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Chapter 2

TECHNOLOGY TRADE AND NAFTA

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ABSTRACT

This paper evaluates the extent to which technology diffusion among NAFTA countries is significantly different from before NAFTA came into force. The *North American Free Trade Agreement* (NAFTA) contains a set of intellectual property provisions that considerably strengthen the intellectual property regimes of the member countries. To the extent that these provisions influence the incentive to innovate and to transfer technologies, the formation of NAFTA should be an important influence on intra-NAFTA technology diffusion. This study uses various indicators of cross-border technology diffusion: patent filings, exports, foreign direct investment, and licensing, and uses a quantitative measure of the strength of patent protection to assess the response of these indicators to the formation of NAFTA and the associated intellectual property reforms.

The empirical analysis compares technology diffusion within NAFTA to technology diffusion between NAFTA and the rest-of-the world in order to control for the influence of global factors which affect the world level of technology diffusion. The empirical analysis finds that NAFTA has played an important role in stimulating technology trade among member countries relative to their trade with the rest of the world. However, the extent and scope of technology trade varies by member countries. Mexico, for instance, is a recipient of large technology inflows (post-NAFTA) but not an originator of technology outflows. Canadian technology outflows and inflows are significantly associated with NAFTA and the intellectual property reforms. The level of U.S. technology trade with NAFTA members, however, is insignificantly different from that with non-NAFTA members.

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1. INTRODUCTION

Existing work on the NAFTA economies has focused predominantly on issues pertaining to trade in goods and services and on cross-border flows of labor and capital. Largely overlooked is the expansion of intra-NAFTA trade in technology or flows of knowledge capital. The *North American Free Trade Agreement* contains provisions on intellectual property rights (Chapter 17) which strengthen the intellectual property regimes of NAFTA countries beyond the global standards established by the *Trade Related Intellectual Property Rights (TRIPS) Agreement* of the *World Trade Organization* (WTO), to which the NAFTA countries are signatories. To the extent that technological change depends significantly on intellectual property rights, NAFTA should influence patterns of technological trade and be an important factor in the determination of technology policy and institutions.

This paper provides an empirical study of innovation and technology diffusion among NAFTA countries, focusing on the effects of the intellectual property reforms. The study, in particular, assesses the extent to which the reforms in intellectual property rights (IPRs) contributed to changes in innovation potential and the volume of technological trade. Innovation potential is measured by patentable outputs and by inputs into research and development. Technological trade and diffusion are measured by exports, stocks of foreign direct investment, and flows of intangible royalties and licensing fees.

The significance of this study is twofold. First, at present, limited evidence exists as to the benefits or costs of intellectual property reform. Thus far, much of the debate has been speculative or theoretical. Some would argue that weak patent systems constrain technological progress and trade. Others would make the case that tight intellectual property rights inhibit innovation because they raise the cost of inputs (to monopolistic price levels), restrict the supply of inputs needed by other innovators, and create transactions costs, as users of proprietary technologies must obtain permissions, negotiate licenses, and write contracts.[1] As a developing country, Mexico provides lessons for other emerging markets. Is the raising of intellectual property standards to industrial country levels appropriate or should intellectual property systems be tailored to the needs of growing economies? Does membership in a free trade area bring greater access to new technologies? In the long term, technology is an important source of economic growth and development, and can be a determinant of the pattern of overall trade, investment, and evolution of comparative advantage.

A second significance of this study is that there are implications for whether further integration or harmonization of technology policies or institutions is desirable among NAFTA members. A long run goal may be to establish a North American patent zone along the lines of the *European Patent Office (EPO)* system. The idea is to provide a single patent filing and registration system, where the intellectual property right is valid in all three countries. Whether this undertaking is worth it for just three members depends on a weighing of the costs and benefits. One benefit is that a regional patent zone could help lower the costs of innovation, patenting, and licensing, and thereby increase intra-regional trade and innovation. But what is not well understood is how technological trade responds to changes in the intellectual property regime. Thus this study provides evidence on how measures of technological innovation and diffusion respond to variables describing the regime, such as intellectual property strength, cost of patenting, and to NAFTA in general.

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[1] See Scotchmer (2004) for a review of cases for and against patent rights.

A priori, the effect of NAFTA on technology trade can be varied. On the one hand, NAFTA provides preferential access and expanded markets for member countries. This should stimulate the incentives and opportunities for innovation and technology. On the other hand, Mexico and Canada also face increased competition from U.S. firms and innovators. As an overview, the results in this study indicate that NAFTA members on net experience significantly more technological trade with one another than before NAFTA came into force. Most of the gains, however, accrue to Mexico since Canada and the U.S. had been strong technology trading partners before NAFTA. For the U.S., the growth in technology trade with Mexico and Canada is marginally different from its growth in technology trade with the rest-of-the-world, such as Japan and Europe. The study also finds that NAFTA's influence on the diffusion of existing technologies is greater than its influence on raising innovation potential. The study concludes with some qualifying remarks about the feasibility and desirability of further harmonization of technology policies and institutions among the NAFTA countries.

This paper is organized as follows: section 2 provides a brief review of intellectual property reforms under NAFTA. Section 3 provides a literature review of the few studies that have analyzed technological developments in NAFTA. Section 4 discusses a conceptual framework for analyzing the effects of intellectual property rights (IPRs) on innovation and technology diffusion. Section 5 presents the empirical framework for assessing the effects of NAFTA and intellectual property reform on innovation and technology diffusion. Section 6 describes the data and presents some sample statistics. Section 7 contains the empirical results and analyses. Section 8 concludes with a summary of the main findings, some ideas for extending the work, and discusses some of the policy implications of the study. The Appendices provide details on the index of patent rights and the data sources.

2. Intellectual Property Provisions in NAFTA

NAFTA came into force at about the same time that the TRIPS Agreement came into force. Canada and Mexico amended their intellectual property laws in anticipation of NAFTA and TRIPS as well as enacted new legislation after NAFTA/TRIPS came into force. Substantive revisions occurred in Canada in 1993 and 1996 and in Mexico in 1991 and 1997. The U.S. revised its Patent Act in 1999. All three NAFTA countries have incorporated the TRIPS agreement as well as the NAFTA provision into their national intellectual property laws.

The TRIPS agreement established minimum international standards. Chapter 17 of the North American Free Trade Agreement addresses the intellectual property obligations. While the TRIPS provisions are incorporated into NAFTA by reference, NAFTA also contains provisions that go beyond TRIPS, and hence NAFTA is regarded as TRIPS-plus.[2] It is useful to review in this section the key differences between TRIPS and the intellectual property provisions of NAFTA, and how they changed the intellectual property systems of Canada, Mexico, and the U.S. I shall focus largely on patent laws since these relate most directly to technological innovation and diffusion.

[2] Article 1701 of NAFTA references previous international IP conventions while article 1702 states that member countries may provide higher levels of protection.

A key difference between NAFTA and the WTO's TRIPS agreement is that private actors do not have standing before the WTO's dispute settlements board. NAFTA, however, contains dispute settlement procedures for private actors (Chapter 19). The TRIPS agreement sets the minimum duration of patent rights to 20 years from the date of application. NAFTA provides for 17 years from the date of patent grant. This is useful if the patent application process takes a long time – time which is taken away from the duration of the patent right. Moreover, in the case of pharmaceutical products, there are delays in the regulatory approval process which also reduces the effective life of the patent. NAFTA's Chapter 17 also provides tighter restrictions on the ability of governments to revoke or limit the exclusive rights of patent holders (for example, to cases where patent holders engage in anti-competitive abuses). The WTO/TRIPS also does not explicitly address piracy issues, whereas NAFTA has provisions dealing with the trading of goods that infringe on intellectual property rights. For example, Article 1714 of NAFTA addresses the enforcement of IPRs at the border, empowering customs administrators to contain counterfeit goods.

In terms of national laws, Mexico had the greatest burden of adjustment. The U.S. had the least since the global standards negotiated during the Uruguay Round reflected U.S. laws and practices the most. In 1997, Mexico put into effect a new copyright system, customs law allowing the seizure of pirated goods, protection for plant varieties and semiconductor chips. In Mexico, protection for computer software and databases is provided for under copyright law; that is, as artistic expressions. Mexico also created an agency – the Mexican Institute for Industrial Property (IMPI) – to implement IPR laws.

In Canada, the compulsory licensing of pharmaceutical patents was eliminated. However, Canada retains the use of compulsory licensing against patent holders that fail to work their invention (i.e. exploit the invention) within a reasonable period of time. Canada also retains its right to promote Canadian cultural industries. This suggests that the intellectual property rights of foreign authors, film, or music creators must be such as not to crowd out Canadian works. Canada was also required to adopt the "nonobviousness" standard as a statutory requirement for patentability (i.e. that the invention is not obvious to someone skilled in the art).

In the U.S., copyright laws were revised to recognize the moral rights of authors. Previously, U.S. laws recognized the economic rights of authors, but did not formally protect against mischaracterization and alteration of an author's work. Furthermore, U.S. laws used to require the secrecy of a patent application until it was granted. Critics of this provision pointed out that secrecy creates uncertainty for contemporary innovators who do not know if some other innovator has developed a particular technology. Under the amended Act, U.S. laws now require the patent application to be published 18 months after filing, so long as the inventor files abroad. If the inventor only applies for a patent application in the U.S. market, the underlying technology is kept secret until it is granted.

3. Literature Review

Few studies exist on the intellectual property rights dimensions of NAFTA and their implications for technological innovation and diffusion. These studies tend to focus on a single NAFTA country. For example, McFetridge (1998), Trajtenberg (1999), Maskus

(2005), and Rafiquzzaman and Mahmud (2005) study the innovation performance of Canada, while Aboites and Cimoli (2002), Lederman and Maloney (2003), and Leger (2005) focus on Mexican innovation. Surveys by Gallini (2002) and Jaffe (2000) focus on U.S. patent reforms and innovation. As of yet, there are few empirical studies that conduct a group (Canada, Mexico, and U.S.) analysis of the technological effects of NAFTA, as in this paper.[3] Most group analyses focus on the trade and investment dimension, not on the intellectual property provisions of NAFTA. Other studies examine whether free trade agreements (FTA) like NAFTA facilitate policy reform in developing country members of FTA (see for example Ferrantino (2006)).

In order to better compare and anchor the results in this paper to previous work, as well as to identify gaps, it is useful to critique the findings of the single NAFTA country studies. Trajtenberg (1999) exhibits data showing that Canada lags behind the U.S. and other G7 countries in terms of patents per capita or patents per RandD. Moreover the share of resources invested by Canada in fields such as computers and communications has not grown as it has in other industrial countries. The quality of Canadian innovations is not perceived as very high value, judging by the low rates of patent citations (that is, relatively few global patents cite earlier Canadian patents). In short, Trajtenberg (1999) sees weakness in Canadian innovative performance but does see potential in terms of the measures of Canada's absorptive capacity, such as the stock of human capital and infrastructure required to benefit from and contribute to innovative activities.

A key limitation in Trajtenberg (1999) is that the profile of Canadian innovation potential is measured by Canadian patenting in the U.S. The study does not examine Canadian patenting in other countries or foreign patenting in Canada; nor does it take into account that patents do not necessarily represent the universe of innovations as some innovations are not patented or are unpatentable. Some technological activities involve exploiting existing knowledge capital, rather than new innovations. These can be studied using measures that reflect technological trade in general, like the exports or imports of innovative goods, foreign direct investment that involve the technology transfer of knowledge-based assets, or the international licensing of knowledge-based assets. While Trajtenberg's study does examine 30 years of data, the latest period examined is the mid-1990s. To the extent that NAFTA (or TRIPS) reforms have made a difference, such a difference would not be picked up in his truncated sample.

