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Constraints of Internally and Externally Derived Knowledge and the Innovativeness of Technological Output: The Case of the United States*

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A major resource of technological innovativeness is knowledge, which can be either internally or externally derived, and constrained or abundant. We employ a longitudinal case study of U.S. industries to assess whether knowledge sources—internal or external to a country's domestic technology—affect an industry's technological innovativeness, and whether knowledge constraints affect technological innovativeness. We use more than 175,000 U.S. patents over 16 years. In contrast to the prevalent thinking that resource constraints inhibit innovation, we find trade-related knowledge constraints are largely positively associated with the innovativeness of technological output. Moreover, although one may expect a negative relationship between internally derived knowledge based on prior technology and technological innovativeness, we find this relationship is curvilinear.

Introduction

Technological innovativeness plays a major role in the development of new products, technologies, and markets. It drives the growth and success of firms and of entire industries. A major resource of technological innovativeness is knowledge. The source of knowledge can be either internal or external; that is, it can be derived from a firm's technology or from a source of technology outside the firm (Cohen and Levinthal, 1990). Taking this notion to the industry level, we suggest an industry can have two major and distinct sources of knowledge: one is the national pool of technology that is available primarily through the existing domestic stock of knowledge, and the other is knowledge that is external to the domestic stock of technology and is available primarily through international trade. We refer to these sources, respectively, as *internally derived knowledge* and *externally derived knowledge*. Mapping the sources of knowledge is useful for understanding innovation consequences. However, the availability of knowledge is also important: knowledge resources can be abundant or constrained, thus affecting the innovativeness of technological output.

We employ a longitudinal case study of U.S. industries to address the following questions: Do knowledge sources—internal or external to a country's domestic technology—affect an industry's technological innovativeness? And how do knowledge constraints affect technological innovativeness? These questions are important for scholars, managers, and policymakers for several reasons. First, the prime source of externally derived knowledge—international trade—is one of the most prominent aspects of globalization. In our increasingly globalized world, understanding the effects of international trade on the evolution of technology cannot be underestimated, especially in light of the constraining effects of economic recessions. Considering the 2008–12 recession alone, analysts and scholars are concerned about the decrease in global trade (Chang, 2009; Eaton, Kortum, Neiman, and Romalis, 2011; Levchenko, Lewis, and Tesar, 2010; Miller, 2010; Williams, 2012), as official reports of international imports and exports have registered a sharp decline for a number of quarters since the first half of 2008 (Bureau of Economic Analysis—US Department of Commerce, 2010; World Trade Organization, 2009). In this respect, the recession poses challenging conditions for entire industries, as raw

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material, finished goods, and new technological knowledge are less accessible than they previously were. Trade-related knowledge constraints and their effect on technological innovativeness become a key issue because we do not know how these constraints affect the evolution of technology. Moreover, specific effects of trade have not been previously studied in the context of technological innovativeness, thereby limiting the knowledge of policymakers as to whether declining trade rates inhibit or facilitate technological innovativeness.

Second, both international trade and reliance on prior technologies change over time. Despite fluctuations, international trade has overall increased in recent decades, as more countries remove trade barriers and exercise open trade policies (Brahmbhatt, 1998; Chase-Dunn, Kawano, and Brewer, 2000; Olstein, 2006). This trend has received steady attention in the innovation literature (i.e., Foster, Golder, and Tellis, 2004; Johnson and Tellis, 2008; Kalish, Mahajan, and Muller, 1995; Mitra and Golder, 2002; Tellis, Stremersch, and Yin, 2003). This literature provides an opportunity to explore the effect of fluctuations in trade and the related knowledge constraints on the innovativeness of technological output. Reliance on prior technologies has increased too, as more new products imitate existing ones, and improvements tend to become marginal (Bayus, 1994, 1998; Kohli, Lehmann, and Pae, 1999). This paper addresses the effects of these dynamics on the innovativeness of technological output. Third, international trade affects not only access to knowledge but also to raw materials, professional networks, and so forth. These effects are likely to have implications for the further development of technologies and new products. Fourth, we study the effects of internally and externally derived knowledge on technological innovativeness, focusing on the industry level. The majority of innovation studies focus on microlevel parameters, such as the innovation itself, the development team, and the firm. Few innovation studies have focused on the industry or on a higher level (i.e., Furman, Porter, and Stern, 2002; Tellis et al., 2003).

We suggest internally and externally derived knowledge affect the innovativeness of technological output. We use the concept of challenging conditions and resource constraints as the framework for our examination. Specifically, we use a longitudinal case study of the United States and examine how challenging conditions, in terms of knowledge constraints, affect an industry's innovativeness of technological output. We suggest knowledge constraints may have a positive effect on an industry's technological innovativeness.

The paper is organized as follows: first, we provide a theoretical background and develop our hypotheses. We then test our hypotheses using longitudinal U.S. trade and patent data from more than 175,000 patents over a 16-year period. We then discuss the findings and limitations and provide suggestions for future research and implications.

Theory

Challenging Conditions and Innovation-Related Processes

Challenging conditions are constraints, problems, and obstacles present in the external or internal environment. One might assume constraints and challenging conditions are likely to hinder innovative processes. However, studies from several disciplines suggest otherwise. For example, in his preeminent work, Toynbee (1934) posits that difficult environmental, economical, or social conditions actually facilitate innovation. This line of research suggests a considerable challenge imposed on a given society stimulates the utilization of creative and innovative capabilities to overcome the challenge. The result is cultural and technological innovation (Kyriazis and Zouboulakis, 2004; Patton, 2002; Toynbee, 1934).

This paper focuses on a specific form of challenging conditions, namely, resource constraints. In the business context, challenging conditions in terms of resource constraints can be financial, human, and so forth. Previous

BIOGRAPHICAL SKETCHES

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research has discussed resource constraints as having various forms of positive effects on performance and on innovation-related processes in general (e.g., Burroughs and Mick, 2004; Gibbert, Hoegl, and Välikangas, 2007; Grinstein, Ofek, and Rosenzweig, 2008; Hoegl, Gibbert, and Mazursky, 2008; Srinivasan, Rangaswamy, and Lilien, 2005; Whited and Wu, 2006). A number of studies discuss the effects of resource constraints on technological innovativeness in particular. These studies suggest that constrained resources can lead to technological innovativeness. For example, Porter and van der Linde (1995) show regulation that constrains the use of material resources can result in technological innovativeness in domains such as refrigeration and printing ink. Ben-Aharon and Golub (2004) find a similar effect on technological innovativeness in the chemicals industry. Brunnermeier and Cohen (2003) find resource constraints lead to successful patent applications, and Cyert and March (1963) suggest firms under resource constraints may not invest in innovations that are merely technological improvements, but they would still invest in other forms of technological innovativeness.

Overall, although somewhat counterintuitive, the potential positive effect of challenging conditions on innovative processes in general—and of challenging conditions in terms of resource constraints on technological innovativeness in particular—is emphasized across studies. Importantly, to achieve a positive effect, the challenge must not be extreme (Gibbert et al., 2007; Toynbee, 1934). Thus, as long as they are not extreme, resource-constraint challenges may positively affect technological innovativeness.

Sources of Knowledge for Innovation

Technological knowledge is an important resource for innovation. Knowledge can be external (developed outside the firm) or internal (developed within the innovative firm). Both sources of knowledge are important for the firm's innovation processes (Branstetter, 2006; Cohen and Levinthal, 1990; Leonard-Barton, 1995; Mansfield, 1988a). We extend this concept beyond the firm level to the industry level. Accordingly, we suggest that an industry's technological innovativeness can be based on externally and internally derived knowledge. *Externally derived knowledge* refers to the knowledge outside the country's existing pool of technology, and *internally derived knowledge* refers to the knowledge within the country's technology.

The prime source of externally derived knowledge is international trade. Numerous studies emphasize this notion (e.g., Coe and Helpman, 1995; Falvey, Foster, and Greenaway, 2002; Feinberg and Gupta, 2004; Grossman and Helpman, 1991; Liu and Buck, 2007; Lumenga-Neso, Olarreaga, and Schiff, 2005). International trade is an exchange of goods. In essence, however, it is an exchange of knowledge (Ahmed, Cheng, and Messinis, 2010). Learning from other countries plays a major role in research and development (R&D) activities (Rosenberg and Steinmueller, 1988). The more open a country's trade, the more externally derived knowledge is available for that country's industry, and the exposure to such foreign knowledge increases. Thus, researchers learn not only from R&D projects in their own environments, but also from technological advancements in other countries (Grossman and Helpman, 1991). Moreover, researchers can learn not only from such advancements in a second country, but also from advancements in a third country trading with the second country. Thus, researchers can benefit from a two-step knowledge source (Lumenga-Neso et al., 2005).

