0}^{N+\widetilde{N}}, h, s'\right\}} \left\{ \begin{array}{l} \pi^X(q) \times s + \pi^M(p) \times s + z \times s - I\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right) - h \times P' \\[2mm] -\Omega(\frac{s}{N}, w) + \frac{1}{R}\mathbb{E}_\lambda\{V(s'; N', \widetilde{N}'; \lambda')\} \end{array} \right\}$$

$$\text{s.t. } s' = \eta s + G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right) + h$$

There are four choices of the intermediate goods firm: the price it charges the final goods producer (q), and the price it charges other intermediate goods firms (p), how much it spends on R&D ($\{m_i\}_{i=0}^{N+\widetilde{N}}$), and how many patents to buy or sell (h). The current payoff of the intermediate goods firm is its operating profits obtained from producing the intermediate goods ($\pi^X(q) \times s + \pi^M(p) \times s$), plus the legal settlement received for being infringed ($z \times s$), minus

its R&D expenditures $(I\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right))$, minus its purchase or sale of patents $(h \times P')$, minus its management costs $(\Omega(\frac{s}{N}, w))$. The law of motion for the number of patents a firm has is: $s' = \eta s + G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right) + h$. At the beginning of the period, every firm starts with the same number of patents, s, and a fraction η of the patents can survive. There will be new patent developed from R&D, $G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right)$. At the end of the period, the firm can choose the number of patents to trade, h.

Analogously, if an intermediate goods firm decides to infringe, its value function is characterized as follows:

$$V^I(s, \lambda, N, \widetilde{N}) = \max_{\left\{q,\, p,\, \{m_i\}_{i=0}^{N+\widetilde{N}}, h, s'\right\}} \left\{ \begin{array}{l} \pi^X(q) \times s + \pi^M(p) \times s + z \times s - I\left(\{m_i\}_{i=0}^{N+\widetilde{N}}, \lambda\right) - h \times P' \\[2mm] -\Delta - \Omega(\frac{s}{N}, w) + \frac{1}{R}\mathbb{E}_\lambda\{V(s'; N', \widetilde{N}'; \lambda')\} \end{array} \right\}$$

$$\text{s.t. } s' = \eta s + G\left(\{m_i\}_{i=0}^{N+\widetilde{N}}\right) + h$$

When an intermediate goods firm decides to infringe, it imitates others' products and produce them in house. Because of this, its R&D expenditures depend on its imitation cost, λ. On the other hand, it has to pay the legal settlement (Δ) if it loses the lawsuit in the court.

The key determinant for the decisions to buy or infringe is the firm's production cost under imitation (λ). This decision is static because λ is independently and identically distributed across periods. In addition, the optimal pricing and R&D decisions are designed to be static in this model, so the only dynamic choice is s', the choice for the scope of business in the next period. In equilibrium every firm will choose the same s', because every firm has the same marginal cost[15] and the same marginal benefit [16] of holding one more patent in the next period.

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[15] The marginal cost of holding one more patent is P', and every firm is facing the same price.

[16] The marginal benefit of holding a patent is how much a firm expects her payoff can be boosted by holding one more patent in the next period, and this expected boost in payoff depends on whether she buys or infringes in the next period. In addition, since λ is i.i.d. across periods, every firm has the same expectation for the next period, and this does not depend on the current status of buying and infringing, so the marginal benefit of holding one more patent is the same for every firm.

3.5 Equilibrium

3.5.1 Cutoff Strategy to Infringe

As revealed in the previous discussion, the key determinant for the decisions to buy or infringe is the firm's production cost under imitation (λ), and an infringer is facing the trade-off between lower R&D cost and paying legal settlement when losing the lawsuit. In equilibrium the firms will follow a cutoff strategy to infringe in the following form:

Proposition 1. (*Cutoff Strategies to Infringe*) A firm infringes if and only if its production cost under imitation $\lambda \leq \widehat{\lambda}$, where $\widehat{\lambda}$ is determined by $V^I(s; N, \widetilde{N}; \widehat{\lambda}) = V^B(s; N, \widetilde{N})$.

Conditional on the decision to buy, the value function of the firm no longer depends on its production cost under imitation (λ). In contrast, the value function of the infringer is strictly decreasing in its λ. Therefore, in equilibrium a firm infringes if and only if its production cost under imitation (λ) is lower than $\widehat{\lambda}$, and the threshold $\widehat{\lambda}$ is determined where the value function of the buying coincides with the value function of infringing. Since λ is uniformly distributed on $[0, \bar{\lambda}]$, the fraction of firms that infringes is $\widetilde{\lambda} = \dfrac{\widehat{\lambda}}{\bar{\lambda}}$.

3.5.2 Balanced Growth Path

Proposition 2. (*Balanced Growth Path*) There exists a balanced growth path[17] along which:

1. The number of the firms (F) is constant.

2. The number of active patents (N) and expired patents ($\widetilde{N}$) grow at the same rate.

3. Output (Y), comsumption (c), wages (w), and the number of patents held by each firm (s) all grow at the same rate as the number of active patents (N).

---

[17] The balanced growth path can be solved by five variables from five equations. The five variables are: the price set for other intermediate goods producer, the cutoff of imitation cost to infringe, the price of the patent, the number of the firms, and the growth rate of the number of active patents.

4   Quantitative Analysis

The theoretical model established in the previous section offers an experiment apparatus to conduct thought experiments and policy evaluations. To achieve this objective, the parameters of this model are calibrated to match the data in this section. The quantitative analysis delivers three major implications of the model: (1) stronger patent rights induce specialization, (2) specialization enhances firm performance, and (3) specialization contributes to economic growth.