In a later study, Rafiquzzaman and Mahmud (2005) use more recent data – namely 1997 to 1999 – and argue that Canada's growth rate of RandD has been the fastest among the G7, next to the U.S.'s. The growth in RandD has occurred in fields such as computers, communications, drugs and medicines, and electronics. They also find an increase in the citation of Canadian patents and an increase in the Canadian patenting propensity over this period. Thus this study finds more positive evidence of Canadian innovation than Trajtenberg (1999) had found. However, Rafiquzzaman and Mahmud (2005) does not assess whether the improved technological performance of Canada can be attributed to factors like NAFTA or the intellectual property reforms.

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[3] Alic (1998) provides a group analysis of the North American innovation system but does not focus on the role of intellectual property rights. The analysis, among other things, addresses the role of the U.S. as to whether it should take advantage of the energy resources and lower labor costs of its NAFTA partners or pursue a coordinated effort to raise productivity growth and wages in its partners.

Maskus (2005) examines the relationship between total factor productivity (TFP) and measures of patent reforms. He finds that patent harmonization (towards U.S. standards) has a statistically insignificant effect on TFP. Maskus (2005) also examines whether U.S. multinational affiliate sales and RandD respond to foreign patent reform and other control variables using data for 1992 and 1997, and again finds no evidence that the harmonization of IPRs would increase U.S. multinational sales and RandD. However, a dummy variable for NAFTA countries (Mexico and Canada) interacted with a variable measuring the loss of patent rights suggest that the harmonization of rules on the revocation of patent rights (e.g. compulsory licensing) may stimulate technology transfers from the U.S. to its NAFTA partners. A similarly cautious conclusion was reached earlier by McFetridge (1998) who argued that while compulsory licensing in Canada failed to nurture a vibrant domestic pharmaceutical industry prior to the 1990s, the weakening of compulsory licensing in Canada via the reforms and the implementation of NAFTA did not stimulate a great increase in RandD. The increase in RandD that did occur may have been part of a political bargain that firms had to fulfill to secure amendments to patent laws.

The empirical studies on Mexico generally find fairly low levels of innovative activity since NAFTA and find limited evidence that intellectual property reforms stimulated innovation. Lederman and Maloney (2003) make cautionary remarks that only a short time has elapsed since the implementation of NAFTA and that Mexico began its entry into NAFTA with a currency crisis (e.g. the devaluation of December 1994). Excluding innovative activities, Lederman and Maloney (2003) do point out that Mexico’s foreign trade has expanded since NAFTA. Without the agreement, Mexico’s global exports would have been 25% less, its inward FDI 40% less, and its adoption of U.S. technological innovations would have taken twice as long.

But on Mexican innovation performance, Lederman and Maloney (2003) conclude that NAFTA is not enough. They assess the national innovation system in Mexico –consisting of the private sector, public sector, and academia – to be inefficient. The key problem appears to be the lack of coordination among universities, private businesses, and government agencies, and the lack of networking activities to stimulate knowledge spillovers. Even Mexican firms, such as the pharmaceutical company *Avimex* which has a high (15%) RandD to sales ratio, have had to look for joint venture partners in foreign countries, like the U.S., due to the lack of networking opportunities locally. Aboites and Cimoli (2002) concur that there is a lack of innovation networking. However, they point out that the problem is that multinational corporations do not pursue networks locally in Mexico. The MNCs conduct RandD in their home countries and file patents in Mexico merely for commercialization. Thus, Aboites and Cimoli (2002) argue that “NAFTA met the expectations of foreign direct investment, but the same is not true for the local diffusion of technology flows.” The intellectual property reforms in Mexico provided better protection for transnational knowledge assets but did not provide mechanisms or incentives for the creation of local technological networks.

In another critical work, Leger (2005) studies innovation in the agricultural sector in Mexico. She finds limited evidence that recent intellectual property reforms induced greater innovation in the maize breeding industry. Her data are based on survey interviews of 25 breeders from private companies and public institutions conducted in the year 2000. Few breeders surveyed indicated that the new IPR regime influenced their research and development of seeds. A few criticisms with this study are that inputs to innovation were measured, not the outputs of inventive activity. It takes time to develop new seed varieties.

Her survey was conducted only 5 - 6 years after NAFTA and 2 - 3 years after Mexico incorporated the IPR provisions of NAFTA into national law. Moreover, Mexico still has bans on genetic modification and the patenting of life forms. This may have affected incentives to innovate and patent, as farmers and breeders would be less inclined to engage in genetic innovation if the laws do not provide intellectual property protection for that type of inventive output.

The surveys in Gallini (2002) and Jaffe (2000) point out that the U.S. patent system has become stronger. A specialized court of appeals has been established to hear patent cases and the prevailing view is that this court has been pro-patents, ruling in favor of patent holders in most of the cases it has heard. In other developments, the U.S. has expanded the types of inventions that can be patented, such as software, biotechnology, and business methods. In the U.S., the problem appears to be that the stronger laws and stronger enforcement of rights have not so much stimulated innovation as they have increased the propensity to patent. Firms are actively seeking to make more of their innovative outputs proprietary. The proliferation of patent rights has also raised the transactions costs of RandD. Innovators must seek more licenses or permissions to utilize existing know-how. Rights holders may also try to block the innovative activity of rivals by refusing to license or share knowledge. The proliferation of patent rights has created a patent thicket and increased the chances of overlapping rights, leading to increased litigation activities.[4] The evidence of the impact on innovation though is inconclusive. Some studies (Bessen and Maskin (2000)) find the innovation activities of firms to be hampered by patent rights held by others, particularly where innovation is a cumulative, sequential process; others (Anand and Khanna (2000)) find that stronger patents facilitate technology transfer as it gives the intellectual property owner stronger bargaining power in licensing negotiations and greater defenses against misappropriation.

The main gaps in the literature are that (a) studies of the effects of NAFTA have been limited to single country investigations rather than a group analysis; (b) the time frame is short, where only a few years of data beyond NAFTA have been examined; and (c) no systematic and comprehensive study of innovation and diffusion among NAFTA countries have been conducted. The single country studies examine different aspects of innovation and diffusion, making it difficult to draw consistent comparisons. In this paper, I provide a group analysis, use data from 1975 to 2005, and examine comprehensive data on inventions (patents, RandD) and diffusion (via patent filings, trade, FDI, and licensing). To isolate the effects of NAFTA, I not only conduct before and after (NAFTA) analyses but also compare activities within NAFTA to activities between NAFTA and the rest-of-the-world (ROW). The ROW countries are a control group to test whether intra-NAFTA technology trade is significantly different than technology trade between NAFTA and ROW.

4. CONCEPTUAL FRAMEWORK

The central goal in this study is to assess the effects of NAFTA and the intellectual property provisions on innovation and technology diffusion among NAFTA countries. The

[4] Hall and Ziedonis (2001) show that in the semi-conductor industry, an important motivation for filing patents is to use them as strategic bargaining chips in cross-licensing negotiations or for defensive purposes. The patent owner can pre-empt litigation threats if it has patents that the accuser might infringe upon.

findings should have implications for the role of free trade areas and the role of harmonized minimum standards for intellectual property. They should also have implications for whether the NAFTA members could further enhance their economic and technological ties towards a North American patent zone.

To measure technology diffusion, I focus first on patent data. Patent data measure inventive output. Moreover, international patent filings indicate where inventions come from and where they go. I then focus on data that measure the means by which technology diffuses; for example, via trade, foreign direct investment, and licensing. Patent applications often accompany – or are correlated with – exports, FDI, and licensing contracts, particularly if the goods or services that are marketed abroad are technologically sensitive, in the sense of being easy to copy and distribute. While international patent applications indicate the inventions that are introduced abroad, they do not show how, or what mode of technology transfer is used to market the product embodying the technology. It is useful to examine these mechanisms or modes of technology diffusion jointly rather than separately because these modes can be 'substitutes'. As Dunning (1977) and others have long ago stressed, firms have a choice of means to market their products abroad, whether by exports, FDI, or licensing. If the foreign market strengthens, for example, its intellectual property laws, firms may switch from exporting to FDI, or from FDI to licensing. Studies that focus only on one mode of technology transfer may pick up a negative relationship between say exporting (or FDI) and intellectual property laws. Misleading conclusions can be reached if it were argued that stronger patent laws inhibit technology diffusion when in fact they have increased the scale of technology diffusion but altered the composition of transfers by different modes. To avoid this problem, I examine the modes of technology diffusion jointly.

To recap, I relate measures of innovation and technology diffusion (patenting, exports, FDI, and licensing) on an indicator variable for NAFTA and on an index of patent rights, controlling for other variables. But what are our prior expectations of the effects of stronger intellectual property protection on innovation and technology diffusion. Here the theoretical literature does not provide clear guidance since the predictions depend on various model assumptions and specifications. In general, different scenarios are plausible. Hence a priori the theoretical effects of stronger IPRs on innovation and diffusion are ambiguous. In Box 1 (adapted from Allred and Park (2007)), I provide a typology of different theoretical channels by which IPRs can affect innovation and diffusion. The channels are not exhaustive, but they illustrate why the theoretical effects can be ambiguous.

For example, the classic argument is that stronger IPRs promote innovation by increasing the ability of the innovator to appropriate the returns to innovation. Since intellectual products have the property of a public good – non-rivalrous and non-excludable – consumers who do not pay for the good can still enjoy the good. This makes it difficult for creators of innovative goods to charge for the good and earn revenues to recoup the costs of innovation. Moreover, the marginal cost of distribution is insignificant: the good is easy to copy and distribute to other consumers. Thus intellectual property protection turns a public good into a proprietary good and allows the innovator to profit from his invention. Additionally, under the prospect theory (Kitch, 1977), a stronger patent system gives pioneers incentives to commercialize and better organize the market for follow-on innovation (via licensing).

However, there are also good arguments as to why IPRs can hinder innovation. One reason is that patent systems give rise to increased transaction costs in the market for technological exchange, as agents are required to obtain permissions to use patented technologies. Licensing or cross-licensing negotiations are especially burdensome if patent rights are fragmented whereby multiple rights holders own different components of a technology (Heller and Eisenberg, 1998). The transaction costs may particularly harm research and innovation when patentees hold rights to *research tools* or where innovation is a cumulative and sequential process.

Box 1. Channels by which Intellectual Property Rights affect Technological Change

Innovation	Diffusion
Positive: Increased Appropriability Prospect Theory	Positive: Market Expansion Effect
Negative: Transaction Costs Reduced Rivalry	Negative: Market Power Effect

Stronger patent rights may also reduce the incentives of patent holders themselves to innovate if they face reduced rivalry, causing a fall in the rate or frequency of innovation (Cadot and Lippman, 1995). The intuition is that if a monopoly faces little or no competitive threats, it has little incentive to innovate a technology that will only displace its own existing technology. It will innovate if the market desires a technological upgrade but it faces no pressure to do so because a rival might be first.

Stronger IPRs may also have ambiguous effects on technological diffusion. Maskus and Penubarti (1995), for example, identify two opposing effects of stronger IPRs on diffusion: *a market expansion effect* and *a market power effect*. Consider a firm in country A that exports patentable commodities to country B. The following argument applies to other forms of technology transfer activities as well, such as FDI and licensing. Now suppose country B strengthens its IPRs. On the one hand, the firm perceives an expansion in its market due to a reduction in imitation by local firms. The demand curve it faces in country B shifts out. On the other hand, stronger IPRs in country B increase the firm’s market power, reducing the elasticity of the demand it faces. The market expansion effect is likely to dominate in countries where the degree of market rivalry and competition is high, but the market power effect could in theory prevail in countries where local competitors pose a weak threat of imitation.