Both imports and exports play a role in the acquisition of externally derived knowledge. Imports of raw materials and finished goods expose the country's industry to new ideas and technological advancements (Falvey et al., 2002; Liu and Buck, 2007). Imports can also upgrade the local technology and domestic production (Chuang and Hsu, 2004). Interestingly, exports have a similar effect. Extensive prior research suggests exporting enables privileged access to information and sources of market and technological knowledge (e.g., Clerides, Lach, and Tybout, 1998; Grossman and Helpman, 1991; Salomon and Jin, 2009; Salomon and Shaver, 2005). Export activity facilitates knowledge diffusion by disseminating information about foreign countries, including new technologies, management skills, production skills, and so on (Chuang and Hsu, 2004; Liu and Buck, 2007; Wei and Liu, 2006). Accordingly, we follow prior literature and treat externally derived knowledge as knowledge that is accessible through international trade.[1]

The prime source of internally derived knowledge is the country's own pool of prior technologies. In this study, we examine the *extent* of usage of *prior technologies*. We relate to internally derived knowledge as the knowledge that is accessible within the country; that is, the country's existing stock of knowledge. Specifically,

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[1] The literature widely recognizes international trade as the prime source of externally derived knowledge. However, it is not the only source. Other sources are foreign direct investment (FDI) and multinational corporations' R&D investments in their subsidiaries. We address these sources and their role in the Method and Discussion sections.

reliance on the knowledge embedded in the country's existing stock of technology can be unlimited, partially constrained, or extremely constrained. An extreme constraint would mean no reliance on prior technology. Supposedly, the relationship between prior technology and the innovativeness of technological output is linear and negative. However, we contend this relationship is more complex. Indeed, prior literature does not view innovativeness solely as a discontinuity in terms of technology, but also as a discontinuity in terms of marketing structure and of meaning and usefulness to customers and compliance with their needs (see Chandy and Tellis, 1998, 2000; Garcia and Calantone, 2002; Sethi, Smith, and Park, 2001). The suggested complex relationship is in line with Moorman and Miner (1997) who postulate that high levels of internal knowledge may increase, decrease, or not affect performance of new products, depending on the circumstances.

Note that prior studies do not consider reliance on prior technologies to be endogenous, but rather a general macrolevel trend (i.e., Bayus, 1994, 1998; Kohli et al., 1999). This trend is affected by industry characteristics, such as the customary reliance on prior technologies, the extent to which knowledge of prior technologies is accessible, and communication capabilities. Thus, the extent to which firms can rely on prior technology-related knowledge is not a simple firm-level decision. It has a clear industry-level aspect because it is subject to—and propelled by—industry conditions. We do not underestimate the firm-specific role in deciding if, and to what extent, prior technology is used. That said, our study focuses on the industry level, suggesting this level's role deserves attention and has thus far been underestimated.

Hypotheses

In this section, we develop hypotheses regarding the effects of internally and externally derived knowledge on the innovativeness of technological output. We do so by using the challenging conditions framework.

Challenging conditions: Externally derived knowledge constraints. Externally derived knowledge stems primarily from international trade. International trade is correlated with the volume and variety of traded goods and the diffusion of ideas, products, and technologies (Broda, Greenfield, and Weinstein, 2006; Findlay and O'Rourke, 2001; Mahajan and Muller, 1994; Tellis et al., 2003). Thus, the more constrained the international trade is, the fewer resources are available for the country and its industries. These fewer resources are both material (raw materials, finished goods, etc.) and nonmaterial (knowledge, ideas, etc.). For example, limited trade constrains local markets from learning about new technologies and products, about novel methods of producing old technologies and products, and about technological advancements in other countries (Coe and Helpman, 1995; Grossman and Helpman, 1991). Although one may intuitively associate a bounty of resources and knowledge available through trade with higher technological innovativeness, the concept of challenging conditions suggests the opposite: the fewer resources, the bigger the challenge—and hence, the greater the incentive to innovate. Once exposed to knowledge of a new technology (assuming it is accessible), firms prefer to copy it rather than reinvent or redevelop it from scratch (Mansfield, 1988b; Menon and Pfeffer, 2003). Moreover, reliance on such externally derived knowledge inhibits internal knowledge creation (Levinthal and March, 1993). Therefore, when trade-related knowledge is constrained, firms in a given industry cannot easily obtain externally derived knowledge. The industry has limited access to ideas and new technologies and is thus forced to come up with ideas and develop its own technologies. Trade constraints are a change in the environment that forces those dealing with innovation to switch to other resources (Hambrick and Snow, 1977; Mokyr, 2000). Therefore, the industry is forced to overcome the challenging conditions of trade-related knowledge constraints by innovating.

These arguments suggest the following:

> *H1: Trade-related knowledge constraints positively affect the innovativeness of technological output.*

As we mentioned earlier, to positively affect the innovativeness of technological output, trade-related knowledge constraints cannot be extreme. This paper focuses on the case of the United States, which practices relatively open trade. However, countries with extremely constrained trade are not expected to demonstrate a positive effect of trade-related knowledge constraints on the innovativeness of technological output. For example, South Africa experienced extreme trade constraints, resulting from international sanctions, and did not demonstrate high innovation levels until the mid-1990s, when sanctions were removed and the country could start rebuilding its international trade (i.e., Kraemer-Mbula and Muchie, 2009). Similarly, in the early 1990s, Cuba experienced extreme trade constraints as a result of the downfall of its East European markets and the tightening of the U.S. trade embargo. Only in the late 1990s, after starting to recover from the extreme trade constraints, could Cuba innovate again (i.e., Thorsteinsdóttir, Sáenz, Quach, Daar, and Singer, 2004).[2]

Innovation and internally derived knowledge constraints. The prime source of internally derived knowledge is the country's own pool of prior technology. Strategic literature suggests firms can utilize prior technology either to develop new technological knowledge on their own (Benner and Tushman, 2002; March, 1991) or as a basis for absorbing external technological knowledge (Cohen and Levinthal, 1990, 1994; Levitt and March, 1988). Thus, prior technology is a viable knowledge resource that enables further technological advancement.

Prior research suggests a curvilinear relationship between various types of knowledge resources and innovation performance. For example, Leonard-Barton (1992) postulates that a firm's knowledge in the form of core capabilities contributes to innovation; however, it might also hinder innovation due to rigidities. Similarly, Nohria and Gulati (1996) find resources in excess of the minimum necessity have an inverted U-shaped relationship with organizational innovation. Prabhu, Chandy, and Ellis (2005) find this inverted U-shaped relationship between similarities in the knowledge of acquiring and acquired firms and the ability of acquiring firms to translate knowledge into innovation. We suggest that the relationship between prior technology as internally derived knowledge and the innovativeness of technological output is also curvilinear.

Challenging conditions: Internally derived knowledge constraints. We now frame internally derived knowledge, in terms of prior technology, in the context of challenging conditions, and suggest the following scheme. We present illustrative examples of this scheme in the Appendix.

High levels of reliance on prior technology mean no prior technology-related knowledge constraints. The absence of knowledge constraints offers *no challenge*. The excess resources diminish discipline in innovation projects (Nohria and Gulati, 1996), and there is little efficiency in investment and R&D (Jensen, 1993; Leibenstein, 1966). No meaningful gap between the prior technology and the new technology, and no stimulus for truly innovative processes exist. That is, the higher the reliance on prior technology, the smaller the challenge and the smaller the incentive to achieve high levels of innovativeness of technological output. This idea is in line with the notion that under certain conditions, the absence of knowledge constraints may harm the innovativeness of new products (Moorman and Miner, 1997).

Low-to-moderate reliance on prior technology presents an *adequate challenge*. Prior technology-related knowledge is restricted, and industries have to make an effort to bridge the gap between the prior technology and the new one. The challenge in bridging this gap facilitates an entrepreneurial approach (Gibbert et al., 2007) and innovative processes (Välikangas and Gibbert, 2005). This idea is in line with the notion that a moderate amount of resources facilitates innovation (Bourgeois, 1981; Cyert and March, 1963).

No reliance on prior technology provides an *extreme challenge*. The extreme prior technology-related knowledge constraints do not present a sufficient platform for fruitful and meaningful innovation (Gibbert et al., 2007; Moreau and Dahl, 2005; Toynbee, 1934). The lack of a basic knowledge platform means there is no absorptive capacity necessary for technological development (Cohen and Levinthal, 1990). Studies have found that deficiency in such a capacity is associated with low innovation (e.g., Gertler and Levitte, 2005; Narasimhan, Rajiv, and Dutta, 2006; Tsai, 2001). In other words, non or extremely constrained prior technology does not enable innovativeness of technological output because innovativeness has nothing upon which to build.

The above arguments suggest the following:

> *H2: A curvilinear relationship exists between prior technology and the innovativeness of technological output, where prior technology-related knowledge constraints positively affect technological innovativeness; however, extreme knowledge constraints negatively affect technological innovativeness.*

A high reliance on prior technologies implies a low technological discontinuity. Nonetheless, prior studies examine innovativeness not only by technological discontinuity, but also by its meaning and usefulness to

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[2] One could argue that two possible effects may work against the suggested hypothesis. First, it stands to reason that trade constraints decrease competition, and that competition and innovativeness are correlated. However, a number of studies suggest the relationship between competition and innovation is not necessarily simple and linear (see Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Aghion and Howitt, 1992; van der Panne, 2004). Second, trade constraints may suggest fewer markets. One may argue the fewer markets are negatively associated with innovation because firms have no incentive to innovate. Here, again, prior research suggests the relationship between fewer markets and innovation is not necessarily simple and linear. First, the effect of potential international markets may differ across nations and industries (Grossman and Helpman, 1991). Second, innovation is not driven solely by economic incentives (Mokyr, 2000). Thus, the relationship between anticipated markets and innovation is not necessarily simple and linear. Moreover, these two options work against our hypothesis, and so, the effect we suggest must be strong enough to override them.

customers (Sethi et al., 2001), and by the extent to which it fulfills their needs (Chandy and Tellis, 1998). Therefore, a high reliance on prior technology-related knowledge does not necessarily mean low technological innovativeness. Moreover, we do not contend a simple monotonic and negative relationship but rather a more complex, curvilinear one.