4.1   Calibration

The value of the parameters in this model are reported in Table 3. These parameters fall into three groups: parameters underlying the preferences of the households, parameters governing the technology of production and R&D, and parameters characterizing the legal system.

Seven of these parameters are determined by a priori information, and the detailed identification strategies are delineated as follows.

1. *CRRA parameter for households*, ϵ. The CRRA parameter is determined by taking the average values of the estimates in Kaplow (2005).

2. *Long-run interest rate*, R. The long-run interest rate in the U.S. follows Cooley and Prescott (1995).

3. *Discount factor for households*, β. The discount factor for households is deduced from the interest rate (R), the CRRA parameter for households (ϵ), and the growth rate of the economy[18].

4. *Capital share*, α. The capital share is based on the U.S. National Income and Product Accounts, as reported in Corrado, Hulton and Sichel (2009).

5. *Imitation cost*, $\bar{\lambda}$. The imitation cost is gathered from Mansfield, Schwartz, and Wagner (1981).

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[18] To be specific, the discount factor for households (β) is pinned down from the Euler equation of the households.

6. *Patent survival rate*, σ. The term of patents in the United States is 17 years, so σ is taken to be $11/(1+17)$.

7. *Litigation cost*, ψ. The litigation cost is based on the report of the American Intellectual Property Law Association (2011)[19].

TABLE 3: **Parameter Values**

Parameter	Value	Description	Identification
β	0.98	discount factor for households	A priori information
ϵ	2.00	CRRA parameter for households	A priori information
R	0.06	interest rate	A priori information
α	0.60	capital share	A priori information
ϕ	140	production cost for intermediate goods associated with active patents	Calibration
$\widetilde{\phi}$	110	production cost for intermediate goods associated with expired patents	Calibration
θ	0.44	concavity of inputs in R&D function	Calibration
$\bar{\lambda}$	1.30	imitation cost	A priori information
ξ	2.71	convexity of management cost function	Calibration
σ	0.94	patent survival rate	A priori information
τ	0.61	parameter for the odds to invalidate a patent	Calibration
ψ	0.21	litigation cost	A priori information
μ	0.68	legal settlement for infringement	Calibration

The other six parameters, ϕ (production cost of intermediate inputs associated with the active patent), $\widetilde{\phi}$ (production cost of intermediate inputs associated with the expired patent), θ (degree of complementarities in R&D), ξ (convexity of the management cost), τ (parameter for the odds to invalidate a patent) and μ (legal settlement for infringement) are calibrated to match five data targets. The model moments are contrasted with the data targets in Table 4. The sources of the

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[19] As reported by the American Intellectual Property Law Association, the average litigation cost is 2.8 million dollars when the value at risk is between 1 million and 25 million dollars.

data targets are discussed as follows.

TABLE 4: **Calibration Target**

| Target	Source	Model (%)	Data (%)
level of integration ($\frac{s}{N}$)	USPTO	1.4	1.4
ratio of expenditure on R&D inputs purchased from the market to in-house R&D	NSF	13.0	13.0
fraction of cases invalidating the patents	US Patents Quarterly	29.0	29.0
litigation cost to R&D ratio	Lerner (1995)	27.0	27.0
R&D to GDP ratio	NIPA	3.3	2.9
growth of real GDP per capita	NIPA	2.1	2.1

1. *Level of integration.* This is the average fraction of technological fields each firm invents in[20]. a firm invents in between 1982 and 2006. The patenting information is obtained from the NBER patent dataset project.

2. *Ratio of expenditure on R&D inputs purchased from the market to in-house R&D.* This is the ratio of royalties to R&D taken from the report of the National Science Foundation (2013)[21].

3. *Fraction of cases invalidating the patents.* This is based on the records of the United States Patents Quarterly (USPQ).

4. *Litigation cost to R&D ratio.* The ratio of litigation cost to R&D is gathered from Lerner (1995).

5. *R&D expenditures to GDP ratio.* The ratio of R&D expenditures to GDP is calculated from the U.S. National Income and Product Accounts.

6. *Growth of real GDP per capita.* This is the average growth rate of real GDP per capita between 1982 and 2006, as calculated from the U.S. National Income and Product Accounts.

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[20] The technological fields are measured at the level of 3-digit International Patent Classification (IPC).
[21] More details can be found in Shackelford (2013).

4.2 Stronger Patent Rights Induce Specialization

The impact of patent rights on firm boundaries is depicted in Figure 9. The horizontal axis of Figure 9 are the odds for the patent to be invalidated by the court, a proxy for the strength of patent rights. The dashed line in Figure 9 is the fraction of firms that infringe on others' patents, and the solid line is the fraction of intermediate goods the firm produces in-house. The scope of business is captured by the fraction of business lines each firm covers, as shown on the left vertical axis of Figure 9. As revealed in this figure, when the patents are more likely to be invalidated by the court, a higher fraction of the firms will decide to infringe on others' patents instead of buying their products. In response, the firms will expand their business scope and produce a higher fraction of the intermediate goods in-house.