To summarize, the net effects of intellectual property rights on innovation and diffusion depend on the interplay of various channels. It is not always clear *a priori* what weight to give the different channels by which IPRs affect innovation and diffusion. Theoretical analyses therefore sometimes provide inadequate guidance on the role of IPRs or of intellectual property related agreements like TRIPS or NAFTA. This situation highlights the need for empirical evaluations to contribute to the debate on the effects of IPR reform.

5. EMPIRICAL FRAMEWORK

In this section, I derive the set of equations to be estimated and the set of hypotheses to be investigated. The empirical framework is based on a gravity model of trade.

A Gravity Model Approach

In order to determine the economy-wide level of patent applications, it is useful to begin with the decision-making process at the microeconomic level. Assume that there are k = 1, ..., N inventions. An inventor will seek patent protection for k^{th} invention if the net benefit of procuring patent protection exceeds the cost of filing for protection, say:

$$\Delta V_k = V_k^{PAT} - V_k^{NO\ PAT} \geq c \qquad (1)$$

where V^{PAT} and $V^{NO\ PAT}$ denote the value of a firm with and without patent protection respectively, and c the cost of filing a patent. The underlying logic is that inventors have means other than patent protection to appropriate the rewards from their innovation (such as lead time, reputation, and secrecy). Thus the value of a patent right is the incremental return (ΔV) an inventor can get above and beyond that which can be realized by alternative (non-patenting) means.

Assume that all firms face the same environment (for example, market size and laws), and that the only source of heterogeneity in the economy is the *quality* of inventions.[5] Assume for simplicity that the N inventions are in ascending order of quality; that is, invention 1 is of a lower quality than invention 2, which in turn is of a lower quality than invention 3, and so forth. Let the critical cut-off invention be the k^{th} invention; that is, $\Delta V_k = c$ for the k^{th} invention. Hence the first k inventions are not patented and the rest are. The quantity of patent counts is therefore:

$$P = (N - k) = f\,N \qquad (2)$$

where P denotes the quantity of patent applications and f = (N - k)/N the fraction of N inventions that are applied for patent protection. We can interpret f as the *propensity to patent*. Patent applications increase if either the patent propensity (f) is higher (say the cutoff value of k is lower) or the overall level of inventive activity (N) is higher.

Equation (2) can be rewritten more explicitly to indicate where patent applications come from and where they go:

$$P_{ij} = f_{ij}\,N_i \qquad (3)$$

where i indexes the *source* country and j the *destination* country. Domestic patenting is the case where i = j. The issues are: what does P_{ij} depend on and what is the functional form? Typically, P_{ij} should depend on a mixture of destination and source country variables,

[5] Invention quality could refer to inventive steps, product and process characteristics (e.g. speed, memory, efficiency), or to some criterion based on consumer tastes.

including source-destination interaction variables (such as bilateral trade treaties), and time effects. But we can break this down further.

In equation (3), f represents the technology diffusion rate. This depends on the interaction between the source and destination country. Let T_{ij} denote the level of interaction between countries i and j. T will depend on whether i and j have an economic treaty or agreement (like NAFTA, European Patent Convention (EPC), or Patent Cooperation Treaty (PCT)) and/or the level of trade between them. Hence I will use bilateral exports as one of my proxies for the level of interaction between the source country i and destination country j.[6] The more trade between two countries the greater the flow of technologies between them, depending on the technological content of the goods and services being exchanged. If the destination country's system of intellectual property protection and enforcement are weak, it is likely that its imports will be low in technological content. Due to the relative success of the gravity model in explaining bilateral trade,[7] I will specify T as a gravity-type equation:

$$T_{ij} = \delta \frac{M_i M_j}{D_{ij}} \qquad (4)$$

where D is the geographic distance between countries i and j and M denotes economic mass. I will use per capita GDP to proxy for M. The δ is a gravitational term that could depend on other factors, for example trade treaties or agreements like NAFTA.

In addition, f (the transfer rate of technologies from the source country to the destination country) is likely to depend on the strength of intellectual property rights (IPRs) in the destination. Consequently,

$$f_{ij} = f(IPR_j, T_{ij}, c_{ij}, \ldots) \qquad (5)$$

that is, the propensity to patent – and thus the technology transfer rate – is a function of the destination level of IPRs, exports from i to j, the source country's cost of patenting in destination j (denoted by c_{ij}), and other factors (denoted by …). By equation (1), patenting cost also determines the propensity to patent. Note that the cost of patenting is country pair specific. The reason is that patent applications must be translated into the official language of the destination (unless a country pair specific treaty or common language exempts that requirement). The cost of translation depends on the source country's official language as well as that of the destination. The agent fees may also depend on whether patent agent firms in the source and destination countries have international connections or businesses.

The exports from i to j in turn are a function of the geographic distance between i and j, the GDP and population of both i and j, and other control factors:

$$T_{ij} = T(D_{ij}, GDP_i, GDP_j, POP_i, POP_j, \ldots) \qquad (6)$$

Lastly, the stock, pool, or supply of innovations (that can be transferred internationally) is assumed to be a function of the source country's level of IPR and other factors:

[6] We can also use foreign direct investment or licensing transactions as a measure of T, which I do below.
[7] See Feenstra (2004) and Evenett and Keller (2002).

$$N_i = N(IPR_i, \ldots) \quad (7)$$

The intuition is that home inventors tend to patent domestically first, obtain priority, and then file patents abroad, if at all. In that sense, inventions and innovations depend to a first degree on the domestic incentives to conduct RandD and the domestic environment. Thus the stock of country i's innovations depends on country i's research and development, which in turn depends on the strength of patent rights in country i. We can think of domestic IPRs as a "supply-push" factor. For multinationals that conduct RandD in many locations of the world, their choice of location is likely to depend on the host country's system of IPRs.[8] This explains why many developing country firms conduct their RandD not in their home country but in foreign countries that protect their IPRs more strongly.[9]

Putting everything together, we can rewrite equation (3) as:

$$P_{ij} = f(IPR_i, IPR_j, T_{ij}, NAFTA, EPC, PCT, c_j, \ldots) \quad (8)$$

where NAFTA = 1 if both the source and destination countries are members of NAFTA. Likewise EPC = 1 if both countries are members of the European Patent Convention, and PCT = 1 if both countries are parties to the Patent Cooperation Treaty.[10] Equation (8) is the main model that I estimate (in log-linear form). I also estimate an equation for bilateral trade:

$$T_{ij} = T(D_{ij}, GDP_i, GDP_j, POP_i, POP_j, NAFTA\ldots) \quad (6)'$$

Equation (8) is a model of technology diffusion. It captures the actual inventions that are being diffused. But I am also interested in the mode (or vehicles) by which technology diffusion takes place. More specifically, the reason a firm may apply for a patent in a country is that the firm has intentions to market a product there, and that the product contains sensitive technological knowledge or materials – knowledge or materials that are easy to copy, imitate, and distribute. Hence, the firm would likely seek patent protection for that technology. The firm, then, has several ways to market a product in a country. If it is the domestic market, it simply manufactures and produces there. If it is a foreign market, the firm can manufacture at home and export the product to the foreign market. Alternatively, it can build a plant directly in the foreign market – that is, engage in foreign direct investment – and manufacture and sell the product there. Finally, the firm can license an entity in the foreign market to manufacture and sell the product in its stead. The firm can share the profits with the licensee via royalties or licensing fees. Hence, these are three main vehicles for technology diffusion: trade, FDI, and licensing. To the extent that trade, FDI, and licensing involve technologically-intensive products, there should be a high correlation between patent applications and these mechanisms of technology diffusion.

An advantage of looking at technology diffusion 'indirectly' at the modes of technology transfer (instead of 'directly' through patent filings of specific technologies) is that not all technologies that are marketed abroad are patented. They may not satisfy the requirements of patentability in terms of the technology area covered (e.g. genetic innovations) or the novelty

[8] If a firm from country X conducts R&D in country Y, the spending is counted as the R&D of country Y, not of country X. R&D data are based on the *location* in which it is performed and/or financed.

[9] See Cantwell (1995).

[10] The EPC and PCT provide applicants from member states access to specialized patent filing procedures.

of the technology. In order for a patent to be granted, the technology must be new (novel); if it is a technology that is older than one year and has been exploited previously, it cannot be patented. Another reason that not all technologies are patented is that the inventor or innovator chooses not to. For strategic reasons, the inventor may choose to keep the underlying knowledge a secret and not reveal it via an application for a patent. Hence, the FDI, trade, and licensing data will capture activities that patent filings may not. But not all FDI, trade, and licensing convey technologically-intensive goods. In that case, some FDI, trade, and licensing flows would not be sensitive to the strength of patent protection. Thus the data and empirical results would reflect to some degree the technological content of foreign transactions.

I will also use a gravity specification for the FDI and licensing equations:

$$X_{ij} = X(IPR_i, IPR_j, GDP_i, GDP_j, NAFTA, \ldots), \text{ where } X = FDI, Licensing \qquad (9)$$

That is, X could denote the outward stock of country i's FDI in country j, the inward stock of country j's FDI in country i, the value of licensing revenues received by country i from country j, or the value of licensing payments made by country i to country j.

The hypotheses are as follows:

H1. NAFTA increased technology diffusion among Canada, Mexico, and the U.S. significantly more than before NAFTA went into force.

H2. NAFTA increased technology diffusion among Canada, Mexico, and the U.S. by significantly more than the increase in technology diffusion between the NAFTA countries and the rest-of-the-world.

H3. IPR reforms among NAFTA countries increased technology diffusion among Canada, Mexico, and the U.S. significantly more than before the reforms.

H4. IPR reforms increased technology diffusion among Canada, Mexico, and the U.S. by significantly more than the increase in technology diffusion between the NAFTA countries and the rest-of-the-world.

Essentially we want to test whether NAFTA has produced a statistically significant difference in the technology diffusion among member countries. There are two ways to test the difference: over time and across space. H1 tests the effect over time, while H2 tests it across countries. The rest-of-the-world is thought of as a control group. The change in technology diffusion among the NAFTA countries may be part of a general global trend. Another possibility is that technology trade is greater with (or biased towards) the rest-of-the-world (ROW) if ROW is a more natural economic partner or provides stronger incentives or opportunities for technology trade. On the other if H2 holds, we would want to know if that has always been the case. The NAFTA countries are geographically close in proximity. Their greater internal technology trade may be a reflection of some factor or variable other than a 'NAFTA'-like agreement. Thus, both H1 and H2 need to be tested in order to determine if a 'NAFTA effect' exists and if further integration (say in the form of a patent union) or harmonization is economically warranted.

Finally, NAFTA contains specific provisions on IPRs. To focus on that specific area, I also examine hypotheses H3 and H4. I utilize a quantitative index of patent rights which incorporates the key IPR reforms that Canada, Mexico, and the U.S. have adopted, and then conduct analogous tests to see if the reforms made a statistically significant difference on intra-NAFTA technology diffusion.

6. DATA

I have assembled a large panel data set of 25 source countries and 40 destination countries for the period 1975 – 2005 (annual). The source country is where exports, investments, and technology come from and the destination country is where the exports, investments, and technology go to. The 40 destination countries include the 25 source countries, the remainder being countries for which I could not get source-related data. I study the NAFTA countries among this large sample of countries in order to compare intra-NAFTA technology trade to NAFTA trade with the rest of the world.