Method

Data and Sample

We present a longitudinal case study of the United States. We use longitudinal U.S. patent and trade data to test our hypotheses. Patents are a form of knowledge transfer (Agrawal and Henderson, 2002). A number of management studies have used patenting indicators to measure technological and innovativeness outputs (e.g., Artz, Norman, Hatfield, and Cardinal, 2010; Chandy, Hopstaken, Narasimhan, and Prabhu, 2006; Narasimhan et al., 2006; Prabhu et al., 2005; Rao, Chandy, and Prabhu, 2008; Sorescu, Chandy, and Prabhu, 2003, 2007; Wuyts, Dutta, and Stremersch, 2004). Patent data have a number of advantages relevant for this study (Hall, Jaffe, and Trajtenberg, 2002; Jaffe, Trajtenberg, and Fogarty, 2002; Trajtenberg, 1987). First, they cover a variety of industries. Second, they cover large time spans. Third, they contain detailed and rich information regarding the technology, prior knowledge upon which the given patents build, the usage of knowledge in subsequent patents, and so forth. Fourth, they are publicly available. Fifth, patents do not focus on marketing aspects such as marketing mix, sales, or product launch capabilities. They indicate mere technological advancements. This distinction enables us to isolate technological innovativeness from other innovation-related capabilities and to focus solely on constraints on technological innovativeness. Specifically, we use the National Bureau of Economic Research (NBER) Patent Data File, which covers patents issued in the United States between 1963 and 1999 (Hall et al., 2002).

We selected for our analysis all patents in industries in which the majority of the patents are likely to yield new consumer products and for which full industry-level trade data are available. We used the technological subcategory classification of Hall et al. (2002), which is based on the classifications of the United States Patent and Trademark Office (USPTO). Altogether, we use six technological subcategories, which represent respective industries. For robustness checks, we use six additional industries (Table 1).

Table 1. Industries Included in the Analyses

Analysis	Industry	Number of Patents 1975–1990
Industries in main analysis	Electrical devices	35,419
	Transportation	34,935
	Agriculture, husbandry, food	25,876
	Apparel and textile	21,085
	Furniture, house fixtures	23,410
	Drugs	34,319
	Number of patents in main analysis	**175,044**
Industries added for robustness checks	Chemical agriculture, food, textiles	11,560
	Amusement devices	11,058
	Communications	42,222
	Computer hardware and software	24,605
	Computer peripherals	7,235
	Information storage	16,156
	Total number of patents in robustness checks	**287,880**

We use *all* patents in these industries that were issued in the United States between 1975 and 1990. We do not use later patents, because we use data regarding citations made and citations received (sometimes referred to as backward citations and forward citations, respectively). The NBER Patent Data File we used provides information until 1999. Because it takes time for patents to be cited by subsequent patents, we address truncation by taking a wide backward time window to obtain adequate coverage of later patents that cite the patents in our sample (Hall et al., 2002). To determine the width of the time window, we plotted all available data of citations made against the patent-issuing year for the period of 1963–1999. According to this descriptive analysis, the period that is not truncated for received citations is 1975–1990. The median year for this period is 1983. Next, we closely examined patents issued in 1983 from the total of 12 industries we analyze. We randomly sampled 20 patents of *each* of the industries, totaling 240 patents. For each of these 240 patents, we retrieved *all* cited patents to determine their age. The average age of a patent cited in 1983 is 8.66 years. To be conservative, we rounded this number up and deducted nine years from the available data set. We thus determined the end of the sampled period as 1990. Thus, our final sample covers the period of 1975–1990. The total number of patents included in our main analysis is 175,044, and 287,880 in the robustness checks.

Level of Analysis

Our level of analysis is the industry level. Accordingly, our main variables are industry-level measures. We aggregate patent data to the industry level, and in our main analysis, we use industry-level trade data. For additional control variables, we use some country-level measures because literature expects them to affect industry-level innovativeness. Accordingly, the business literature frequently uses country-level data in lower-level analyses. For example, Tellis et al. (2003) use country- and continent-level data in their product-level analysis; Van den Bulte (2000) uses country-level data in an analysis of consumer durables; Feinberg and Gupta (2004) use country-level data in their firm-in-industry analysis; and Liu and Buck (2007) use country- and meta-industry data in their industry-level analysis. We elaborate below on the control variables and further discuss the challenges and opportunities stemming from our analysis.

Measures

Innovativeness of technological output. Our dependent variable is the mean number of citations patents received in a single industry in a single year (Trajtenberg, 1990):

$$Innovativeness_{jt} = \frac{\sum_{i=1}^{n_{jt}} \left(1 + CitationsReceived_i\right) - n_{jt}}{n_{jt}}, \quad (1)$$

where i is a patent, j is an industry, t is time (year), and n is the number of patents issued in industry j in year t. The logic behind this measure is that the more innovative technologies receive more frequent citations (Narasimhan et al., 2006). Trajtenberg (1989, 1990) show patent citation counts provide a good indication of the economic value of innovations, and economic and managerial research have since used such counts as approximations for value, importance, quality, potential, and innovativeness of technology (e.g., Aghion et al., 2005; Audia and Goncalo, 2007; Benner and Tushman, 2002; Chandy et al., 2006; Lanjouw and Schankerman, 1999; Narasimhan et al., 2006; Sorescu et al., 2007). Because the counts are averaged and aggregated, their distribution is close to normal, and there is no zero inflation.

Trade-related knowledge constraints. We measure externally derived knowledge constraints using U.S. trade data. The influential work of Grossman and Helpman (1991) suggests that international trade is an international transmission of knowledge. International trade data are a direct measure of such externally derived knowledge. Specifically, we use the sum of exports and imports of goods and services in a single industry relative to gross domestic product (GDP), which is a common measure of trade (see Guillén, 2001; Polillo and Guillén, 2005; Tellis et al., 2003) and is useful in detecting longitudinal trends (Brahmbhatt, 1998; World Bank, 2006). Trade-related knowledge may take time to influence patents. Prior research has found no lag or a very short one (usually one year) between access to resources and patent applications (i.e., Brunnermeier and Cohen, 2003; Hall, Griliches, and Hausman, 1986). The mean time lag between patent application and patent issue in our sample of six industries is 1.84 years. Thus a three-year trade-knowledge-related time lag seems conservative and is also in line with prior research (Furman et al., 2002). We also conducted analyses with a single-year and a two-year lag. These provide similar results to an analysis with a three-year lag. Because we focus on trade constraints rather than trade flows, we use this term in its negative form. We retrieved the data from the Center for International Data at UC Davis (Feenstra, Romalis, and Schott, 2002).

Prior technology. Internally derived knowledge in terms of prior technology is the second major explanatory variable. We use the mean of citations patents made to prior patents as a measure of this variable (i.e., backward citations). Specifically, we use citations to prior patents within the United States, that is, domestic citations, even if foreign applicants applied for the patents, because they become a part of the United States' technology-knowledge assets. We use this measure because these citations reflect the United States' stock of technology —an actual record of internally derived knowledge. We exclude self citations (i.e., citations made to patents from the same firm):

$$PriorTech_{jt} = \frac{\sum_{i=1}^{n_{jt}} \left(1 + CitationsMade_i\right) - n_{jt}}{n_{jt}}. \quad (2)$$

The rationale behind this measure is that citations made to prior patents account for actual prior technology used for the development of the present one (Hall et al., 2002). Thus, they are inherently time lagged and account for the time between the prior and current technology. Citations made to prior patents are not biased because inventors have no incentive to overcite prior patents, and to be approved by patent examiners, they must cite all prior patents upon which they relied (Chandy et al., 2006). Our analysis incorporates this measure of prior technology as well as a squared term of this variable to account for a curvilinear relationship.

Patent counts. We use patent counts to control for the intensity of inventive activity and capacity in the industry. Moreover, the seminal works of Griliches (1984) and Trajtenberg (1990) found patent counts to be an informative measure of R&D expenditures. Accordingly, a wide-scale cross-country study found a correlation of .928 between patent counts and R&D expenditures (Furman et al., 2002). Based on these studies, and drawing from our theory regarding resource constraints, we incorporate patent counts and a squared term of this variable to account for a possible curvilinear relationship.

Country-level control variables. A number of country-level variables may affect the innovativeness of technological output of an industry. Per capita *GDP* is considered an indication of the ability of a country to convert knowledge into economic development and provides control for technological sophistication (Furman et al., 2002). GDP also indicates economic development and purchasing power (Guillén and Suárez, 2005; Tellis et al., 2003). We also control for *population size*, as it indicates labor resources available for innovation (Furman et al., 2002).