FIGURE 9: PATENT RIGHTS AND FIRM BOUNDARIES
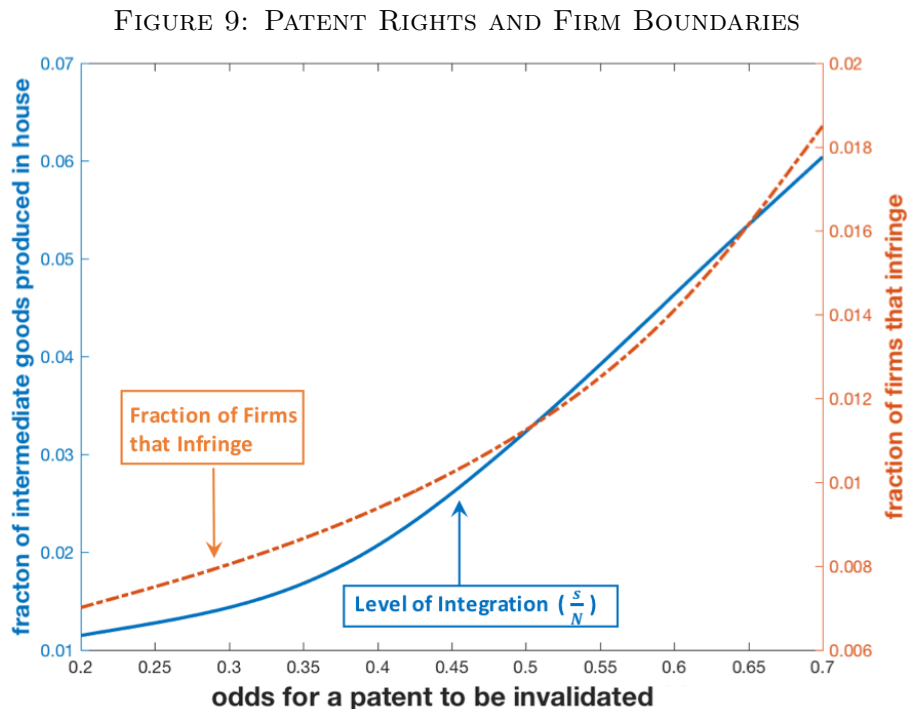
This is because a major benefit of broader business scope in this model is to fend off potential infringement. The expansion of business scope is achieved by merger and acquisition. After acquiring some suppliers and customers, a firm will be facing a smaller number of trading partners. The firm is less likely to be infringed, because the odds to be infringed are increasing in the number of

trading partners the firm deals with. In this way, the firm can fend off infringement, by expanding our business scope and acquiring its trading partners. In the extreme, imagine a firm acquires all the patents of all the other firms, then there would be a single firm in this economy. All the transactions will be internalized and there will be no issues of infringement. From this perspective, when a firm is concerned of being infringed, it can expand its business scope to fend off potential infringement and litigation.

In addition, this benefit is increasing in the odds for the patent to be invalidated. This is because the patents of a firm are more likely to be infringed and invalidated with weaker patent rights. Hence, the consequences of infringement and litigation are more severe, and the benefit of expanding business scope to fend off infringement increases. Therefore, weaker patent rights can discourage specialization and stronger patent rights can induce specialization.

4.3 Specialization Enhances Firm Performance

Figure 10 evaluates how the business scope decision of a firm affects its performance.

FIGURE 10: SPECIALIZATION AND FIRM PERFORMANCE
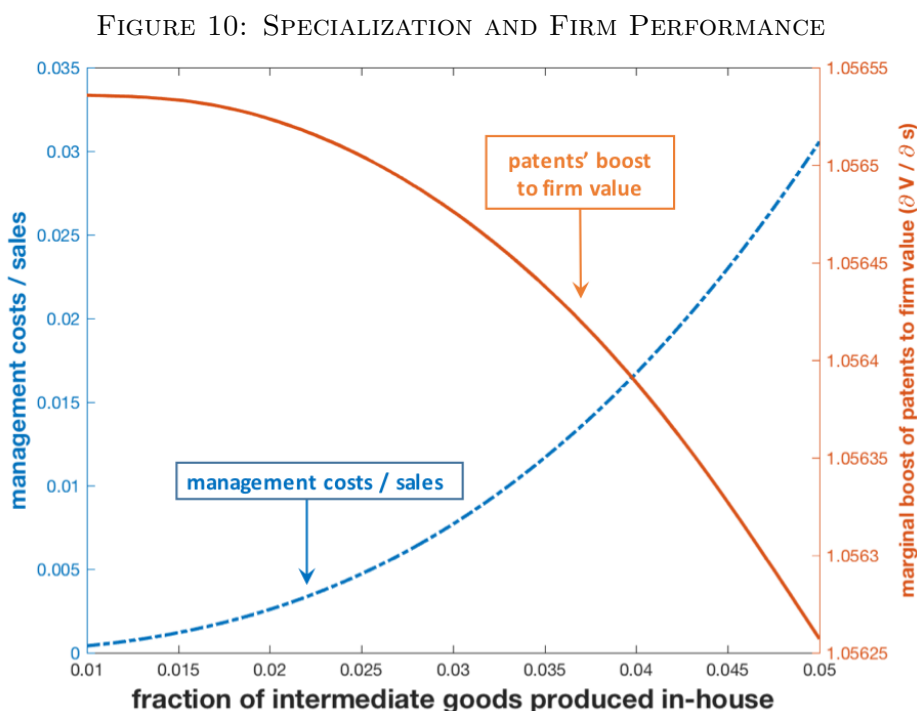
The horizontal axis in Figure 10 is the fraction of intermediate goods each firm produces in-

house. A higher fraction of intermediate goods produced in-house implies a broader business scope. The dashed line in Figure 10 is the ratio of management costs in sales, and the solid line is the marginal boost of patents to firm value. As demonstrated in Figure 10, broader business scope leads to higher management costs. Increasing costs originate from the convexity of the management costs function with respect to the fraction of intermediate goods the firm produces in-house. In consequence, the marginal boost of patents is increasingly lower when a firm has a broader business scope. Hence, specialization enhances firm performance by improving firms' management efficiency.

4.4 Specialization Contributes to Economic Growth

Figure 11 examines the relationship between specialization and economic growth. The horizontal axis in Figure 11 is the fraction of intermediate goods each firm produces in-house. The dashed line in Figure 11 is the ratio of R&D to GDP, and the solid line is the growth rate of GDP per capita.