This section discusses the dependent and independent variables of interest. First, I discuss the main independent variables of interest (NAFTA and IPRs) and the control variables. I then turn to the dependent variables. Appendix 2 summarizes the variables and the data sources.

NAFTA: I create an indicator (or dummy) variable where the value equals one if both the destination country and source country are NAFTA members and zero otherwise.

Index of Patent Rights: I use patent protection to proxy for IPRs. Copyrights and trademark rights could also be included but they tend to be collinear with patent rights. The source of data is Ginarte and Park (1997) and Park (2008). The index of patent rights ranges from zero (weakest) to five (strongest). The value of the index is obtained by aggregating the following five components: extent of coverage, membership in international treaties, duration of protection, absence of restrictions on rights, and statutory enforcement provisions. Coverage refers to the subject material (type of invention) that can be protected; duration refers to the length of protection; restrictions refer to the less than exclusive use of those rights; membership in international treaties indicates the adoption into national law of certain substantive and procedural laws of those international agreements. Membership in an international treaty may also signal the willingness of particular nations to adhere to shared international principles such as non-discrimination. The enforcement component consists of mechanisms that aid in enforcing one's patent rights (such as preliminary injunctions against infringers). Each of these components is scored on a scale from 0 to 1 (reflecting the fraction of legal features that are available). The overall value of the patent rights index is the unweighted sum of the component scores. Appendix 1 summarizes the scoring methodology.

Figure 1 shows the evolution of the scores for the NAFTA countries. According to this figure, both Mexico and Canada have been catching up to the U.S. in terms of the strength of patent protection. The gap in strength among the three countries has narrowed considerably since 1980. As discussed earlier, both Canada and Mexico initiated reforms before 1994 in anticipation of NAFTA and TRIPS. However, both instituted further changes after 1995. Mexico has approached the strength of regimes in most (high-income) industrialized countries.

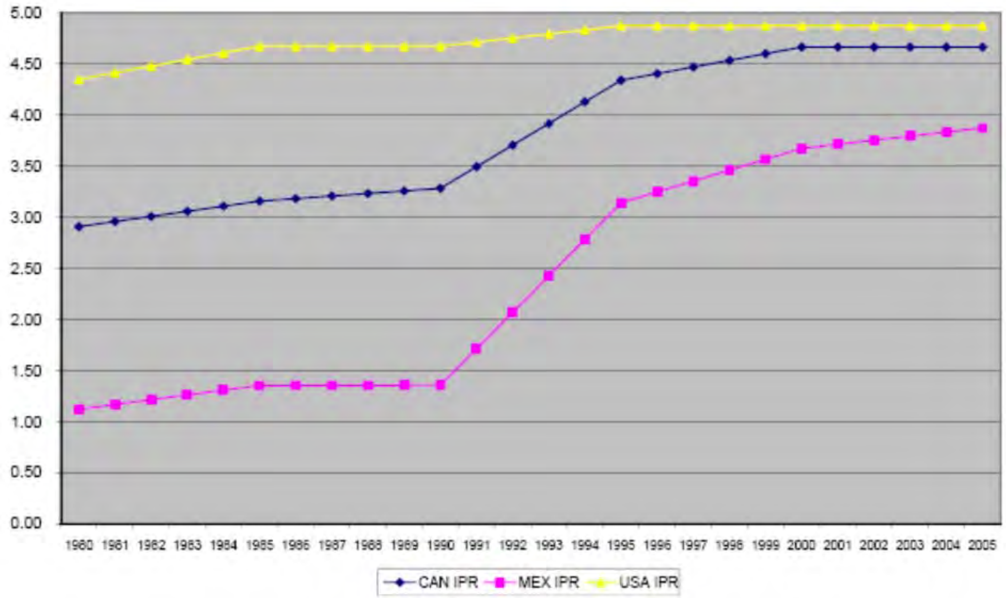

Figure 1. Index of Patent Rights.

Control Variables: A number of factors (other than IPRs) could affect innovation and technology transfer. I control for other regional agreements like the European Patent Convention (EPC) and Patent Cooperation Treaty (PCT). The EPC countries are those that can file patents at the European Patent Office. The PCT is a system for international patent filing and is run by the World Intellectual Property Office (WIPO), an agency of the United Nations. I also control for the cost of patenting (i.e. sum of official filing fees, translation costs, and agent fees), market sizes (i.e. the source and destination gross domestic product (GDP)), geographic distance, and population sizes. I also control for year effects, source country effects, and destination effects. These effects help control for any omitted variables that might be time specific or country specific.

Dependent Variables: As per the theoretical and empirical framework, I examine the effects of NAFTA, patent strength, and other control variables on patent applications, research and development expenditures (RandD), bilateral exports, stocks of foreign direct investment (FDI), and licensing receipts and payments. Except for patent counts, all of the dependent variables are in real 2000 U.S. dollars. Before proceeding to the empirical results, I provide some sample statistics of these dependent variables.

According to Figure 2, the RandD/GDP ratio is stable for the U.S., hovering between 2.5% and 3%. Mexico's ratio of RandD to GDP was stable and less than half a percent until the mid-1990s, when the ratio increased above half a percent and has largely remained stable since. The Canadian ratio of RandD to GDP, however, has grown the fastest among the NAFTA countries, from under 1.5% to just under 2.5% in 2005.

The low levels and rates of innovation in Mexico are reflected in the low numbers of scientists and engineers in the labor force. According to Figure 3, there are fewer than 10 scientists and engineers in Mexico per 10,000 workers. In Canada, there are 80 scientists and engineers per 10,000 workers in 2002, while in the U.S. there are 90 in 2002. In both Canada and the U.S., the share of scientists and engineers in the workforce has increased since the passage of NAFTA. Both figures 2 and 3 reflect the state of innovative activity in Mexico relative to its NAFTA partners. Mexico has a long way to go in order to catch up in innovative capacity. Hence, even though institutionally Mexico has taken great strides in strengthening its legal system for protecting innovation, more attention needs to be paid in Mexico as to how to raise its capacity to generate new innovations.

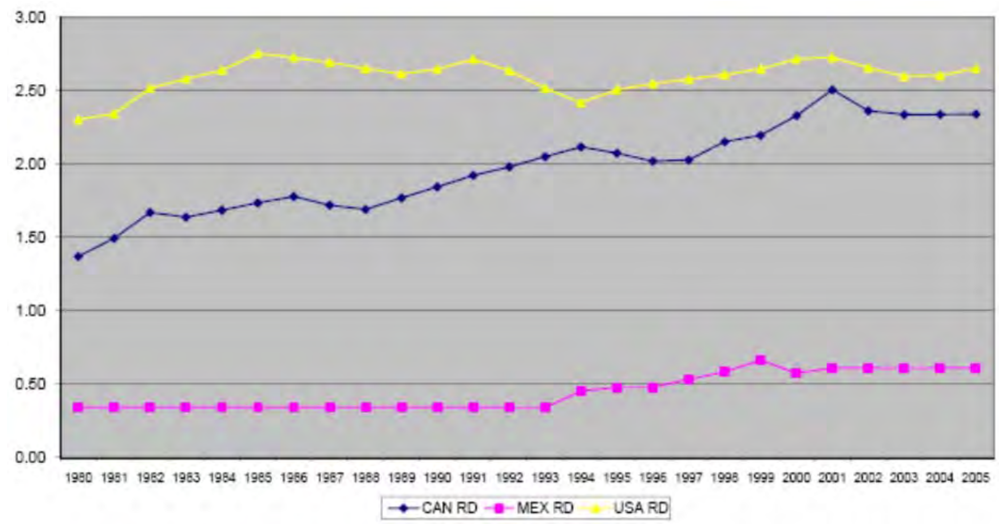

Figure 2. Research and Development as a % of GDP.

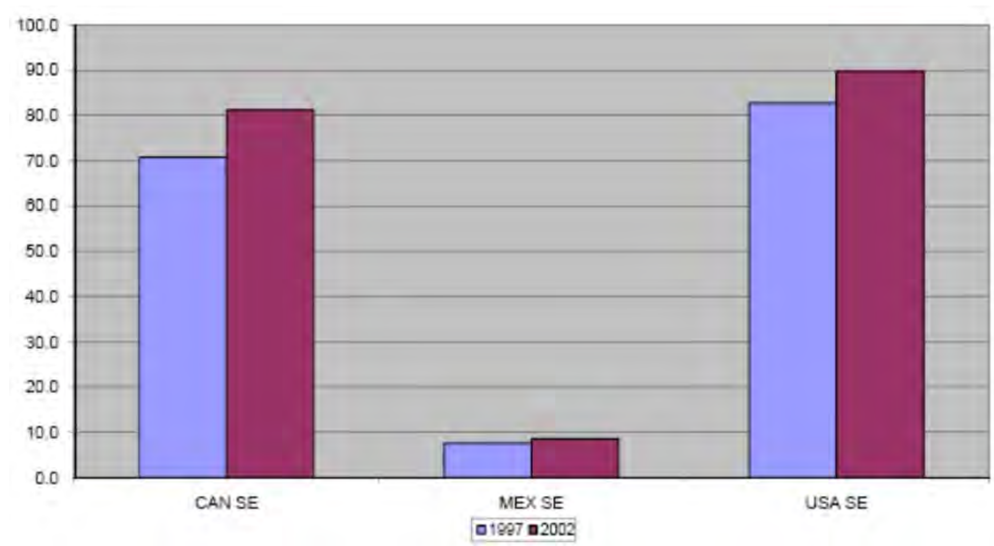

Figure 3. Scientists and Engineers per 10,000 Workers.

Tables 1 - 4 examine the pattern of technology diffusion among the NAFTA countries and the *rest-of-the-world* (ROW).[11] They provide an initial look at the overall volume of

[11] By ROW, I mean the rest of the 37 non-NAFTA countries in the sample.

innovation and technology diffusion within NAFTA and between NAFTA countries and the rest of the world.

Table 1. International Patent Filings

		Destination			
		Canada	Mexico	USA	Average ROW
Source	Canada	3745	509	6384	660
		63.5%	*938.8%*	*140.2%*	*364.8%*
	Mexico	24	477	154	15
		41.2%	*12.0%*	*83.3%*	*400.0%*
	USA	17354	11256	156305	14292
		19.0%	*438.6%*	*119.1%*	*304.4%*
	Average ROW	698	430	4476	4608
		21.0%	*760.0%*	*81.5%*	*1372.2%*

Notes: Each entry shows the average annual patent filings from the row country to the column country during the period 1994 - 2005. In italics below each entry is the growth rate of the average annual patent filings from the row to the column country from the 1975 - 1994 period to the 1994 - 2005 period.Average ROW denotes average rest-of-the-world country.

Table 1 shows the patents filed by the 'row' country in the 'column' country, before and after the year that NAFTA entered into force. Each entry shows the annual average quantity of patent applications filed by the row country in the column country after NAFTA went into force; below that figure is the percentage growth in average annual patent applications from before NAFTA went into force.[12] Since NAFTA, Canada has increased its patent applications the most in Mexico, followed by ROW, and the U.S. Canada's *level* of patenting is still highest in the U.S., followed by its own (domestic) patenting. Canada's increased patenting outside the NAFTA area may reflect either a technology-push effect (that is, intellectual property reforms increased Canadian innovation and expansion abroad) or the greater attractiveness of ROW destinations. That is, despite the intra-NAFTA liberalizations and strengthening of intellectual property rights, reforms in ROW may have been more significant. For example, Asia and Europe have also strengthened their IP systems, technological capabilities, and markets. The regression analysis should control for these other developments.