Prior research suggests that in addition to imports and exports, foreign direct investment (FDI) is an indicator of international knowledge flows (e.g., Branstetter, 2006; Chuang and Hsu, 2004; Wei and Liu, 2006). Moreover, a decline in FDI may pose financial resource constraints. Therefore, we control for *FDI*. We also control for *telephone line availability* (per 100 people), *electric power consumption* (kWh), and *consumption expenditure* (as a share of GDP) because they represent available resources and indicate changes in the national economy and resource stock over time. The country-level variables we list here are likely to affect industry- (and firm-) level innovativeness. As such, controlling for them is important in the empirical context of the study. We retrieved data from the World Development Indicators of the World Bank.

Our analysis is time variant. To conduct a cross-sectional time-series (TSCS) analysis, we include the country-level control variables for each industry. We use a random-effect model and introduce industry interactions to enhance the industry aspect of our analysis. We provide robustness checks and further discuss the advantages and challenges of our analysis below.

Model

To test our hypotheses, we estimate the following TSCS model:

$$\begin{aligned} Innovativeness_{jt} &= \alpha + \beta_1 TradeConstraints_{jt-3} \\ &+ \beta_2 PriorTechnology_{jt} + \beta_3 PriorTechnology_{jt}{}^2 \\ &+ \beta_4 Ln\_n_{jt-1} + \beta_5 Ln\_n_{jt-1}{}^2 + \beta_6 Ln\_GDP_{t-1} \\ &+ \beta_7 Ln\_Population_{t-1} + \beta_8 Ln\_FDI_{t-1} \\ &+ \beta_9 Ln\_Phone_{t-1} + \beta_{10} Ln\_Electricity_{t-1} \\ &+ \beta_{11} Ln\_Consumption_{t-1} + \upsilon_j + \varepsilon_{jt}, \end{aligned} \tag{3}$$

where *j* is an industry, *t* is time (year), *Innovativeness* is the mean innovativeness of technological output as defined in Equation (1), *TradeConstraints* is the inverse of the sum of industry imports and exports relative to GDP with a three-year lag, *PriorTechnology* is prior technology as defined in Equation (2) and is inherently lagged, *Ln_n* is the natural logarithm (ln) of the number of patents issued, *Ln_GDP* is the ln of GDP, *Ln_population* is the ln of population size, *Ln_FDI* is the ln of FDI, *Ln_Phone* is the ln of telephone lines availability, *Ln_Electricity* is the ln of electric power consumption, *Ln_Consumption* is the ln of consumption expenditure, α and β_1-β_{11} are coefficients to be estimated, and υ and ε are error terms. We focus on the innovativeness of technological output, and not on new products or sales performance. We expect the effects on the latter two to be evident only a few years after the technological innovativeness takes place (see Artz et al., 2010). Conversely, one can expect the effects on the actual technological innovativeness, evident in the patent stock, to be much more immediate. For this reason, we use single-year lags and not longer ones (for variables other than *TradeConstraints*).

Results

We provide unit root testing, the main model estimation, and a focus on the effect of trade constraints and prior technology across industries. Table 2 exhibits a correlation matrix of the control variables.

Model Estimation

We conducted Augmented Dickey–Fuller tests for each series. For each industry, we determined the number of lags to be included in the test by maximizing the number of lags that yields a significant regression coefficient. For the six industries, we could not reject the null hypotheses and treated the variables as nonstationary.

Table 2. Correlation Matrix Country-Level Variables 1975–1990

Variable Name	1	2	3	4	5	6	7
1. GDP	1						
2. Population size	−.575**	1					
3. FDI	.888***	−.643***	1				
4. Phone lines availability	.926***	−.629***	.876***	1			
5. Electric power consumption	.982***	−.614**	.894***	.917***	1		
6. Consumption expenditure	.616**	−.071	.478*	.702***	−.299	1	
7. Trade constraints	−.100	.533**	−.323	−.514**	.714***	−.402	1

* $p < .1$; ** $p < .05$; *** $p < .01$.
GDP, gross domestic product; FDI, foreign direct investment.

We used a TSCS model with random effects. Columns a and b in Table 3 exhibit the estimation of coefficients of a control-only model and of our main model, respectively. In line with our hypotheses, trade constraints are positively associated with the innovativeness of technological output ($B = .271$, $p < .001$), and prior technology exhibits a curvilinear relationship with the innovativeness of technological output, where prior technology is positive and its squared term is negative ($B = .601$ and $B = -.060$, respectively, $p < .001$). To account for a possible heterogeneity across industries in terms of internally and externally derived knowledge, we include interaction terms between those and the industries.

Column c in Table 3 exhibits unstandardized coefficients of a model allowing for heterogeneity of trade-related knowledge-constraint effects across industries

Table 3. Effects of Trade Constraints and Prior Technology on Innovativeness of Technological Output (Annual) (Cross-sectional Time-series Model) Unstandardized Coefficients (SE)

Variable Name	(a) Control Variables Only	(b) Main Model	(c) Model with Trade Constraints Interactions	(d) Model with Prior Technology Interactions	
Trade constraints		.271 (.047)***	−.176 (.146)	−.023 (.196)	
Prior technology		.601 (.218)***	1.321 (.248)***	.875 (.389)**	
Prior technology^2		−.060 (.020)***	−.108 (.016)***	−.057 (.033)*	
Patent counts	6.442 (2.013)***	10.172 (6.778)	6.129 (4.363)	2.215 (4.231)	
Patent counts^2	−.404 (.139)***	−.628 (.455)	−.415 (.293)	−.159 (.285)	
GDP	−5.058 (3.200)	−.517 (2.935)	1.666 (1.883)	1.655 (1.777)	
Population size	−.835 (.270)***	−.578 (.263)**	−.022 (.186)	.008 (.192)	
FDI	−.430 (.188)**	−.150 (.177)	.022 (.114)	.054 (.109)	
Phone lines availability	3.115 (1.877)*	2.047 (1.718)	1.155 (1.103)	1.033 (1.045)	
Electric power consumption	2.632 (3.784)	−2.557 (3.481)	−6.242 (2.432)**	−6.081 (2.343)***	
Consumption expenditure	−.222 (5.986)	−2.838 (5.469)	−6.251 (3.701)*	−5.101 (3.550)	
Interaction terms between industry and:			**Trade constraints**	**Prior technology**	**Prior technology^2**
Electrical devices			.095 (.037)**	.769 (171)***	−.092 (.030)***
Transportation			.170 (.046)***	.316 (.159)**	−.043 (.020)**
Agriculture, husbandry, food			.117 (.043)***	.584 (.114)***	−.066 (.015)***
Apparel and textile			.184 (.039)***		
Furniture, house fixtures			.087 (.043)**	.510 (.196)***	−051 (.020)**
Drugs				1.094 (.421)***	−.121 (.081)
Intercept	14.106 (27.245)	11.665 (34.607)	42.898 (23.896)*	51.661 (23.894)**	
	Wald $\chi^2_{(8)} = 44.05$***	Wald $\chi^2_{(11)} = 74.38$***	Wald $\chi^2_{(16)} = 327.74$***	Wald $\chi^2_{(21)} = 418.88$***	
R^2 within	.214	.466	.596	.687	
R^2 between	.205	.505	1.00	1.00	
R^2 overall	.082	.469	.805	.849	
Change in R^2 from main model (b)	$\chi^2_{(3)} = 39.85$***		$\chi^2_{(5)} = 136.72$***	$\chi^2_{(10)} = 187.41$***	

* $p < .1$; ** $p < .05$; *** $p < .01$.
GDP, gross domestic product; FDI, foreign direct investment.

using interactions between trade constraints and industry dummy variables. Compared with the drugs industry, all the interaction terms of trade constraints and industry are positive and significant, indicating the innovativeness of technological output grows with a growth in trade constraints. Column d in Table 3 exhibits unstandardized coefficients of a model that emphasizes the effect of prior technology within each industry by including interaction terms of prior technology and industry dummy variables. The estimated coefficients indicate a curvilinear relationship between innovativeness of technological output and prior technology across industries.

Robustness Checks

Industry-level trade data before the year 2000 are rare, particularly in the 1970s and the 1980s. Thus, our industry-level trade data are limited to six industries. We conducted a number of analyses and found that industry-level trade data are comparable to country-level trade data.[3] Therefore, conducting some robustness checks by replacing industry trade data with country trade data seems reasonable. Moreover, prior research recognizes the advantages of such an approach, as we elaborate in the Level of Analysis section. In our case, such an analysis provides two major advantages. First, as we elaborate in the Hypotheses section, trade-related knowledge constraints of a country are likely to affect industry technological innovativeness. Second, historical country-level trade data are not as rare as industry-level data, thereby enabling us to expand our analysis to six *additional* industries. Therefore, for a robustness check, we substitute $TradeConstraints_{jt-3}$ in Equation 3 with $TradeConstraints_{t-3}$. Table 4 Column b reports the estimation of Equation 3 with country-level trade constraints, this time across 12 industries. In line with our hypotheses, trade constraints are positively associated with the innovativeness of technological output at a 90% level ($B = .201$, $p = .07$), and prior technology exhibits a curvilinear relationship with the innovativeness of technological output, where prior technology is positive and its square term is negative ($B = 1.903$ and $B = -.141$, respectively, $p < .01$). Because in this analysis trade constraints are at a country level, their interaction with each industry further enhances the industry aspect of this analysis (Table 4 Column c). Interestingly, the effect of trade constraints varies across industries: Compared with the drugs industry, in most industries, technological innovativeness increases with an increase in trade constraints. However, in communication- or computation-related industries (i.e., communications, computer hardware and software, computer peripherals, and information storage), technological innovativeness *decreases* as trade constraints increase.