FIGURE 11: SPECIALIZATION AND ECONOMIC GROWTH
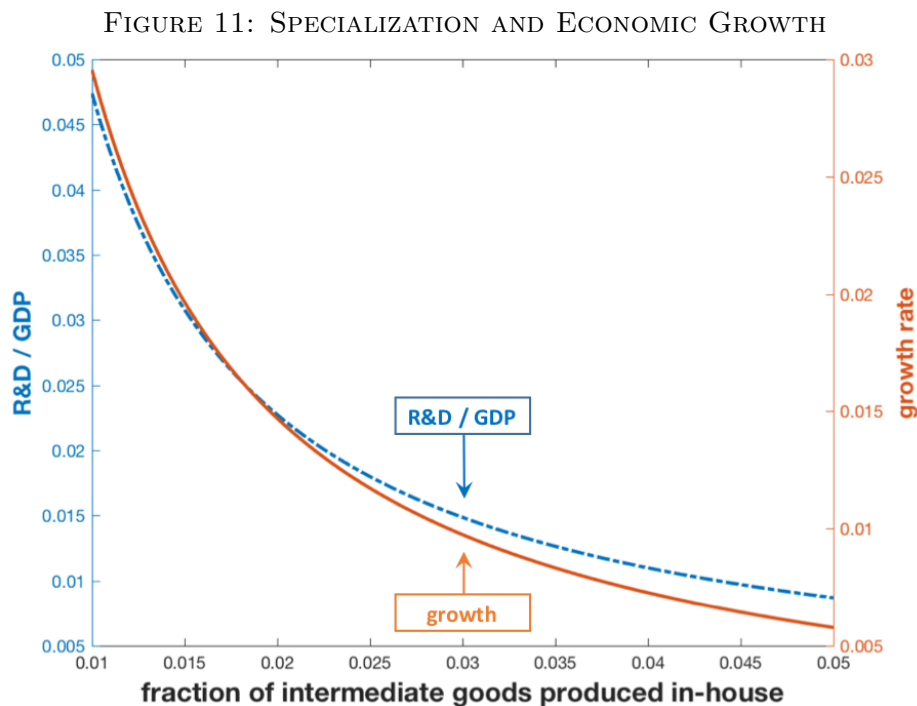
As shown in Figure 11, when the firms pursue a more focused business scope strategy by producing a lower fraction of intermediate goods in-house, the economy will experience faster

economic growth. When each firm produces a lower fraction of intermediate goods in-house, there will be a higher number of firms in this economy, each pursuing a more focused business scope strategy with narrower business scope. Each firm faces more buyers for its products, and its patents generate more revenue. Hence, the patents become more valuable, and the firms have stronger R&D incentives to develop more patents. As demonstrated in Figure 11, the economy features higher ratio of R&D to GDP, and, thus, it grows faster.

5 Empirical Evidence

As highlighted in the previous section, the model delivers three major implications: (1) stronger patent rights induce specialization, (2) specialization enhances firm performance, and (3) specialization contributes to economic growth. These implications will be tested by the empirical analysis in this section.

5.1 Business Scope and Technological Distance

In the empirical analysis, the business scope of the firm is measured as the technological distance between the new patents the firm develops to the existing patent portfolio of the firm. Figure 12 illustrates how this notion of technological distance is mapped into the model. Every firm has s patents in the model. These existing patents of the firm are indexed from 0 to s. In addition, imagine the firm develops new patents in the amount of ϵ. These new patents are indexed from s to $s + \epsilon$. Define the distance between 2 patents i and j, as the difference between their indices in absolute value, i.e., $d(i, j) = |i - j|$. In this scenario, the average distance of new patents to the firms' existing patent portfolio is $\dfrac{s + \epsilon}{2}$[22]. Hence, the new patents will be more far away from the existing patent portfolio of the firm, when the firm has a larger business scope, s. This is how the notion of business scope in the empirical analysis and the model are connected with each other.

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[22] To be specific, for each new patent $i \in (s, s + \epsilon]$, the distance of patent i to firm's existing patent portfolio is $\dfrac{\int_{j=0}^{s} d(i,j)dj}{s} = i - \dfrac{s}{2}$. Hence, The average distance of new patents to firm's existing patent portfolio is $\dfrac{\int_{i=s}^{s+\epsilon}(i - \frac{s}{2})di}{\epsilon} = \dfrac{s + \epsilon}{2}$.

FIGURE 12: BUSINESS SCOPE AND TECHNOLOGICAL DISTANCE
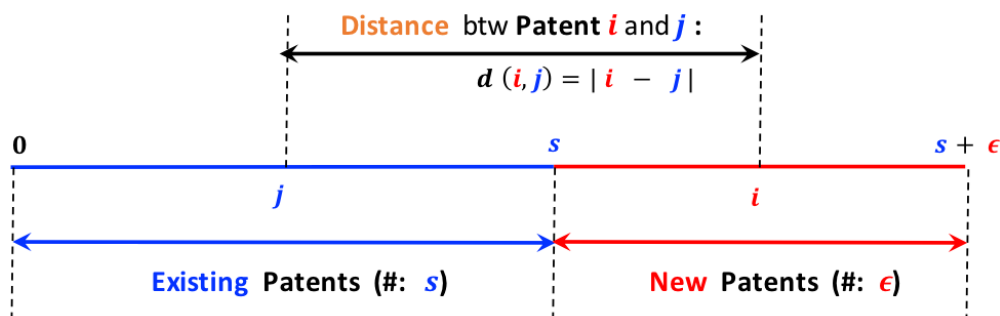
5.2   Stronger Patent Rights Induce Specialization

As outline in the introduction section, the recent decades have witnessed both stronger patent rights and increasing innovation specialization over time. Are they related to each other? To address this question, this section conducts a regression analysis to test the hypothesis that stronger patent rights can induce specialization.