Most of Mexico's patent applications are domestic, followed by patents in the U.S., then in Canada and the rest-of-the-world. Post-NAFTA, Mexico has increased its pace of patenting at home and abroad. This may be mostly due to an increase in the propensity to patent rather than an increase in innovation potential (given that Mexico's RandD sector is still relatively underdeveloped). Membership in NAFTA has likely provided greater security for Mexican

[12] The average annual patent applications before NAFTA went into force is calculated as the average of 1975 - 1993.

technologies, which may explain the increased filings. In level terms, Mexican patenting in ROW is very small. This may reflect the cost of patenting abroad or transport costs of technology diffusion. Most of Mexican innovations are, consequently, diffused within North America.

After NAFTA went into force, the U.S. also increased its patenting abroad and at home. Its patenting in Mexico increased the most (by more than 400% from before NAFTA went into force). U.S. patenting in Canada increased relatively modestly after NAFTA. This suggests that NAFTA did not provide much greater incentives or opportunities for U.S. firms to transfer technologies to Canada.

The market expansion effect of NAFTA in Canada seems to be perceived to be small by U.S. intellectual property owners. To be sure, Canada is and always has been an important destination for U.S. inventors, which may be why NAFTA has a small influence on technology diffusion from the U.S. to Canada. Indeed, U.S. patenting in the rest-of-the-world grew faster than U.S. patenting at home and in Canada. As discussed above, Canadian patenting in the rest-of-the world has also grown faster than Canadian patenting in Canada and in the U.S. The U.S. patent regime has always been strong; NAFTA has only made the U.S. system incrementally stronger, at best. It has largely strengthened Mexico's, just as TRIPS has largely strengthened the systems of the developing countries.

The average rest-of-the-world country has also increased its average annual patenting in Mexico by more than 700% after NAFTA. Although ROW countries are not part of NAFTA, the policy reforms in Mexico provide an important signal to outside investors and inventors. Of course, these raw statistics do not control for other factors that may have played a role in the infusion of new technologies to Mexico, for example, its growing market size and improved macroeconomic stability. Furthermore, note that the rest-of-the-world has increased its patenting with one another more than with the NAFTA countries (for example, the European Union countries patent more amongst one another). In that sense, a regional effect can be associated with NAFTA.

Table 2 provides a cross-matrix analysis of export flows, from the row (source) country to the column (destination) country. Each entry shows the average annual exports after NAFTA went into force, in real 2000 dollars. Below, I report the percentage growth in average annual exports from before NAFTA went into force (namely 1975 - 1993). Canada's exports to the U.S. are largest, followed by its exports to the average ROW country, but its exports to Mexico grew faster recently. Since NAFTA went into force, Canada's average annual real exports to Mexico increased by more than 300% compared to its average annual real exports to Mexico during the period 1975-1993.

Similarly, Mexico's average annual exports to Canada and the U.S. increased significantly since NAFTA went into effect. U.S. real exports to Mexico have also increased the most, followed by real exports to Canada. Thus export patterns exhibit a strong regional (NAFTA) effect. Compared to their exports to the rest-of-the-world (and to ROW's exports to NAFTA countries), intra-NAFTA exports have expanded the most since 1994. NAFTA exports to ROW grew but not as significantly. The level of NAFTA exports to ROW is relatively smaller because we are averaging across all of the other 37 countries in the sample – a sample which consists of large markets such as Japan and Europe and smaller economies like Sri Lanka and Pakistan.

Table 2. Exports of Goods and Services in Real 2000 U.S. dollars

		Destination			
		Canada	Mexico	USA	Average ROW
Source	Canada		5.64E+08 *311.7%*	2.05E+11 *123.1%*	7.42E+08 *16.1%*
	Mexico	2.58E+09 *399.0%*		1.18E+11 *456.6%*	2.67E+08 *25.0%*
	USA	1.58E+11 *114.4%*	8.46E+10 *242.5%*		8.9E+09 *65.1%*
	Average ROW	1.39E+09 *46.3%*	8.68E+08 *141.8%*	1.69E+10 *79.4%*	

Notes: Each entry shows the average annual exports from the row country to the column country during the period 1994 - 2005. In italics below each entry is the growth rate of the average annual exports from the row to the column country from the 1975 - 1994 period to the 1994 - 2005 period. Average ROW denotes average rest-of-the-world country.

Table 3. Outward Foreign Direct Investment Stocks in real 2000 U.S. dollars

		Destination			
		Canada	Mexico	USA	Average ROW
Source	Canada		2689 *586.0%*	139646 *87.8%*	2871 *109.9%*
	Mexico	86.6 *129.1%*		3960 *242.6%*	16.63 *116.8%*
	USA	135259 *75.6%*	39505 *282.9%*		24835 *177.0%*
	Average ROW	3397 *37.1%*	1081 *11.6%*	33958 *105.5%*	

Notes: Each entry shows the average annual foreign direct investment stock of the row country in the column country during the period 1994 - 2005. In italics below each entry is the growth rate of the average annual FDI stock of the row in the column country from the 1975 - 1994 period to the 1994 - 2005 period. Average ROW denotes average rest-of-the-world country.

Table 3 provides a cross-matrix analysis of the average annual stocks of foreign direct investment of the row country in the column country. FDI is in real 2000 U.S. dollars. Again, Mexico is an important beneficiary of foreign long-term capital. Canada increased its stock of FDI in Mexico by almost 600%. The U.S. increased its annual stock of FDI in Mexico by almost 300%. Mexico increased its annual FDI stock in the U.S. by almost 250%. Relatively less growth has occurred in the FDI stocks of the U.S. in Canada and of Canada in the U.S. As explained earlier, this may have to do with the fact that NAFTA may have incrementally improved the attractiveness of Canada to the U.S. (or of the U.S. to Canada) since both were strong markets for each other initially. Note also that there is a regional effect. While Canada and the U.S. have significantly increased their FDI in Mexico, the average rest-of-the-world country has increased its FDI stock in Mexico by less than 12%.

Table 4 U.S. Receipts of R.oyalties and Licensing Fees for the Use of Intangible Assets in constant 2000 dollars

		Destination		
		Canada	Mexico	Average ROW
Source	USA	2492	949.8	1176.4
		87.2%	*224.1%*	*90.0%*

Notes: Each entry shows the average annual licensing revenues of the row country from the column country during the period 1994 - 2005. In italics below each entry is the growth rate of the average licensing revenues of the row country from the column country from the 1975 - 1994 period to the 1994 - 2005 period. Average ROW denotes average rest-of-the-world country.

Table 4 shows the licensing of U.S. technologies to Canada, Mexico, and ROW before and after NAFTA. Comprehensive licensing data (on a cross-matrix basis) is not widely available except for U.S. firms. Each entry in the table shows the value of licensing fees and royalties that American firms received from firms abroad (from both affiliates and arms-length entities) in real 2000 dollars. Since NAFTA went into force, American firms have increased their licensing of intangible assets (like intellectual property) to Mexican entities the most. In terms of level, though, the volume of U.S. licensing in Canada and the rest-of-the-world is greater than in Mexico.

These sample statistics and cross-border flows are suggestive of a NAFTA effect on intra-NAFTA technology diffusion; however, it is important to control for other developments during the period. The regression analyses in the next section will investigate the potential effects of NAFTA holding other factors constant.

7. Empirical Results

This section first presents estimates of the patent filing equation, followed by estimates of the technology diffusion models.

I. International Patenting

I start with an examination of the international patent filings for the sample as a whole. This large sample enables us to discern if NAFTA countries engage in relatively more technology diffusion with one another than with the rest of the world.

Table 5. Bilateral Patent Filings and Real Exports – All 40 Countries

Dependent Variable:	Bilateral Patent Filings (1)	Bilateral Patent Filings (2)	Bilateral Exports (3)
Constant	10.96*** (0.24)	2.57*** (0.31)	-31.46*** (3.68)
Destination IPR	0.186*** (0.069)	0.023 (0.067)	
Source IPR	-0.101 (0.088)	-0.167* (0.086)	
EPC	1.90*** (0.042)	1.40*** (0.042)	
PCT	0.984*** (0.041)	0.924*** (0.040)	
NAFTA	0.698*** (0.15)	-0.664*** (0.147)	1.93*** (0.11)
Patenting Cost	-0.575*** (0.022)	-0.403*** (0.022)	
Bilateral Exports		0.348*** (0.009)	
Destination GDP			1.20*** (0.063)
Source GDP			1.36*** (0.097)
Destination Population			-0.86*** (0.13)
Source Population			-0.081 (0.163)
Distance			-0.0002*** (0.0000024)
Adjusted R^2	0.75	0.78	0.81
Number of Observations	16508	16192	20551

Notes: EPC is an indicator variable (1 = both source and destination countries belong to the European Patent Convention), PCT (1 = both source and destination countries belong to the Patent Cooperation Treaty), and NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). All variables except for the indicator variables are in natural log units. The regression models all control for source country effects, destination effects, and year effects. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2.

According to Table 5, column 1, NAFTA members significantly file more patents with one another, holding other variables constant. The coefficient of 0.698 suggests (taking the exponent of that) that NAFTA members file more patents with one another by a factor of 2, or twice as much, holding other determinants constant. This effect is strongly significant at better than the 1% level of significance. As for the other factors, only the destination country's IPRs matter to patent filings. This suggests that most international patent filings are driven by the propensity to patent, whereby stronger patent rights abroad increase the profitability of patenting existing innovations. The source country's IPR is insignificant, implying that stronger regimes at home do not necessarily spur an increase in the stock of innovations. While the coefficient of the source IPR variable is insignificant, its measured value is negative, which would suggest that stronger IPRs produce a market power effect.

Just as NAFTA membership is associated with increased patenting, membership in the European Patent Convention (EPC) and in the Patent Cooperation Treaty (PCT) also facilitates the diffusion of patentable technologies. Patenting cost exerts the expected negative influence on patent filings. The coefficient suggests, however, that the demand for patents is inelastic. Firms appear relatively dependent on patent filings and thus vary filings less than proportionately to variations in fees. Overall the model explains 75% of the variation in the data.

The second column of Table 5 is illuminating. Here we include or control for bilateral trade (or exports more specifically). As the gravity model suggests, bilateral exports should be a significant driver of technological exchange. Indeed a 1% increase in bilateral exports is associated with a 0.348% rise in bilateral patenting, holding other factors constant. But once trade is controlled for, the NAFTA effect turns negative. One important reason why this would occur is if the NAFTA dummy and trade are strongly correlated. According to column 3 of Table 5, that is indeed the case. The third column fits the trade gravity model to the data. The source and destination income and population variables, and geographic distance, are controlled for. The signs are all as expected; however, the source population coefficient is insignificantly different from zero. Other than that, NAFTA is a significant determinant of trade. NAFTA countries trade relatively more with one another, especially after NAFTA went into force.

Returning to column 2, the results for the remaining variables are similar except that destination IPR is also insignificant once we control for trade. In this situation, the primary motive for filing patents is the market size of the destination or the market expansion effects of expanded trade. The trade variable captures those effects. A strengthening of the destination's IPR has the effect of also expanding markets (creating more demand for the IP owner, and less for imitators and infringers), but the trade variable measures that more directly. Again, the model performs well in terms of the goodness of fit; 78% of the variation in the data is captured.

It is important to note that throughout the results in Table 5, I controlled for time effects, destination and source country effects. This is to help control for omitted factors that vary by year, destination, and source.

In Tables 6 and 7, I examine sub-samples of the data. Table 6 focuses on patent filings (controlling for exports) and Table 7 focuses on bilateral exports. In both of these tables, column 1 shows the results for sample in which Canada is either a destination or a source; in other words, it is that part of the sample involving Canada. Columns 2 and 3 do the same for Mexico and the U.S. respectively. Lastly, column 4 is where the source and destination countries are both in NAFTA. In other words, column 4 refers to the sub-sample of NAFTA countries only.