We also conducted an additional analysis to examine the nature of the curvilinear relationship between prior technology and technological innovativeness. We plotted the innovativeness of technological output against prior technology. Importantly, scales are different across industries as a result of differences in the propensity to patent and in citation patterns in different industries (e.g., Mansfield, 1986). To exhibit a cross-industry aggregated graph, we log-transformed both the dependent variable and the explanatory variable. Figure 1 exhibits an aggregated ln-ln plot of technological innovativeness and a discrete prior technology scale across 12 industries. Importantly, this analysis uses industry data exclusively. In accordance with the estimated model, very low prior technology levels (i.e., extreme knowledge constraints) are associated with low technological innovativeness; moderate prior technology is associated with high technological innovativeness, with an indication of diminishing returns; and high prior technology levels (i.e., no knowledge constraints) are associated with low technological innovativeness.

Discussion

Contributions

The management literature frequently discusses innovativeness. Still, the literature discusses it mostly in the context of innovativeness outcomes, whereas only a few studies deal with the antecedents of technological innovativeness. This study uses a longitudinal case study of the United States to examine the effects of knowledge constraints on the innovativeness of technological output. Specifically, we examine the effects on the innovativeness of technological output of (1) trade-related externally derived knowledge and (2) prior technology-related internally derived knowledge. We suggest that in certain cases, knowledge constraints can positively affect the innovativeness of technological output. Hence, constrained accessibility to knowledge sources does not nec-

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[3] Specifically, we retrieved trade data from the Historical Statistics of the United States for the clothing industry and for the automobile industry for the period of 1975–1990. We tested the correlation between those and the national-level trade data. The correlations are positive, high, and significant: The correlation of imports of clothing and general national imports is .98, and the correlation between exports of clothing and general national exports is .93; the correlation of imports of automotive vehicles, parts, and engines and general national imports is .96, and the correlation between exports of the latter is .97.

Table 4. Effects of Trade Constraints and Prior Technology on Innovativeness of Technological Output (Annual)[a] (Cross-Sectional Time-Series model) Unstandardized Coefficients (SE)

Variable Name	(a) Control Variables Only	(b) Model with Country-level Trade Constraints	(c) Model with Trade Constraints Interactions	(d) Model with Prior Technology Interactions	
Trade constraints[a]		.201 (.113)*	.223 (.114)*	.190 (.105)*	
Prior technology		1.903 (.421)***	1.706 (.387)***	1.663 (.580)***	
Prior technology^2		−.141 (.031)***	−.130 (.029)***	−.133 (.046)***	
Patent counts	6.442 (2.013)***	7.358 (1.928)***	6.091 (1.892)***	6.472 (2.458)***	
Patent counts^2	−.404 (.139)***	−.474 (.133)***	−.405 (.131)***	−.432 (.167)**	
GDP	−5.058 (3.200)	−7.252 (4.161)*	−7.039 (4.177)*	−6.776 (3.858)*	
Population size	−.835 (.270)***	−.666 (.285)**	−.636 (.287)**	−.534 (.277)*	
FDI	−.430 (.188)**	−.352 (.178)**	−.380 (.187)	−.352 (.169)**	
Phone lines availability	3.115 (1.877)*	7.495 (3.034)**	8.188 (3.080)***	7.441 (2.788)***	
Electric power consumption	2.632 (3.784)	−2.024 (3.821)	−2.059 (3.680)	−1.781 (3.546)	
Consumption expenditure	−.222 (5.986)	−3.178 (5.664)	−1.856 (5.754)	−2.602 (5.185)	
Interaction terms between industry and:			**Trade constraints[a]**	**Prior technology**	**Prior technology^2**
Electrical devices			.070 (.023)***	.413 (.363)	−.070 (.062)
Transportation			.134 (.028)***	−.122 (.272)	−.004 (.040)
Agriculture, husbandry, food			.095 (.031)***	.100 (.209)	−.018 (.027)
Apparel and textile			.142 (.029)***	−.469 (.229)**	.045 (.031)
Furniture, house fixtures			.088 (.035)**		
Drugs				.892 (.667)	−.139 (.135)
Chemical agriculture, food and textiles			.080 (.022)***	.339 (.476)	−.067 (.088)
Amusement devices			.079 (.033)**	−.509 (.302)*	.079 (.043)*
Communications			−.101 (.025)***	.531 (.274)*	.009 (.041)
Computer hardware and software			−.366 (.030)***	2.042 (.265)***	−.120 (.036)***
Computer peripherals			−.352 (.031)***	2.303 (.456)***	.157 (.063)**
Information storage			−.147 (.021)***	1.288 (.478)***	−.090 (.089)
Intercept	14.106 (27.245)	66.928 (33.971)**	62.319 (34.186)*	58.171 (33.549)*	
	Wald $\chi^2_{(8)} = 44.05$***	Wald $\chi^2_{(11)} = 77.13$***	Wald $\chi^2_{(22)} = 3647.10$***	Wald $\chi^2_{(33)} = 4654.51$***	
R^2 within	.214	.306	.303	.482	
R^2 between	.205	.055	1.00	1.00	
R^2 overall	.082	.012	.956	.967	
Change in R^2 from model (b)	$\chi^2_{(3)} = 24.25$***		$\chi^2_{(11)} = 2948.96$***	$\chi^2_{(22)} = 3773.98$***	

* $p < .1$; ** $p < .05$; *** $p < .01$.

[a] Country-level trade constraints.

essarily hurt the industry's technological innovativeness: under certain circumstances, these knowledge constraints can facilitate technological innovativeness. Importantly, to facilitate technological innovativeness, knowledge constraints must not be extreme. Our findings demonstrate how extremely constrained internally derived knowledge can hinder technological innovativeness. This is also true for externally derived knowledge: closed countries (i.e., countries with extreme trade constraints) cannot experience the positive effect of externally derived knowledge constraints. A country experiencing extremely limited international trade due to sanctions, embargos, etc., cannot access basic knowledge platforms necessary for technological innovativeness. Examples are countries such as South Africa and Cuba that experienced renewed innovativeness only after their international trade started recovering (Kraemer-Mbula and Muchie, 2009; Thorsteinsdóttir et al., 2004).

This study makes the following contributions. First, the economic crisis in 2012 (when this paper was finalized for publication) poses considerable constraints on entire industries, as international trade continues to decline since 2008. To our knowledge, this study is a first attempt to understand the effects of trade-related knowledge constraints on the innovativeness of technological output. Examining a longitudinal case of the United States is an important step toward a broader understanding. Second, studies see a surge in incremental product

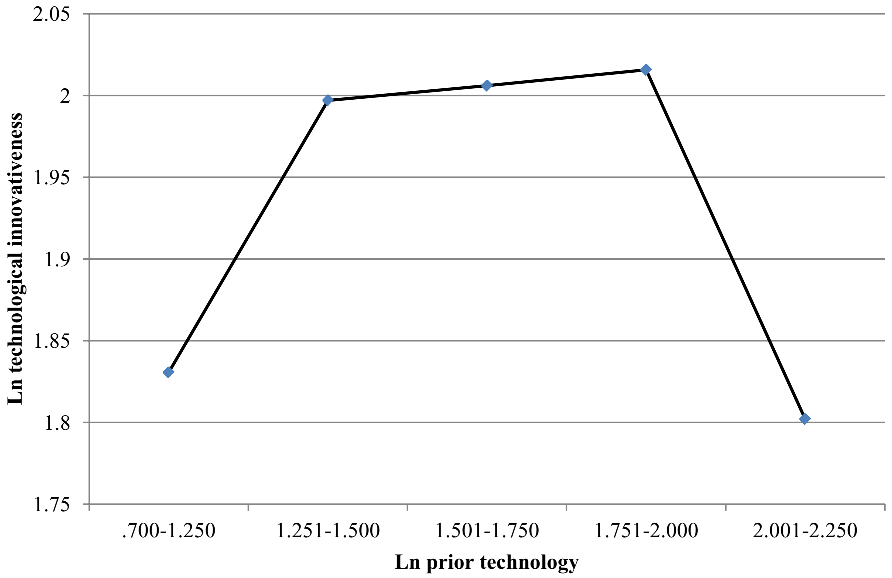

Figure 1. Innovativeness of Technological Output as a Function of Prior Technology

improvements and a surge in fluctuations in international trade. Consequently, the importance of understanding these dynamics and their effects on technological innovativeness increases. Third, this study builds on the idea of knowledge and its sources at the firm level and extends it to the industry level.