To begin with, the impact of patent rights can be different across firms. To the extent the patent rights has an effect on the business scope decisions of the firms, this effect should be stronger for firms facing higher exposure to patent litigation. Based on this idea, the regression analysis is designed as follows.

$$y_{i,j,t} = \alpha \text{ invalidation rate }_{j,t} + \beta \text{ invalidation rate }_{j,t} \times \text{ litigation exposure }_{i,t} + X_{i,j,t}\delta + \epsilon_{i,t}$$

This regression is based on the U.S. public firms between 1976 and 2006. The dependent variable is the technological distance of the new patents a firm obtains in each year, to the existing patent portfolio of the firm at the beginning of the year. To be more specific, $y_{i,j,t}$ is the technological distance of the new patent to existing patent portfolio of firm i located in circuit court j. The main explanatory variable in this regression is the "invalidation rate", and it refers to the fraction of cases invalidating the patents in the circuit court where the firm is located. This is a proxy for the strength of patent rights in the firm's local environment[23].

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[23] This patent invalidation rate varies both within a circuit over time, and across the circuits at each point in time.

In addition, to capture potential heterogeneous effect across firms, there is an interaction term between the patent invalidation rate and the exposure to litigation at the firm level (i.e., "litigation exposure"). The measure of patent litigation exposure follows Mezzanotti (2017). As shown in Mezzanotti (2017), firms are facing different risks to litigation because they are inventing in different technological fields with different intensities of litigation. From this perspective, the litigation intensity of a technological class is measured as the fraction of patents litigated in this class[24]. Based on this measure of litigation intensity, the exposure to litigation at the firm level is the weighted average of the litigation intensities of all the technological classes the firm invents in, and the weight is the share of the firms' patents in each technological class.

$X_{i,j,t}$ refers to the control variables in this regression. To be specific, this regression controls for firm employment, firm age (and age squared), the patent stock of the firm (with quality adjustment)[25], year trend, industry effect, circuit court effect, and firm fixed effect.

Based on this setup, the regression results are presented in Table 5. As shown on the first row of Table 5, the estimate of the regression coefficient of the patent invalidation rate is positive. Hence, when the patents are less likely to be invalidated in a circuit court, firms located in this circuit tend to innovate in more closely related technological fields. In addition, the estimate of the regression coefficient of the interaction term is also positive, so the impact of patent rights is more pronounced for firms facing higher exposure to patent litigation. To address potential endogeneity issues, the instrument variable (IV) approach is adopted in the last column of Table 5. The IV is a dummy variable for the legal reform in 1982, which takes the value of 1 after 1982. As shown in the last column of Table 5, the conclusions are robust in this IV regression. Therefore, these regressions support the hypothesis that stronger patent rights can induce innovation specialization.

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[24] In the baseline empirical analysis, technological fields are measured at the level of 3-digit International Patent Classification (IPC).

[25] Quality adjustment of patent is performed by weighting the patent counts by the number of citations the patent receive, and the truncation issue is addressed following Hall, Jaffe and Trajtenberg (2001).

TABLE 5: PATENT RIGHTS AND SPECIALIZATION

	ln(Tech Distance)		
	OLS		IV
	(1)	(2)	(3)
ln(invalidation rate)	0.0121**	0.0738***	0.386***
	(0.00516)	(0.0232)	(0.0648)
ln(invalidation rate) × ln(litigation exposure)		0.0166***	0.0919***
		(0.00609)	(0.0155)
Observations	17,547	17,547	17,547
R-squared	0.6377	0.6379	

NOTES: COMPUSTAT, FIRM-LEVEL REGRESSIONS. THE CONTROL VARIABLES ARE FIRM EMPLOYMENT, FIRM AGE (AND AGE SQUARED), THE PATENT STOCK OF THE FIRM (WITH QUALITY ADJUSTMENT), YEAR TREND, INDUSTRY EFFECT, CIRCUIT COURT EFFECT, AND FIRM FIXED EFFECT. STANDARD ERRORS ARE IN PARENTHESES. *** DENOTES SIGNIFICANCE AT THE 1 PERCENT LEVEL, ** AT THE 5 PERCENT LEVEL, AND * AT THE 10 PERCENT LEVEL. THE IV IS A DUMMY VARIABLE FOR THE LEGAL REFORM IN 1982, WHICH TAKES THE VALUE OF 1 AFTER 1982.

5.3 Specialization Enhances Firm Performance

Does it matter for the firms to have a broad or narrow business scope? It does matter. It matters at the firm level because the business scope strategy is key to the fate of the firm, and it matters at the country level because of its impact on the economic growth of nations.

A telling example is the rise and fall of Yahoo. Yahoo was already a giant in both search engine and e-commerce when Google and e-Bay were still fledging start-ups. However, Yahoo has never been clear in where it should focus, and gradually it was defeated by Google in search engine and it was dwarfed by e-Bay in e-commerce. Yahoo is not alone, and the story of Yahoo is echoed in the regression in Table 6. This regression is based on the U.S. public firms between 1976 and 2006, and it evaluates the impact of specialization on firm performance along three dimensions: the number

of patents obtained per R&D dollar, the TFP of the firm [26], and its market value.