Where Canada is involved, both the source and destination levels of IPR matter for bilateral patenting, as does the cost of filings (see Table 6). NAFTA has a statistically insignificant effect.

Table 6. Bilateral Patent Filings – Country Sub-groups

Dependent Variable:	Bilateral Patent Filings			
	Sample consists of at least the following as a source and/or destination:			
	Canada (1)	**Mexico** (2)	**USA** (3)	**NAFTA** (4)
Constant	11.6***	2.42*	0.61	-7.54***
	(1.48)	(1.36)	(1.69)	(3.22)
Destination IPR	0.998***	0.503***	0.45***	0.486
	(0.181)	(0.197)	(0.141)	(0.321)
Source IPR	0.518**	0.297	0.204	3.486***
	(0.26)	(0.199)	(0.21)	(0.311)
PCT	1.09***	1.47***	0.531***	-0.467
	(0.118)	(0.18)	(0.087)	(0.466)
NAFTA	-0.145	-0.43**	-0.767***	-3.418***
	(0.175)	(0.17)	(0.11)	(0.805)
Patenting Cost	-0.963***	-0.118	-0.327***	-0.458
	(0.061)	(0.145)	(0.053)	(0.30)
Bilateral Exports	-0.159**	-0.037	0.327***	0.599***
	(0.07)	(0.04)	(0.075)	(0.054)
Source Country Effects	Yes	Yes	Yes	No
Destination Effects	Yes	Yes	Yes	No
Year Effects	Yes	Yes	Yes	Yes
Adjusted R^2	0.87	0.86	0.89	0.78
Number of Observations	1155	1003	1205	183

Notes: PCT (1 = both source and destination countries belong to the Patent Cooperation Treaty) and NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). All variables except for the indicator variables are in natural log units. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2.

Canada does not significantly patent more and receive significantly more patents from NAFTA members than from non-members, nor after NAFTA went into effect relative to before NAFTA went into effect. Bilateral exporting surprisingly has a negative influence on patenting by Canada and patenting in Canada. This may be because bilateral trade with Canada has been displaced by FDI, licensing, or joint ventures with Canada, so that the vehicle by which patentable technology is diffused has changed (or shifted away from exports). PCT members also engage in relatively more bilateral patenting with Canada.

The corresponding column in Table 7 shows that bilateral trade with Canada is well explained by the simple gravity model; 96% of the variation in the data are captured. Furthermore, the income and population variables are all significant and have the correct signs. The NAFTA variable is also strongly significant (at better than the 1% level). But as reported above, neither NAFTA nor bilateral trade significantly influenced technology trade with Canada. The IP levels and costs of patenting play a more important role.

Table 7. Bilateral Exports – Country Sub-groups

Dependent Variable: Bilateral Exports

	Sample consists of at least the following as a source and/or destination:			
	Canada (1)	**Mexico** (2)	**USA** (3)	**NAFTA** (4)
Constant	16.3** (7.02)	-91.6*** (14.2)	0.39 (5.35)	-8.68*** (1.95)
Destination GDP	0.814*** (0.103)	2.14*** (0.22)	0.922*** (0.083)	0.245*** (0.088)
Source GDP	0.92*** (0.195)	2.091*** (0.38)	1.313*** (0.159)	0.122 (0.087)
Destination Population	-1.29*** (0.13)	-0.12 (0.43)	-0.898*** (0.166)	0.639*** (0.122)
Source Population	-1.17*** (0.16)	-0.17 (0.48)	-1.29*** (0.262)	0.741*** (0.121)
Distance	-0.0002*** (0.00003)	-0.0003** (0.0001)	-0.0001*** (0.00006)	-0.0013*** (0.00004)
NAFTA	0.644*** (0.074)	0.16 (0.161)	0.542*** (0.059)	0.894** (0.40)
Source Country Effects	Yes	Yes	Yes	No
Destination Effects	Yes	Yes	Yes	No
Year Effects	Yes	Yes	Yes	Yes
Adjusted R^2	0.96	0.90	0.97	0.91
Number of Observations	1328	1319	1328	189

Notes: Exports are in real 2000 U.S. dollars. PCT (1 = both source and destination countries belong to the Patent Cooperation Treaty) and NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). All variables except for the indicator variables are logged (natural logarithms). Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2.

Where Mexico and the U.S. are involved (see columns 2 and 3 of Table 6 and 7), NAFTA membership has a negative effect on patenting. In the case of the U.S., this negative effect is the result of the NAFTA variable being correlated with the export variable. Indeed, NAFTA membership is an important driver of bilateral exports with the U.S. That is, both Canadian and Mexican imports and exports with the U.S. are significantly greater than those with the rest-of-the-world.

However, for Mexico, bilateral exports with NAFTA members are not significantly different before and after NAFTA went into effect, nor are bilateral exports with NAFTA members significantly different from those with non-members. Thus, despite what the sample statistics showed, once other factors determining trade and technology diffusion are controlled for, NAFTA has had a negligible role on bilateral dealings with Mexico. Due to the relatively small bilateral trade with Mexico (compared with other trading partners), bilateral exports with NAFTA are not a significant explanatory factor in bilateral patenting with Mexico (see column 2, Table 6). Moreover, the NAFTA dummy variable has a significantly negative effect on patenting in Mexico (at the 5 percent level of significance). This might be due to the possibility that the IP provisions in NAFTA have better enabled technology owners to exploit their market power – that is, reduce technology diffusion and enjoy higher prices for technological goods.

Finally for the NAFTA club (see column 4 of Tables 6 and 7), the behavior of patenting and exports does differ significantly between the period before NAFTA went into effect and the period after.[13] After NAFTA went into effect, NAFTA countries did enjoy increased trade with one another. The increased trade also stimulated increased technology flows with one another (or increased patenting with one another). In this smaller sample, the NAFTA dummy simply exhibits a "before and after effect". In previous columns, the NAFTA dummy exhibits the "before-after effect" and captures differences in effects between members and non-members of NAFTA. Thus while, for Mexico, there is not an appreciable difference in technology trade with fellow NAFTA countries versus that with non-members, it does appear to enjoy increased technology trade with fellow NAFTA countries *after* NAFTA went into effect.

Interestingly, for the NAFTA club, source IPR does matter to patenting. Within this group, stronger IPRs appear to influence innovation (or the "supply" of innovations). Destination IPRs do not matter to patenting. In the case of the U.S. and Canada, their markets are quite attractive to begin with, and their IP regimes are fairly strong. Mexico's reforms are thus more important for influencing technology trade. But since Mexican data are mixed here with U.S. and Canadian data, the net effect is positive (see coefficient of 0.486 in column 4 of Table 6), but not statistically significant at conventional levels. Consistent with this view is that destination GDP – or market size – does matter to bilateral exports.

Graphically, we can see the NAFTA and TRIPS effect from a different angle.[14] Figure 4 plots all the year effects in the estimated regression models thus far. Specifically, these are plots of the coefficients of the year dummies over time. Between 1994 and 2000, patent filings were higher than average for the sample involving NAFTA countries, holding other factors constant.[15] The effect is most pronounced for Mexico and then NAFTA as a group. Canada and the U.S. have positive but milder year effects. However, after 2000, the year effects are all zero or insignificant. The timing is unusual. The year effects suggest that there was a temporary post-NAFTA/TRIPS boom in technological trade. After 2000, the boom may have ended due to an economic downturn (due to oil shocks, terrorism) and/or that the NAFTA/TRIPS effects are absorbed into the variables that are measured explicitly, like IPRs or GDPs.

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[13] The difference between these findings and the previous results in columns 1 – 3 of Tables 6 and 7 is that NAFTA has a "time" effect rather than a "spatial" effect.

[14] With year effects, we cannot separate out the effects of NAFTA from TRIPS because both agreements came into force at about the same time.

[15] This includes holding IPR levels and the NAFTA dummy constant. Thus these plots are indicating that something is going on during the years 1994 – 2000.

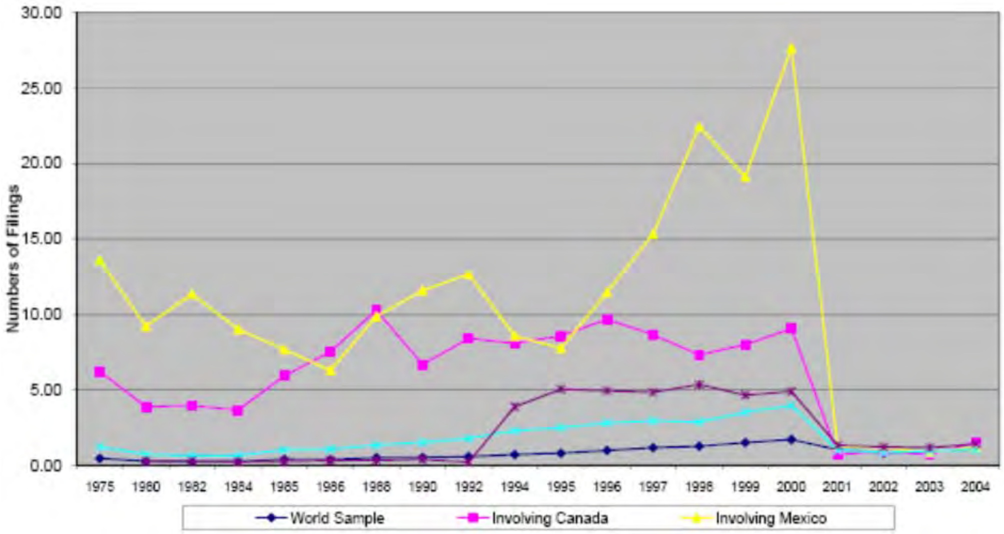

Figure 4. Patent Filing Year Effects.

The patent filings data thus far relate to outputs of innovation, namely the inventions produced. I next examine expenditures on research and development (RandD), which reflect the inputs into innovation, or the investments in innovation. Table 8 presents estimates of a log-linear RandD equation for the NAFTA club. Column 1 indicates that the RandD to GDP ratio is positively influenced by the strength of patent rights, holding other factors constant. The measured elasticity is 0.388%. However, the cost of patenting does not negatively deter research. Rather, costs have a positive association with RandD/GDP. The costs may be picking up the anticipated budget for commercialization and the patenting of the outcomes of RandD. This may spur researchers to intensify their RandD activities. Another possibility is that of ‘reverse causality’: high rates of RandD bid up the cost of patenting agents and other professionals involved in transferring research results to the marketplace.

The NAFTA dummy variable is also not a significant influence on RandD activities. Any important provision related to IPRs in NAFTA must have been incorporated in the variable measuring the strength of patent rights. Another possibility is that NAFTA represents an expansion in markets rather than a factor influencing productivity in research, opportunities for RandD, or the profitability of RandD. In contrast, the PCT dummy is a significant determinant of the RandD to GDP ratio. The PCT represents a larger number of member states, so that this could conceivably influence the perception of market size, opportunities for RandD, and the profitability of investing in RandD.

In column 2, the RandD model is re-estimated with the IPR variable disaggregated by country. In this case, investments in research and development are significantly influenced by the strength of IPRs in Mexico and Canada, but not in the U.S. In the U.S., patent laws have a positive effect, but the effect is not statistically significant at conventional levels. The U.S. patent system is already quite strong. Thus variations in the strength of U.S. patent laws must not be particularly important to the RandD sector in the United States. To some critics, the U.S. system is ‘too strong’ and may eventually exert negative effects on innovation. The present statistically insignificant estimate may portend a regime in the U.S. where innovation is stifled by the excessively strong rights of technology owners which block follow-on innovations and raise the cost of RandD inputs. But the focus of the results in Table 8 is to see whether RandD behavior is significantly different before or after NAFTA, and apparently it is not.