Findings

The main findings of this study are as follows:

1. Trade constraints are positively associated with the innovativeness of technological output in most industries.
2. Prior technology-related knowledge exhibits a curvilinear relationship with the innovativeness of technological output.

Our findings suggest that trade-related externally derived knowledge and reliance on prior technology—which expresses internally derived knowledge—affect the innovativeness of technological output. Trade constraints pose considerable knowledge challenges on industries. Most often, and contrary to prevalent thinking, these constraints seem to be associated with increasing technological innovativeness. Nonetheless, we see an indication that industries associated with computation and communications are different, possibly because computation- and communication-related technologies *facilitate* international trade and the related knowledge, but they are also *facilitated by* trade-related knowledge. Thus, these industries might benefit from low trade constraints.

Our findings suggest both low and high reliance on prior technology negatively affect the innovativeness of technological output, whereas moderate reliance positively affects innovativeness of technological output. Hence, although prior technology becomes increasingly accessible, and is appealing to firms because it reduces risks and costs, unconstrained reliance on prior technology is likely to hinder technological innovativeness.

Limitations

In this paper, we study a longitudinal case of U.S. industries. During the 16 years we examine, the U.S. international trade is dynamic, and trade-related knowledge constraints change over time. Still, relative to other countries, the United States practices open trade policies. Future research can examine trade-related knowledge constraints across countries with an array of trade policies. Moreover, this paper focuses on a specific aspect of externally derived knowledge, namely international trade-related knowledge. Additional sources can be FDI (i.e., Ahmed et al., 2010; Chuang and Hsu, 2004) and multinational corporations (MNCs) investing in R&D in their overseas subsidiaries—a specific form of FDI (Feinberg and Gupta, 2004; Liu and Buck, 2007). MNCs investing in R&D in their overseas subsidiaries became prominent only around 1990 and especially afterwards, and therefore exceed the period examined in the current study. As we mention earlier, the literature indicates that the prime source of externally derived knowledge is international trade. Indeed, contrary to FDI and MNCs' investing in R&D, knowledge associated with actual imports and exports is a much more critical source for knowledge regarding new technologies, materials, markets, and ideas, for several reasons. First, goods embody technological abilities and advances (Grossman and Helpman, 1991; Lumenga-Neso et al., 2005). Second, material goods provide knowledge through imitation or reverse engineering (Criscuolo and Verspagen, 2008; Liu and Buck, 2007). Third, financial-related knowledge such as FDI and MNCs investing in R&D is often affected by language differences (Criscuolo and Verspagen, 2008; Feinberg and Gupta, 2004; Jaffe, Trajtenberg, and Henderson, 1993). Knowledge associated with traded goods does not suffer from this limitation because it does not require any form of personal or linguistic interaction.

The usage of patent data presents some limitation. Not all innovations are patentable or are actually patented, and those that are may differ in quality (Griliches, 1990; van der Panne, 2004). Patenting exposes knowledge that may be protected by secrecy, and inventors may choose to protect this knowledge by not patenting it (Hall et al., 2002). That said, numerous recent innovation-related studies have shown patenting indicators, and patent citations in particular are valuable and rigorous measures (e.g., Chandy et al., 2006; Narasimhan et al., 2006; Rao et al., 2008; Sorescu et al., 2007).

Some studies have indicated distinguishing between citations by the applicant and citations by the patent examiner may be important (Alcacer, Gittelman, and Sampat, 2009; Criscuolo and Verspagen, 2008). However, although in the European system the patent examiner adds a large portion of the patent citations, in the U.S. system, applicants are responsible for a full disclosure of prior technology (i.e., Branstetter, 2006; Criscuolo and Verspagen, 2008; Maurseth and Verspagen, 2002). Moreover, based on findings of Trajtenberg (1990), *total* citations (applicant and examiner) are what indicate the *actual* value of the cited patent.

Implications

This study has a number of implications for policymakers, industry leaders, entrepreneurs, and managers. First, our results may indicate the need for establishing priorities for policymakers: if specific industries can benefit from certain levels of trade constraints, policymakers should prioritize and focus on eliminating trade barriers in other industries, such as computation and communications. Second, although the use of prior technologies may be tempting, managers and entrepreneurs should consider its technological innovativeness-hindering potential. Even when available, the use of prior technologies should be monitored and constrained. Managers should also consider establishing the optimal level of prior technology usage in their firms. Moreover, industry leaders can set the appropriate balance of prior technology usage for the entire industry with the help and guidance of industry policymakers. That is, industry leaders and policymakers can publicly state that the usage of less than or more than specific threshold quantities of prior patents is likely to hinder technological innovativeness. Given that managers and industry leaders have limited control over trade policies and the related externally derived knowledge, the ability to optimize internally derived knowledge is important. Third, entrepreneurs have thus far considered mainly firm-level variables, such as marketing mix and characteristics of the specific innovation, when deciding whether or not to invest in an innovative technology. Our results suggest that entrepreneurs should also take into account industry-level considerations. Future research could further explore specific effects of environmental dynamism and industry size on technological innovativeness.

This research also has some theoretical implications. First, although a number of prior studies have pointed to the positive effect of constraints on innovation consequences, the present research emphasizes the complexity of this effect. Future research should explore potential thresholds, that is, under which precise conditions the effect of knowledge constraints on technological innovativeness is positive, and at what point the effect is reversed. Additionally, future research should also explore other industry-level constraints such as constrained financial or human resources. Second, this research expands the idea that knowledge can be derived from within or outside the firm to within or outside the country's industry. Indeed, scholars can explore knowledge not only from the single firm's point of view, but also from the industry and country point of view (e.g., Falvey et al., 2002; Porter and Van der Linde, 1995). Future research can explore the nature and consequences of inter- and cross-industry knowledge transfer.

References

Aghion, P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt. 2005. Competition and innovation: An inverted–U relationship. *The Quarterly Journal of Economics* 120 (2): 701–28.

Aghion, P., and P. Howitt. 1992. A model of growth through creative destruction. *Econometrica* 60 (2): 323–51.

Agrawal, A., and R. Henderson. 2002. Putting patents in context: Exploring knowledge transfer from MIT. *Management Science* 48 (1): 44–60.

Ahmed, A. D., E. Cheng, and G. Messinis. 2010. The role of exports, FDI and imports in development: Evidence from Sub-Saharan African countries. *Applied Economics* 42 (1): 1–13.

Alcacer, J., M. Gittelman, and B. Sampat. 2009. Applicant and examiner citations in US patents: An overview and analysis. *Research Policy* 38 (2): 415–27.

Artz, K. W., P. M. Norman, D. E. Hatfield, and L. B. Cardinal. 2010. A longitudinal study of the impact of R&D, patents, and product innovation on firm performance. *Journal of Product Innovation Management* 27 (5): 725–40.

Audia, P. G., and J. A. Goncalo. 2007. Past success and creativity over time: A study of inventors in the hard disk drive industry. *Management Science* 53 (1): 1–15.

Bayus, B. L. 1994. Are product life cycles really getting shorter? *Journal of Product Innovation Management* 11 (4): 300–8.

Bayus, B. L. 1998. An analysis of product lifetimes in a technologically dynamic industry. *Management Science* 44 (6): 763–75.

Ben-Aharon, N., and G. Golub. 2004. Diffusion of environmental regulations and standards between countries: Barrier or trigger for innovation? Paper presented at *Bridging the Gap: Sustainable Environment, UN Global Compact Academic Conference*, Istanbul, May 2004.

Benner, M. J., and M. Tushman. 2002. Process management and technological innovation: A longitudinal study of the photography and paint industries. *Administrative Science Quarterly* 47 (4): 676–706.

Bourgeois, L. J. 1981. On the measurement of organizational slack. *Academy of Management Review* 6 (1): 29–39.

Brahmbhatt, M. 1998. Measuring global economic integration: A review of the literature and recent evidence. Working Paper. Washington, DC: World Bank. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.116.5900&rep=rep1&type=pdf.

Branstetter, L. 2006. Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's in the United States. *Journal of International Economics* 68 (2): 325–44.

Broda, C., J. Greenfield, and D. Weinstein. 2006. From groundnuts to globalization: A structural estimate of trade and growth. NBER Working Paper No. 12512. Cambridge, MA: National Bureau of Economic Research. Available at: http://papers.nber.org/papers/w12512.

Brunnermeier, S., and M. Cohen. 2003. Determinants of environmental innovation in U.S. manufacturing industries. *Journal of Environmental Economics and Management* 45 (2): 278–93.

Bureau of Economic Analysis—US Department of Commerce. 2010. Real exports and imports of goods and services by type of product, chained dollars. Available at: http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=134&Freq=Qtr&FirstYear=2007&LastYear=2009.

Burroughs, J. E., and D. G. Mick. 2004. Exploring antecedents and consequences of consumer creativity in a problem-solving context. *Journal of Consumer Research* 31 (2): 402–11.

Chandy, R. K., B. Hopstaken, O. Narasimhan, and J. Prabhu. 2006. From invention to innovation: Conversion ability in product development. *Journal of Marketing Research* 43 (3): 494–508.