TABLE 6: SPECIALIZATION AND FIRM PERFORMANCE

	ln(patent, quality adj.)	*ln(TFP)*	*ln(market value)*
	(1)	(2)	(3)
ln(R&D)	0.186***		
	(0.0139)		
ln(R&D) × ln(tech distance)	−0.0163***		
	(0.00529)		
ln(patent stock)	0.812***	0.0823***	0.105***
	(0.0104)	(0.0228)	(0.0195)
ln(patent stock, dist-adj.)		−0.0376**	−0.0833***
		(0.0191)	(0.0167)
Observations	22,214	7,222	25,590
R-squared	0.804	0.951	0.918

NOTES: COMPUSTAT, FIRM-LEVEL REGRESSIONS. THE CONTROL VARIABLES ARE FIRM EMPLOYMENT, FIRM AGE (AND AGE SQUARED), THE PATENT STOCK OF THE FIRM (WITH QUALITY ADJUSTMENT), YEAR EFFECT, INDUSTRY EFFECT, AND FIRM FIXED EFFECT. STANDARD ERRORS ARE IN PARENTHESES. *** DENOTES SIGNIFICANCE AT THE 1 PERCENT LEVEL, ** AT THE 5 PERCENT LEVEL, AND * AT THE 10 PERCENT LEVEL.

Regression (1) is a patent production function, where the input is R&D of a firm and the output is patent that the firm obtains. To capture the impact of specialization on the R&D productivity of the firm, an interaction term between firm R&D and "technological distance" is introduced in regression (1). "Technological distance" here refers to the technological distance of the new patents a firm obtains each year, to its existing patent portfolio at the beginning of the year. As shown on the second row of regression (1), the interaction term between R&D and technological distance has a negative regression coefficient. Hence, a firm will harvest more patents from the same R&D dollar when it invents in technological fields that are closer to its existing patent portfolio.

Regression (2) and (3) assess the relationship between the firms' patent stock and their TFP and

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[26] The TFP estimation is based on Levinsohn and Petrin (2003).

market value. As shown in regression (2) and (3), while the patent stock has a positive contribution to firm TFP and market value, the distance-adjusted patent stock has a negative contribution[27]. Therefore, the patent will have a stronger boost to TFP and market value when a firm invents in more closely related technological fields. The ratio of the second regression coefficient to the first one in regression (2) and (3) captures the loss of larger technological distance, or, the gain of a more focused strategy. The bottom line of Table 6 is that innovation specialization (or a more focused business scope strategy) enhances firm performance, and is embraced by the shareholders.

5.4 Specialization Contributes to Growth

Built on the firm-level evidence, this section extends the analysis to the cross-country study. To evaluate the impact of innovation specialization on economic growth, a cross-country panel regression is conducted and the results are presented in Table 7.

The regression in Table 7 covers 88 countries between 1987 and 2006. These countries account for 98% of world GDP during this sampling period. This 2-decade sample is divided into 4 periods, each lasting for 5 years. The dependent variable in this regression is the average growth rate of each country in each period, and the main explanatory variable is the average technological distance between new patents and the existing patent portfolio of the innovators in each country in each period[28]. The regression in Table 7 controls for the initial GDP per capita and the Barro and Lee (2013) human capital index at the beginning of each period, the 2 main factors demonstrated to be important in the empirical literature. Since the propensity of the innovators in a country to patent in the U.S. can depend on its trade relation with the U.S., the export to the U.S. and the import from the U.S. of each country are included as control variables. In addition, country dummies are added in this regression to control for country fixed effect, and period dummies are included to control for the global aggregate shocks to all countries.

An IV regression is performed to address potential endogeneity issues. The IV is the average

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[27] When constructing the distance-adjusted patent stock, every patent is weighed by its distance to the existing patent portfolio of the firm when this patent is developed. The setup of regression (2) and (3) follows Akcigit, Celik, and Greenwood (2016).

[28] To be specific, for each innovator in each country in each year, the technological distance between the new patent it obtains and its existing patent portfolio at the beginning of the year is calculated. The explanatory variable in this regression is the average technological distance across the innovators in each country in each period.

technical distance between new patents and existing patent portfolio of the innovators for each country in the pre-sampling period[29], following the strategy pioneered in Barro and Lee (1994). The pre-sampling period is one period before the sample starts (i.e., 1982 – 1986).

TABLE 7: SPECIALIZATION CONTRIBUTES TO GROWTH

	growth of GDP per capita	
	OLS	**IV**
	(1)	(2)
tech distance	−4.548**	−5.692*
	(2.062)	(3.361)
Observations	267	185
R-squared	0.531	

NOTES: COUNTRY-LEVEL REGRESSIONS. THE CONTROL VARIABLES ARE THE INITIAL GDP PER CAPITA AND THE BARRO AND LEE (2013) HUMAN CAPITAL INDEX, THE EXPORT TO THE U.S. AND THE IMPORT FROM THE U.S. OF EACH COUNTRY, THE COUNTRY DUMMIES, AND THE PERIOD DUMMIES. *** DENOTES SIGNIFICANCE AT THE 1 PERCENT LEVEL, ** AT THE 5 PERCENT LEVEL, AND * AT THE 10 PERCENT LEVEL. THE IV IS THE AVERAGE TECHNOLOGICAL DISTANCE BETWEEN NEW PATENTS AND EXISTING PATENT PORTFOLIO OF THE INNOVATORS FOR EACH COUNTRY IN THE PRE-SAMPLING PERIOD.

As demonstrated by the negative estimates in Table 7, when the innovators in a country invent in more closely related technological fields, this implies a higher level of specialization and the country tends to experience faster economic growth. Hence, innovation specialization can contribute to economic growth. In addition, the estimate suggests economically large impact of specialization on growth. For instance, if the technological distance declines from the Japanese level to the U.S. level, the annual growth rate in Japan would have been higher by 62 basis point. Japan's GDP per capita would have been 13% higher after two decades.

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[29] The country dummies have to be dropped because the IV is country-specific and time invariant.