Table 8. Research and Development – NAFTA group

Dependent Variable: R&D expenditures as a percentage of GDP

	(1)	(2)
Constant	-19.43*** (0.429)	-19.5*** (0.58)
IPR Strength	0.388*** (0.054)	
IPR Strength in Canada		0.63*** (0.212)
IPR Strength in Mexico		0.43*** (0.088)
IPR Strength in the U.S.A.		0.37 (0.53)
PCT	0.169*** (0.037)	0.126** (0.05)
Patenting Cost	0.098* (0.058)	0.093 (0.059)
NAFTA	0.027 (0.059)	0.014 (0.091)
Year Effects	Yes	Yes
Adjusted R^2	0.94	0.94
Number of Observations	63	63

Notes: This sample only consists of the NAFTA countries. All variables except for PCT are in natural log units. PCT is an indicator variable which equals 1 when a country joined the Patent Cooperation Treaty. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2. Estimation is by fixed effects.

II. Modes of Technology Diffusion

I now turn to measures of technology diffusion, such as FDI and licensing, focusing on the NAFTA countries as the ‘source’ and/or destination countries. Regarding licensing data, I only have detailed data for U.S. transactions with the rest-of-the-world.

First, I pool all the NAFTA countries and examine their inward and outward FDI. This is shown in the first two columns of Table 9. I also examine U.S. licensing payments to foreigners and licensing receipts from foreigners, the results of which are shown in columns 3 and 4 respectively. As was just mentioned, among the NAFTA club, only U.S. international licensing data are available. Licensing payments by the U.S. to foreigners represent technology inflows; the U.S. is paying for the right to utilize technologies developed by foreigners. Conversely, licensing receipts by the U.S. from foreigners represent technology outflows; foreigners are paying the U.S. for the right to utilize technologies developed by the U.S.

Table 9. Modes of Technology Transfer by NAFTA Source Countries

Dependent Variable:	Inward FDI (1)	Outward FDI (2)	Licensing Payments (3)	Licensing Receipts (4)
Constant	-77.3*** (3.58)	-61.6*** (3.01)	-98.2*** (8.03)	-34.0*** (4.18)
Destination IPR	0.24* (0.13)	0.067 (0.078)	0.165 (0.246)	0.87*** (0.116)
Source IPR	0.071 (0.16)	1.63*** (0.167)	4.91 (3.77)	8.07*** (1.95)
Destination GDP	0.42** (0.203)	1.32*** (0.139)	0.51 (0.39)	1.36*** (0.186)
Source GDP	2.57*** (0.196)	1.13*** (0.159)	2.70*** (0.49)	-0.33 (0.245)
NAFTA	0.192* (0.111)	-0.08 (0.11)	1.01*** (0.24)	-0.134 (0.127)
Adjusted R^2	0.58	0.59	0.56	0.68
Number of Observations	1040	1392	426	495

Notes: NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). FDI refer to stocks in real 2000 US dollars. Licensing flows are also in constant 2000 US dollars and refer to flows into and from the U.S. (as source country). All variables except for the indicator variables are in natural log units. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2. Estimation is by fixed effects.

According to Table 9, the destination level of IPR matters for inward FDI. This should be as expected since inward FDI represents the stock of FDI created in the destination. Source country IPR matters more for outward FDI. This too would make sense if the strength of the source country's IPR strengthens its capacity to invest in FDI abroad and its availability of technological capital with which to invest abroad. Both source and destination GDP exert positive influences on inward and outward foreign direct investment. NAFTA has a significant positive effect on inward FDI (at the 10% level of statistical significance), but not on outward FDI. This indicates that the NAFTA countries receive relatively more FDI after NAFTA went into effect but did not appreciably influence member countries' capacity or incentive to engage in outward FDI.

On licensing transactions, U.S. payments abroad are not affected significantly by the strength of patent rights (whether it is the strength of U.S. patent rights or that of foreign country rights). That is, U.S. users of foreign technology must find the attractiveness or utility of foreign technologies not to depend on the foreigner's IPR regime. To the extent that foreign IPR regimes influence the quality of their technologies, U.S. users should be positively influenced, at least indirectly, by the strength of foreign IPR regimes. It may well be that the connection between technological quality and patent regime is not that strong. Another possibility (that needs to be investigated further) is whether this is due to the high share of payments to U.S. affiliates, in which case the payments are not specifically for arms-length foreign technologies, but for technologies developed by U.S. multinational branches. Yet another possibility is that stronger foreign IPRs enable foreigners to exercise stronger market power and thereby charge higher fees or royalties. This may reduce U.S. demand for foreign technologies and offset the positive effects of foreign IPRs on the quantity and quality of foreign technologies.

Source GDP – in this case, U.S. GDP – exerts a significantly positive influence on U.S. licensing payments abroad. Higher U.S. incomes increase the demand for foreign technologies and the willingness to pay for them. Another significantly positive determinant of U.S. licensing payments is NAFTA. The U.S. has purchased or licensed more technologies from Canada and Mexico than from other countries after NAFTA went into effect.

U.S. licensing receipts, however, are strongly dependent on source (U.S.) and destination levels of IPR. Stronger patent rights in the U.S. may have had an innovation effect in increasing the volume or supply of technologies that can be licensed. Likewise the incentive to license these technologies to foreigners depends on the strength of foreign patent rights. The weaker the protection, the less likely the U.S. would license technologies, and vice versa. Foreign market size, as proxied by destination GDP, also has a positive influence on U.S. licensing to foreigners. U.S. 'home' market size (i.e. source GDP) is not important to this endeavor. NAFTA also weakly affects U.S. licensing abroad. U.S. firms are not licensing technologies to Canada and Mexico any more than they are to other countries/region, like Japan, Korea, Europe, or Australia. Foreign markets are as attractive as the NAFTA market to U.S. technology owners. In contrast, technology inflows are a different matter. NAFTA better enables Canada and Mexico to license technologies to the U.S. market, holding other factors constant but does not influence the U.S.'s global strategy for licensing its technologies.

Tables 10 and 11 repeat the analysis of inward and outward FDI where the source or destination country is a NAFTA country. These tables allow us to focus the results more sharply by NAFTA country, rather than by pooling the NAFTA countries as was done for the results in columns 1 and 2 of Table 9.

According to Table 10, the destination's level of IPR attracts FDI into Canada and Mexico, but not significantly into the U.S. In other words, holding other factors constant, stronger patent rights in Mexico and Canada help attract inward FDI. The U.S. is already a country with a very strong patent system – perhaps in some cases too strong for foreign competitors to get a foothold. Furthermore, the U.S. market is attractive for its size. Hence it should not be too surprising that its level of patent strength is not a significant driver of FDI into the U.S. The patent strength of the source country from which FDI emanates is not statistically important for FDI coming into the U.S. and Canada. This might suggest that the technologies embedded in FDI capital is largely existing technologies, not new ones (for which patent rights can be sought). Foreign firms may be establishing plants for the purposes of sales, distribution, and production for which the destination's IPR matters more. The source country's IPR may matter more if the stronger IPRs stimulated the source country's pace and level of new innovation. The lack of significance of the home country's IPR suggests that foreign firms are transferring older vintages of technologies. They are not the product of recent innovative efforts.

Table 10. Inward Foreign Direct Investment into NAFTA Countries

Dependent Variable: Inward FDI	Destination Country: Canada (1)	Mexico (2)	U.S.A. (3)
Constant	-79.6*** (11.6)	-108.3*** (20.1)	-81.1*** (4.59)
Destination IPR	0.78*** (0.29)	1.79* (1.05)	0.096 (0.15)
Source IPR	-0.66 (0.49)	-0.513* (0.301)	0.13 (1.54)
Destination GDP	0.21 (0.44)	0.44 (1.26)	0.56*** (0.226)
Source GDP	2.96*** (0.511)	3.72*** (1.08)	2.52*** (0.29)
NAFTA	-0.113 (0.244)	0.504** (0.24)	0.21 (0.14)
Adjusted R^2	0.38	0.54	0.70
Number of Observations	361	127	552

Notes: NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). FDI refer to stocks in real 2000 US dollars. All variables except for the indicator variables are in natural log units. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2. Estimation is by fixed effects.

These older vintages may, of course, still be highly productive capital or recognized brands, but they are already in existence. In this situation, the only patent regime that matters is the host country's so that imitation and infringement can be deterred. In Mexico's case, the source country's IPR exerts a negative influence (which is statistically significant at the 10% level). One possibility is that foreign firms transfer less technology-intensive FDI to Mexico. FDI in Mexico may largely be present to take advantage of cheaper labor and access to the U.S. market and to South America. FDI in Mexico is likely not for the purposes of conducting RandD locally.

Source country GDP strongly – qualitatively and quantitatively – determines FDI into Canada, Mexico, and the U.S. This shows that richer foreign economies have a stronger FDI presence in the NAFTA region. They also have more capital to invest abroad. The destination GDP is not important except for the U.S.'s. This shows that the large market size of the U.S. is an important driver of inward FDI. The size of the Canadian and Mexican markets matter positively but not statistically significantly. The population of Canada is relatively small among OECD countries and Mexico's population is relatively large but the purchasing power of residents is relatively weak. Finally, the critical variable of interest – i.e. the NAFTA dummy – is only significant for Mexico. This shows that Mexico is the key beneficiary of NAFTA in terms of being able to attract FDI (due to its membership in NAFTA). The inward FDI of the Canadian and U.S. economies has only been marginally affected by the formation of NAFTA. Other factors have played greater importance in attracting foreign long-term capital.

Table 11. Outward Foreign Direct Investment by NAFTA Source Countries

Dependent Variable:	Outward FDI		
		Source Country:	
	Canada (1)	Mexico (2)	U.S.A. (3)
Constant	-65.4*** (11.7)	-149.7*** (44.2)	-67.0*** (3.08)
Destination IPR	0.33 (0.21)	1.64*** (0.61)	0.007 (0.066)
Source IPR	2.17*** (0.51)	-1.62** (0.70)	-4.04*** (1.29)
Destination GDP	0.68* (0.41)	0.88 (2.31)	1.48*** (0.112)
Source GDP	1.86*** (0.48)	4.78*** (1.78)	1.47*** (0.183)
NAFTA	0.023 (0.26)	0.42 (0.46)	0.05 (0.11)
Adjusted R^2	0.52	0.42	0.74
Number of Observations	480	77	835

Notes: NAFTA (1 = both source and destination countries belong to the North American Free Trade Agreement). FDI refer to stocks in real 2000 US dollars. All variables except for the indicator variables are in natural log units. Standard errors are in parentheses. ***, **, and * indicates statistical significance at the 1%, 5%, and 10% levels respectively. Other variable definitions and data sources are in Appendix 2. Estimation is by fixed effects.

The results of studying the outward FDI of Canada, Mexico, and the U.S. are shown in Table 11. Stronger IPRs in Canada stimulate outward FDI. In Canada's case, IP reforms stimulated new innovations, which are then embodied in the long term capital outflows of Canada. For Canada, then, it appears that patent reform influenced the technology content of FDI towards newer technologies, rather than simply extant technologies. But the IPR levels of Mexico and the U.S. have exerted a negative influence on their outward FDI. Tighter patent protection may be creating shifts in the composition of technology transfers: from FDI to trade (exports) or licensing. The U.S. may be shifting towards higher end technology transfers via licensing.