Chandy, R. K., and G. J. Tellis. 1998. Organizing for radical product innovation: The overlooked role of willingness to cannibalize. *Journal of Marketing Research* 34 (4): 474–87.

Chandy, R. K., and G. J. Tellis. 2000. The incumbent's curse? Incumbency, size, and radical product innovation. *Journal of Marketing* 64 (3): 1–17.

Chang, G. G. 2009. Worse than a trade war: We've entered an era of decreasing global commerce. *Forbes*. September 18. Available at: http://forbeslife.nl/2009/09/17/decreasing-global-trade-china-us-opinions-columnists-gordon-chang.html.

Chase-Dunn, C., Y. Kawano, and B. D. Brewer. 2000. Trade globalization since 1795: Waves of integration in the world-system. *American Sociological Review* 65 (1): 77–95.

Chuang, Y. C., and P. F. Hsu. 2004. FDI, trade, and spillover efficiency: Evidence from China's manufacturing sector. *Applied Economics* 36 (10): 1103–15.

Clerides, S. K., S. Lach, and J. K. Tybout. 1998. Is learning by exporting important? Micro-dynamic evidence from Colombia, Mexico and Morocco. *The Quarterly Journal of Economics* 113 (1): 903–47.

Coe, D. T., and E. Helpman. 1995. International R&D spillovers. *European Economic Review* 39 (5): 859–87.

Cohen, W. M., and D. A. Levinthal. 1990. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly* 35 (1): 128–52.

Cohen, W. M., and D. A. Levinthal. 1994. Fortune favors the prepared firm. *Management Science* 40 (2): 227–51.

Criscuolo, P., and B. Verspagen. 2008. Does it matter where patent citations come from? Inventor vs. examiner citations in European patents. *Research Policy* 37 (10): 1892–908.

Cyert, R. M., and J. G. March. 1963. *A behavioral theory of the firm*. Englewood Cliffs, NJ: Prentice-Hall.

Eaton, J., S. Kortum, B. Neiman, and J. Romalis. 2011. Trade and the global recession. NBER Working Paper No. 16666. Cambridge, MA: National Bureau of Economic Research. Available at: http://www.nber.org/papers/w16666.

Falvey, R., N. Foster, and D. Greenaway. 2002. North-South trade, knowledge spillovers and growth. *Journal of Economic Integration* 17 (4): 650–70.

Feenstra, R. C., J. Romalis, and P. K. Schott. 2002. U.S. imports, exports and tariff data. NBER Working Paper No. 9387. Cambridge, MA: National Bureau of Economic Research. Available at: http://www.nber.org/papers/w9387.

Feinberg, S. E., and A. K. Gupta. 2004. Knowledge spillovers and the assignment of R&D responsibilities to foreign subsidiaries. *Strategic Management Journal* 25 (8-9): 823–45.

Findlay, R., and K. H. O'Rourke. 2001. Commodity market integration, 1500–2000. NBER Working Paper No. 8579. Cambridge, MA: National Bureau of Economic Research. Available at: http://www.nber.org/papers/w8579.

Foster, J. A., P. N. Golder, and G. J. Tellis. 2004. Predicting sales takeoff for Whirpool's new personal valet. *Marketing Science* 23 (2): 182–5.

Furman, J. L., M. E. Porter, and S. Stern. 2002. The determinants of national innovative capacity. *Research Policy* 31 (6): 899–933.

Garcia, R., and R. Calantone. 2002. A critical look at technological innovation typology and innovativeness terminology: A literature review. *Journal of Product Innovation Management* 19 (2): 110–32.

Gertler, M. S., and Y. M. Levitte. 2005. Local nodes in global networks: The geography of knowledge flows in biotechnology innovation. *Industry and Innovation* 12 (4): 487–507.

Gibbert, M., M. Hoegl, and L. Välikangas. 2007. In praise of resource constraints. *MIT Sloan Management Review* 48 (3): 15–17.

Griliches, Z., ed. 1984. *R&D, patents, and productivity*. Chicago: University of Chicago Press.

Griliches, Z. 1990. Patent statistics as economic indicators: A survey. *Journal of Economic Literature* 28 (4): 1661–707.

Grinstein, A., E. Ofek, and S. Rosenzweig. 2008. Challenging conditions, social networks, and performance of academic research in marketing. *Journal of Macromarketing* 28 (1): 87–89.

Grossman, G. M., and E. Helpman. 1991. Trade, knowledge spillovers, and growth. *European Economic Review* 35 (3): 517–26.

Guillén, M. F. 2001. Is globalization civilizing, destructive or feeble? A critique of five key debates in the social science literature. *Annual Review of Sociology* 27: 235–60.

Guillén, M. F., and S. L. Suárez. 2005. Explaining the global digital divide: Economic, political and sociological drivers of cross-national Internet use. *Social Forces* 84 (2): 681–708.

Hall, B. H., Z. Griliches, and J. A. Hausman. 1986. Patents and R and D: Is there a lag? *International Econometric Review* 27 (2): 265–83.

Hall, B. H., A. B. Jaffe, and M. Trajtenberg. 2002. The NBER patent-citation data file: Lessons, insights, and methodological tools. In

Patents, citations and innovations: A window on the knowledge economy, ed. A. B. Jaffe and M. Trajtenberg, 403–59. Cambridge, MA: The MIT Press.

Hambrick, D. C., and C. C. Snow. 1977. A contextual model of strategic decision making in organizations. *Academy of Management Proceedings* 1: 109–12.

Hoegl, M., M. Gibbert, and D. Mazursky. 2008. Financial constraints in innovation projects: When is less more? *Research Policy* 37 (8): 1382–91.

Jaffe, A. B., M. Trajtenberg, and M. S. Fogarty. 2002. The meaning of patent citations: Report on the NBER/Case-Western Reserve survey of patentees. In *Patents, citations and innovations: A window on the knowledge economy*, ed. A. B. Jaffe and M. Trajtenberg, 379–401. Cambridge, MA: The MIT Press.

Jaffe, A. B., M. Trajtenberg, and R. Henderson. 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics* 108 (3): 577–98.

Jensen, M. C. 1993. The modern industrial revolution, exit, and the failure of internal control systems. *Journal of Finance* 48 (3): 831–80.

Johnson, J., and G. J. Tellis. 2008. Drivers of success for market entry into China and India. *Journal of Marketing* 72 (3): 1–13.

Kalish, S., V. Mahajan, and E. Muller. 1995. Waterfall and sprinkler new-product strategies in competitive global markets. *International Journal of Research in Marketing* 12 (2): 105–19.

Kohli, R., D. R. Lehmann, and J. Pae. 1999. Extent and impact of incubation time in new product diffusion. *Journal of Product Innovation Management* 16 (2): 134–44.

Kraemer-Mbula, E., and M. Muchie. 2009. Neighbourhood systems of innovation: South Africa as a regional pole for economic development in Africa. *Proceedings of the 7th Globelics International Conference*, Dakar, 6–8 October 2009. Available at: http://smartech.gatech.edu/handle/1853/36373?show=full.

Kyriazis, N. C., and M. S. Zouboulakis. 2004. Democracy, sea power and institutional change: An economic analysis of the Athenian naval law. *European Journal of Law and Economics* 17: 117–32.

Lanjouw, J. O., and M. Schankerman. 1999. The quality of ideas: Measuring innovation with multiple indicators. NBER Working Paper No. 7345. Cambridge, MA: National Bureau of Economic Research. Available at: http://papers.nber.org/papers/w7345.

Leibenstein, H. 1966. Allocative efficiency vs. "X-efficiency." *The American Economic Review* 56 (3): 392–415.

Leonard-Barton, D. 1992. Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal* 13 (S1): 111–25.

Leonard-Barton, D. 1995. *Wellsprings of knowledge: Building and sustaining the source of innovation*. Boston: Harvard Business School Press.

Levchenko, A. A., L. T. Lewis, and L. L. Tesar. 2010. The collapse of international trade during the 2008–2009 crisis: In search for the smoking gun. NBER Working Paper No. 16006. Cambridge, MA: National Bureau of Economic Research. Available at: http://www.nber.org/papers/w16006.

Levinthal, D. A., and J. G. March. 1993. The myopia of learning. *Strategic Management Journal* 14 (Winter Special Issue): 95–112.

Levitt, B., and J. G. March. 1988. Organizational learning. *Annual Review of Sociology* 14: 319–40.

Liu, X., and T. Buck. 2007. Innovation performance and channels for international technology spillovers: Evidence from Chinese high-tech industries. *Research Policy* 36 (3): 355–66.

Lumenga-Neso, O., M. Olarreaga, and M. Schiff. 2005. On "indirect" trade-related R&D spillovers. *European Economic Review* 49 (7): 1785–98.

Mahajan, V., and E. Muller. 1994. Innovation diffusion in a borderless global market: Will the 1992 unification of the European community accelerate diffusion of new ideas, products, and technologies? *Technological Forecasting and Social Change* 45 (3): 221–35.

Mansfield, E. 1986. Patents and innovation: An empirical study. *Management Science* 32 (2): 173–81.