6 Optimal Strength of Patent Rights

The optimal strength of patent rights is characterized by counterfactual analysis in this section, and it is compared with the actual patent law enforcement in practice. Through the lends of the model, the pro-patent legal reform in 1982 was welfare-enhancing, but it was too extreme.

6.1 Patent Rights and Welfare

The welfare profile against the strength of patent rights is characterized in Figure 13. The horizontal axis of Figure 13 are the odds for the patent to be invalidated by the court, and the vertical axis is the consumption equivalent variation of the households. To be specific, the benchmark scenario is the economy with the optimal strength of patent rights, and the vertical axis is the fraction of consumption the households are willing to pay, if the strength of patent rights is changed from the optimal level to a suboptimal level.

FIGURE 13: OPTIMAL STRENGTH OF PATENT RIGHTS
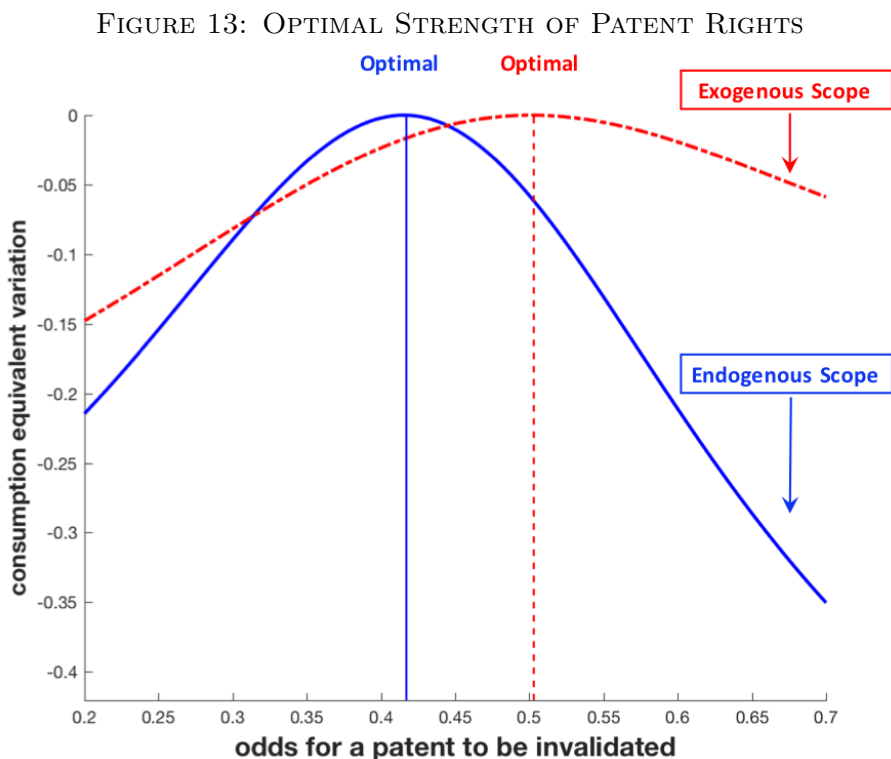
In addition, two scenarios are portrayed and contrasted in Figure 13. In the first scenario, the

business scope decision is an endogenous choice made by the firms, as delineated in the model. To unveil the role of the business scope decisions, the scope of business is fixed exogenously in the second scenario[30]. As shown in this figure, in both scenarios the welfare profile is hump-shaped with respect to the strength of patent rights. Part of this hump arises from this classic trade-off in the literature: stronger patent rights encourage R&D, but spur monopoly pricing by patent owners. The contribution of this paper is to introduce one additional impact of patent rights: the impact on firms' business scope strategies. In response to stronger patent rights, firms shrink their scope of business and specialize. This enhances firm performance and constitutes an additional benefit of patent rights. Hence, the optimal patent rights will be stronger when its impact on firm boundaries is taken into account. The optimal odds for patent invalidation is 42% with endogenous business scope, and it is 50% with exogenous business scope. Hence, the optimal strength of patent rights would be weaker, if the impact of patent rights on firms' business scope decisions is ignored. In consequence, there will be a welfare loss of 6% in terms of consumption equivalent variation.
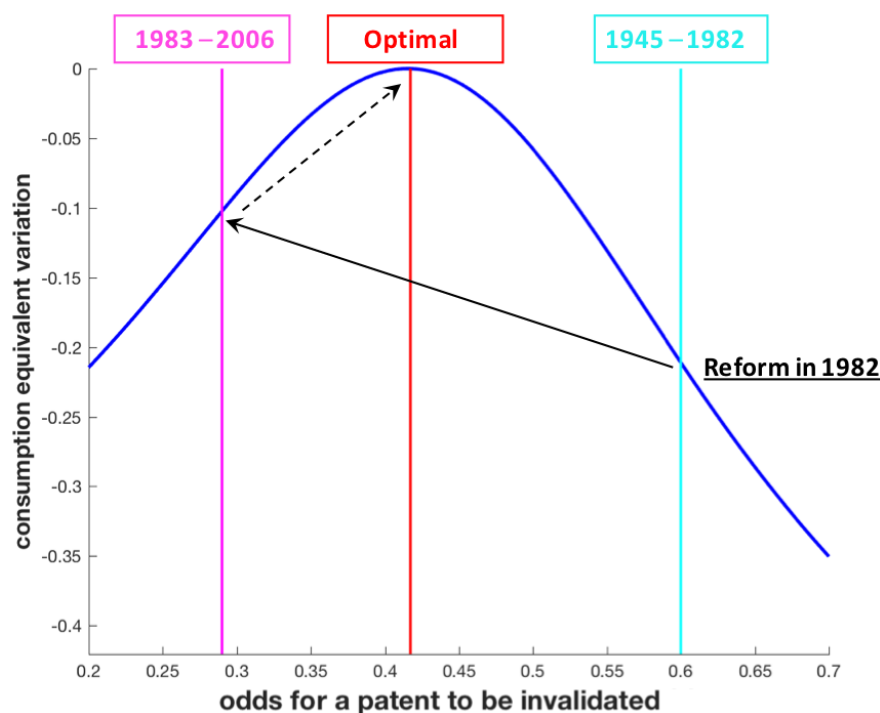
6.2   Legal Reform in 1982

Are the actual patent law enforcement optimal? To address this question, the optimal strength of patent rights implied by the model is contrasted with the actual law enforcement in Figure 14. As shown in Figure 14, the legal system before 1982 was characterized by a weak patent regime where the patents were invalidated in 60% of the cases. In contrast, the patent rights have been substantially strengthened after the reform in 1982. The legal reform in 1982 was definitely welfare-enhancing. This reform contributes to a welfare gain of 11.3% in terms of consumption equivalent variation. Through the lens of the model, however, this reform has been too extreme. Swinging back the legal pendulum and weakening patent rights to the optimal level will contribute to a welfare gain of 13.7% in terms of consumption equivalent variation.

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[30] In this scenario, the business scope is fixed at the calibration level. The model is calibrated to match the U.S. economy after the legal reform in 1982, so the business scope is fixed at the level of the post-1982 economy.

FIGURE 14: OPTIMAL VS. ACTUAL STRENGTH OF PATENT RIGHTS

7   Conclusion

Stronger intellectual property rights induce specialization and contribute to economic growth. In the United States, a sweeping legal reform in 1982 created a more pro-patent legal environment with stronger patent rights. This pro-patent legal reform fostered specialization in the innovating sectors and enhanced firm performance. Around the world, countries experience faster economic growth when their innovating sectors are characterized by higher level of specialization.

An endogenous growth model with endogenous firm boundaries is developed to disentangle the relationship between legal institutions, firm boundary decisions, and economic growth. Patent law enforcement is a crucial element of the model, and litigation concern plays a key role in the firm boundary decisions.

The model is matched with stylized facts of firm boundaries and patent litigation, and it delivers three major implications: (1) stronger patent rights induce specialization, (2) specialization enhances firm performance, and (3) specialization contributes to economic growth. These implica-

tions are supported by the empirical analysis. When the patent rights are strengthened in a circuit court, firms located in this circuit tend to innovate in more closely related technological fields. When a firm invents in technological fields that are closer to its existing patent portfolio, it will harvest more patents from the same R&D dollar, and its patent stock will have a stronger boost to its TFP and market value. At the country level, a nation will experience faster economic growth when its innovators invent more closely related in technological fields.

Furthermore, the optimal strength of patent rights is characterized through the lens of the model. There is a classic trade-off for optimal patent rights in the literature: stronger patent rights encourage R&D, but spur monopoly pricing by patent owners. The contribution of this paper is to incorporate the impact of patent rights on firm boundaries, and by extension, the industrial organizational structures in the innovating sectors. In response to stronger patent rights, firms shrink their scope of business and specialize. This enhances firm performance and constitutes an additional benefit of patent rights. Hence, the optimal patent rights will be stronger when its impact on firm boundaries is taken into account. In addition, the optimal strength of IPRs is contrasted with the actual patent law enforcement in practice. Through the lends of the model, the pro-patent legal reform in 1982 was welfare-enhancing, but it was too extreme. Swinging back the legal pendulum and weakening patent rights can improve welfare.

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Appendix

Data Sources

Detailed information of the patents granted in the United States Patent and Trademark Office (USPTO) between 1976 and 2006 is offered in the NBER-USPTO Utility Patents Grant Data (PDP)[31]. Accounting information of the publicly held corporations is available in Compustat North American Fundamentals (Annual) retrieved from Wharton Research Data Services. The matching between patent assignees and corporate entities are developed in the NBER Patent Data Project.

Litigation information of a patent is obtained by combining three data sets: Lex Machina Database on Patent Litigations, Derwent Litalert Database on Patent Litigations, and UGA Patent Litigation Datafile. For patents involved in litigation after 2000, Lex Machina Database on Patent Litigations is the most thorough data base[32]. Information on litigated patents before 2000 relies on Derwent Litalert Database on Patent Litigations[33]. However, neither Lex Machina Database nor Derwent Litalert Database provides information on the detailed court decisions. To address this issue, UGA Patent Litigation Datafile is applied. This dataset covers all patent-related cases where at least one court decision (district or appellate court) is recorded in the United States Patents Quarterly (USPQ). USPQ maintained the same publisher since 1929, and it includes the entire opinions for all appellate court decisions and a large sample of district court decisions (especially when they constitute important precedents for later judicial review)[34].

In the cross-country study, the national accounts of countries is based on the World Development Indicator of the World Bank[35]. The Barro and Lee (2013) human capital index is contained in the Penn World Table[36]. The import and export of each country with the U.S. is gathered from Schott (2008)[37].

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[31] Source link of NBER-USPTO Utility Patents: https://sites.google.com/site/patentdataproject/Home

[32] Source link: https://lexmachina.com/

[33] More detailed information can be found in Galasso, Schankerman, and Serrano (2013).

[34] Source link of UGA Patent Litigation Datafile: http://people.terry.uga.edu/jlturner/patentlitigationdata/

[35] Source link of the World Development Indicator: https://data.worldbank.org/data-catalog/world-development-indicators.

[36] Source link of Penn World Table (Version 8.0): http://cid.econ.ucdavis.edu/pwt.html

[37] Source link: http://faculty.som.yale.edu/peterschott/sub_international.htm