Mansfield, E. 1988a. The speed and cost of industrial innovation in Japan and the United States: External vs. internal technology. *Management Science* 34 (10): 1157–68.

Mansfield, E. 1988b. Industrial R&D in Japan and the United States: A comparative study. *The American Economic Review* 78 (2): 223–28.

March, J. G. 1991. Exploration and exploitation in organizational learning. *Organizational Science* 2 (1): 71–87.

Maurseth, P. B., and B. Verspagen. 2002. Knowledge spillovers in Europe: A patent citations analysis. *The Scandinavian Journal of Economics* 104 (4): 531–45.

Menon, T., and J. Pfeffer. 2003. Valuing internal vs. external knowledge: Explaining the preference for outsiders. *Management Science* 49 (4): 497–513.

Miller, J. W. 2010. Trade slump swamps Maersk. *The Wall Street Journal* (March 5) (accessed March 16, 2010). Available at: http://online.wsj.com/article/SB10001424052748704187204575100932350914988.html.

Mitra, D., and P. N. Golder. 2002. Whose culture matters? Near-market knowledge and its impact on foreign market entry timing. *Journal of Marketing Research* 39 (3): 350–65.

Mokyr, J. 2000. Evolutionary phenomena in technological change. In *Technological innovation as an evolutionary process*, ed. J. Ziman, 52–65. Cambridge, UK: Cambridge University Press.

Moorman, C., and A. S. Miner. 1997. The impact of organizational memory on new product performance and creativity. *Journal of Marketing Research* 34 (1): 91–106.

Moreau, P. C., and D. W. Dahl. 2005. Designing the solution: The impact of constraints on consumers' creativity. *Journal of Consumer Research* 31 (1): 13–22.

Narasimhan, O., S. Rajiv, and S. Dutta. 2006. Absorptive capacity in high-technology markets: The competitive advantage of the haves. *Marketing Science* 25 (5): 510–24.

Nohria, N., and R. Gulati. 1996. Is slack good or bad for innovation? *Academy of Management Journal* 39 (5): 1245–64.

Olstein, D. 2006. Le molteplici origini della globalizzazione. Un dibattito storiografico (The multiple origins of globalization: An historiographic debate). *Contemporanea* 3: 403–22.

Patton, J. D. 2002. The role of problem pioneers in creative innovation. *Creativity Research Journal* 14 (1): 111–26.

Polillo, S., and M. F. Guillén. 2005. Globalization pressures and the state: The worldwide spread of central bank independence. *The American Journal of Sociology* 110 (6): 1764–802.

Porter, M., and C. Van der Linde. 1995. Green and competitive: Ending the stalemate. *Harvard Business Review* 73 (5): 120–33.

Prabhu, J. C., R. K. Chandy, and M. E. Ellis. 2005. The impact of acquisitions on innovation: Poison pill, placebo, or tonic? *Journal of Marketing* 69 (1): 114–30.

Rao, R. S., R. K. Chandy, and J. C. Prabhu. 2008. The fruits of legitimacy: Why some new ventures gain more from innovation than others. *Journal of Marketing* 72 (4): 58–75.

Rosenberg, N., and W. E. Steinmueller. 1988. Why are Americans such poor imitators? *The American Economic Review* 78 (2): 229–34.

Salomon, R. M., and B. Jin. 2009. Do leading or lagging firms learn more from exporting? *Strategic Management Journal* 31 (10): 1088–113.

Salomon, R. M., and J. M. Shaver. 2005. Learning by exporting: New insights from examining firm innovation. *Journal of Economics and Management Strategy* 14 (2): 431–60.

Sethi, R., D. C. Smith, and C. W. Park. 2001. Cross-functional product development teams, creativity, and the innovativeness of new consumer products. *Journal of Marketing Research* 38 (1): 73–85.

Sorescu, A. B., R. K. Chandy, and J. C. Prabhu. 2003. Sources and financial consequences of radical innovation: Insights from pharmaceuticals. *Journal of Marketing* 67 (4): 82–102.

Sorescu, A. B., R. K. Chandy, and J. C. Prabhu. 2007. Why some acquisitions do better than others: Product capital as a driver of long-term stock returns. *Journal of Marketing Research* 44 (1): 57–72.

Srinivasan, R., A. Rangaswamy, and G. L. Lilien. 2005. Turning adversity into advantage: Does proactive marketing during a recession pay off? *International Journal of Research in Marketing* 22: 109–25.

Tellis, G. J., S. Stremersch, and E. Yin. 2003. The international takeoff of new products: The role of economics, culture, and country innovativeness. *Marketing Science* 22 (2): 188–208.

Thorsteinsdóttir, H., T. W. Sáenz, U. Quach, A. S. Daar, and P. A. Singer. 2004. Cuba—Innovation through synergy. *Nature Biotechnology* 22: DC19–24.

Toynbee, A. J. 1934. *A study of history*, Vol. 1. London: Oxford University Press.

Trajtenberg, M. 1987. Patents, citations and innovations: Tracing the links. NBER Working Paper No. 2457. Cambridge, MA: National Bureau of Economic Research. Available at: http://papers.nber.org/papers/w2457.

Trajtenberg, M. 1989. The welfare analysis of product innovations, with an application to computed tomography scanners. *The Journal of Political Economy* 97 (2): 444–79.

Trajtenberg, M. 1990. A penny for your quotes: Patent citations and the value of innovations. *RAND Journal of Economics* 21 (1): 172–87.

Tsai, W. 2001. Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. *Academy of Management Journal* 44 (5): 996–1004.

Välikangas, L., and M. Gibbert. 2005. Boundary-setting strategies for escaping innovation traps. *MIT Sloan Management Review* 46 (3): 58–65.

Van den Bulte, C. 2000. New product diffusion acceleration: Measurement and analysis. *Marketing Science* 19 (4): 366–80.

van der Panne, G. 2004. Agglomeration externalities: Marshall versus Jacobs. *Journal of Evolutionary Economics* 14 (5): 593–604.

Wei, Y., and X. Liu. 2006. Productivity spillovers from R&D, exports and FDI in China's manufacturing sector. *Journal of International Business Studies* 37 (4): 544–57.

Whited, T. M., and G. Wu. 2006. Financial constraint risk. *The Review of Financial Studies* 19 (2): 531–59.

Williams, C. J. 2012. Euro crisis imperils recovering global economy, OECD warns. *Los Angeles Times*. May 22. Available at: http://latimesblogs.latimes.com/world_now/2012/05/eurozone-crisis-global-economy.html.

World Bank. 2006. Assessing globalization briefing paper. Available at: http://www.worldbank.org/economicpolicy/globalization/documents/AssessingGlobalizationP1.pdf.

World Trade Organization. 2009. WTO sees 9% global trade decline in 2009 as recession strikes. *WTO Press Release*. March 23. Available at: http://www.wto.org/english/news_e/pres09_e/pr554_e.htm.

Wuyts, S., S. Dutta, and S. Stremersch. 2004. Portfolios of interfirm agreements in technology-intensive markets: Consequences for innovation and profitability. *Journal of Marketing* 68 (2): 88–100.

Appendix

We provide some illustrative examples of the suggested curvilinear relationship between prior technology-related knowledge and technological innovativeness. For the sake of uniformity, we present examples of innovations that were patented in 1990.

Very high reliance on prior technologies provides no knowledge constraints, and hence *no challenges*. For example, in 1990, the United States Patent and Trademark Office (USPTO) issued a patent for a folding umbrella (patent number 4934395). This patent was based on 69 prior patents (including prior folding umbrellas), a substantial number considering the simple technology of folding umbrellas. Although some technological advancement exists (otherwise the patent would not have been issued), the patent is not very innovative. It provides a marginal contribution to technological evolution, as only two subsequent patents indicated it as prior technology, one of them assigned to the same applicant (e.g., a self-citation).

Low-to-moderate reliance on prior technology presents an *adequate challenge*, where innovators need to make an effort to bridge the gap between current and new knowledge. For example, in 1990, the USPTO issued a patent for handwritten input into a computer (patent number 4972496). This patent relied on prior technology, including computer graphics, coordinate detection, and text editing, altogether citing 16 prior patents. Still, the inventor had to bridge a technological gap of handwritten character recognition on a computer screen. This technology became the basis for numerous technological advancements, indicating its technological innovativeness. Indeed, it contributed to no less than 197 subsequent technologies, as is indicated by the number of citations it received from subsequent patents.

No reliance on prior technology is an *extreme challenge*. The extreme knowledge constraints do not provide a sufficient platform for innovative processes, and the result is very low levels of technological innovativeness. For example, in 1990, the USPTO issued a nicotine decomposer patent (patent number 4930526). The patent is based on a mineral that decomposes nicotine, and consumers can put it in their cigarette packs. The invention is not based on previous technologies (e.g., it does not cite previous patents), and it is not assigned to an inventor or a firm with experience in tobacco, cigarettes, or related products. It was not used later as a basis for new technologies, indicating its insignificance to the evolution of technology. The lack of a basic technological platform did not enable a meaningful implementation of the innovation, and with no usage or technological contribution, it cannot be regarded as innovative. Accordingly, it was never cited by subsequent patents.