It is not clear which way Mexico is shifting. If stronger IPRs deterred innovation, this could explain the negative effect on outward FDI, assuming the latter contains technology sensitive capital. (If the latter contains capital used purely for distribution and marketing, source country IPR should not matter, positively or negatively.) If stronger IPRs encouraged innovation, then both countries must have sought alternative outlets for technology transfers abroad. More information is needed.

The destination's IPR matters only to Mexico. As with other developing economies' technologies, Mexico's technologies may be easier to imitate, or more easily subject to imitation, and hence Mexican multinationals may depend more on foreign patent protection levels.

The destination GDP matters to outward FDI from Canada and the U.S., as would be the case if the ultimate purpose of FDI is production and sales. However, Mexican goods and services appear to require less foreign presence via affiliates. Mexican foreign affiliates may primarily serve as outlets for communication and administration. For example, the world demand for Mexico's oil is largely satisfied via exports, rather than FDI or licensing. The source country's GDP stimulates the outward FDI of all NAFTA countries. Larger home markets provide a base for product development and international capital expansion. As trade researchers have shown, countries tend to develop a specialization in goods for which there is a large home market.[16]

Lastly, the NAFTA variable is not statistically significant for the outward FDI of these countries. The outward FDI in any case is going to both non-member and member markets. It is likely that among member countries, the influence of NAFTA's formation may be incorporated in changes in market size and IPR levels.

CONCLUSIONS

The empirical analysis in this study examined the response of technology trade to the formation of NAFTA and to the associated strengthening of intellectual property rights. NAFTA's provisions strengthen intellectual property laws beyond those set forth in the TRIPS agreement of the WTO, to which the NAFTA countries are parties. This study measured technology trade via the flows of international patenting, exports, FDI, and licensing.

Generally, exports, FDI, and licensing comprise alternative modes of technology transfer. In some cases, all modes could increase or decrease, but technology transfers may be biased in favor of one mode over another (or one mode may increase while the other decreases). Associated with these transfers – whether the vehicle of transfer is exports, FDI, or licensing – are patent filings, particularly if the technological goods and services being transferred are susceptible to widespread copying, imitation, or infringement. Otherwise, firms need not seek patent protection, given that patenting is costly (in terms of attorney fees and administration fees).

But if the value of protecting the technology is greater than the cost, firms would seek patents. Thus patent filings are revealing. They suggest that the firm has something of value

[16] See, for example, Krugman (1994) Chapters 2 and 13.

to protect. Hence the exports, licensing, and foreign direct investment of technologically valuable assets should be positively associated with patent filings.

In this section, I summarize the main findings and discuss some extensions and implications for policy. First, the NAFTA countries are of diverse innovation potential. The U.S. and Canada are nations with relatively high rates of research and development and patenting.

Mexico, however, lags behind them considerably in terms of investments in innovative activities and innovative performance. It may be a consensus in the literature that Mexico needs more than a trade liberalization agreement or the passage of intellectual property laws that meet the standards of much wealthier countries in order to ignite growth in the local innovation system.

Investments in human capital and RandD infrastructure require further attention, along with other supporting institutions and policies to provide both the incentives and opportunities for learning, adaptation, and innovation.

In terms of the inward diffusion of technological innovations, however, Mexico is a key beneficiary of NAFTA. Since the agreement went into effect, Mexico has received large filings of patentable technologies from the U.S. and Canada, along with exports, foreign direct investment, and licenses to use foreign technologies. The U.S. and Canada have increased their cross-border trade, FDI, licensing, and patenting marginally since NAFTA went into effect.

This presumably is due to the fact that the U.S. and Canada have long been engaged in technological trade with each other and have long had incentives (other than a liberalization of trade and investment) for engaging in such trade with each other. Now, while the *growth rate* of technology inflows into Mexico is the largest among the NAFTA countries, Mexico has still much to catch up to in terms of the *levels* of technology inflows that Canada and the U.S. currently experience.

The regression analyses overall find that NAFTA and the associated reforms in intellectual property laws have contributed to increased intra-NAFTA technology diffusion, holding other factors constant. In terms of the channels of influence, this study finds that NAFTA is a statistically significant determinant of cross-border patenting, but the influence of NAFTA is indirect.

It stimulates exports, which in turn stimulates patenting. In other words, by expanding markets, NAFTA provides innovators with a greater incentive and wherewithal to exchange technological innovations.

Stronger intellectual property rights are an important driver of Canadian innovation and technology diffusion. They stimulate both Canadian RandD and patenting activities. Stronger intellectual property protection does not seem to have been associated with increased innovation in the U.S. or Mexico.

Rather, stronger patent rights appear to have stimulated the diffusion of existing innovations. In Mexico, RandD (i.e. inputs into innovation) appears to have responded to stronger patent rights but the RandD has not significantly translated into patentable technologies (i.e. outputs of innovation).

In terms of other channels of technology diffusion (e.g. exports, FDI, and licensing), NAFTA is found to be strongly associated with increased U.S. and Canadian exports but weakly with Mexican exports.

Market access is critical, but the nature of goods also influences the ability of firms to penetrate foreign markets; for example, the technological quality of goods, their cost of production, and their complementarities or substitutability with other goods. Mexico appears to score lower on these counts.

NAFTA is also positively associated with U.S. licensing payments. This means that the ability of Canada and Mexico to market (license) their technologies in the U.S. has been enhanced by NAFTA. Inward FDI is also enhanced by NAFTA, especially FDI into Mexico. However, NAFTA appears to have had an insignificant effect on the outward FDI of all NAFTA countries. Other factors were more important in their ability and incentive to invest capital abroad. Alternatively, other regions and markets were just as important as (or more important than) the NAFTA market.

The associated intellectual property reforms are also important factors determining technology trade. Stronger patent protection in the Canada and Mexico attracted FDI and licensing from abroad, but not in the U.S. since the latter already represents a large market and has a very strong system of intellectual property protection. Stronger patent protection, by stimulating local innovation, also contributed to the ability of NAFTA members to engage in FDI abroad as well as transfer technologies abroad via licensing. There was, however, some evidence that stronger patent rights in Mexico enabled foreign firms to exercise greater market power in Mexico.

Stronger patent rights, for example, are associated with a reduction of FDI into Mexico, holding other factors constant. In other words, foreign plants contracted in order to reduce production and raise prices (i.e. the monopoly effect of IPRs). The U.S. also appears to have exercised greater market power abroad where patent protection is stronger. Holding other factors constant, U.S. outward FDI also decreased in response to tighter intellectual property protection abroad.

There are a number of ways in which to extend this study. The first is to study the nature of technology diffusion and innovation by industry, since the benefits and costs of IPR reform should vary by sector (for example, pharmaceutical, software, biotechnology, or transportation).

A second extension is to examine alternative ways in which to stimulate technology diffusion and innovation, other than IPRs, such as government funded and performed RandD, subsidies, and clusters.

A third extension is to address normative issues, such as whether there should be further technology policy coordination or harmonization, or whether it is desirable to form a regional patent office in North America.

In the remainder of this paper, I shall outline some thoughts on the idea of the formation of a regional patent office, along the lines of the European Patent Office (EPO). Ultimately it is a question of weighing the costs and benefits of forming an institution dedicated to administering and issuing patent rights. If the volume of technological trade within North America can justify the cost, it would be worth forming a North American Patent Office (NAPO). Of course, an endogeneity problem also exists: the volume may depend on whether a regional office (like NAPO) is available. Such an institution would lower the costs of patenting and simplify procedures, and make technology trade with (and within) NAFTA more attractive. But there are some challenges and obstacles. First, our estimates indicate that the demand for patents is inelastic. Reducing the cost would not stimulate more patenting than it would reduce fees or revenues collected. Second, the cost of patent applications for

Canadian and U.S. inventors in each other's market is relatively low due to the fact that there are no translation costs of filings. However, if a NAPO requires Spanish to be an official language, this might raise the translation costs of a North American patent to U.S. and Canadian inventors (and other inventors from the rest-of-the-world). Otherwise, if English is made the only official language, only Mexican inventors would bear the burden of translation costs.

In addition, there are some administrative issues, such as whether national patent offices would wither away. Or will patents still have to be validated by each of the three jurisdictions (as they do in the EPO system)? If there is a regional patent office, how will the revenues from patent applications be shared, and will surpluses be diverted to national treasuries? Who can practice before NAPO? Will patent agents be uniformly licensed in North America and be able to practice anywhere in the U.S., Canada, and Mexico? How are licensing standards to be established and licenses issued?

In order for NAPO to work, the three jurisdictions must, by definition, further harmonize their standards. A consensus is needed as to what constitutes an innovation – its novelty, nonobviousness, and utility or industrial applicability. Whether NAFTA members can harmonize further depends on whether or not they have reached their capacity to do so. Presently, the three jurisdictions do not have uniform standards or coverage for all areas of inventive activities. The U.S. provides patent protection for software, business methods, surgical procedures, and life forms. Canada and Mexico do not, although they do permit patents on technologies that utilize software algorithms but not for programs per se. These jurisdictions do not have uniform interpretations of what constitutes a patentable innovation. Procedural differences also exist: Canada offers pre-grant opposition, Mexico post-grant opposition, while the U.S. offers neither. The U.S. system of patent priority is based on first-to-invent while the other two are based on first-to-file. These are not easy legal provisions to change since there are strong entrenched interests in each of the three jurisdictions who prefer their existing practices. Further harmonization ignores also the needs of a developing country like Mexico. A strong IPR system is not uniformly regarded by many to be appropriate for countries with an incremental, adaptive innovation system.[17] The existing reforms have emphasized (or overemphasized?) legal rights and enforcement, rather than address the innovative and absorptive capacities of the NAFTA economies, particularly those of Mexico.

To further explore the feasibility and desirability of a regional patent zone requires assessing the cost – the administrative as well as the economic costs of tighter IPR standards.[18] The present paper has focused primarily on the benefit side of integrating and strengthening patent laws among NAFTA members.

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[17] See, for example, Grossman and Lai (2004).
[18] See also the discussion is provided in Schmidt (2007).

APPENDIX 1. COMPONENTS AND SCORING METHOD OF PATENT RIGHTS INDEX

1) Membership in International Treaties	Signatory	Not Signatory
Paris Convention and Revisions	1/5	0
Patent Cooperation Treaty	1/5	0
Protection of New Varieties (UPOV)	1/5	0
Budapest Treaty (Microorganism Deposits)	1/5	0
Trade-Related Intellectual Property Rights (TRIPS)	1/5	0

2) Coverage	Available	Not Available
Patentability of pharmaceuticals	1/8	0
Patentability of chemicals	1/8	0
Patentability of food	1/8	0
Patentability of surgical products	1/8	0
Patentability of microorganisms	1/8	0
Patentability of utility models	1/8	0
Patentability of software	1/8	0
Patentability of plant and animal varieties	1/8	0

3) Restrictions on Patent Rights	Does Not Exist	Exists
Working Requirements	1/3	0
Compulsory Licensing	1/3	0
Revocation of Patents	1/3	0

4) Enforcement Mechanisms	Available	Not Available
Preliminary (Pre-trial) Injunctions	1/3	0
Contributory Infringement	1/3	0
Burden of Proof Reversal	1/3	0

5) Duration of Protection	Full	Partial
	1	$0 < f < 1$

where f is the duration of protection as a *fraction* of 20 years from the date of application or 17 years from the date of grant (for grant-based patent systems).

Overall score for Patent Rights Index: sum of points under (1) – (5).

APPENDIX 2. VARIABLE NAMES AND DATA SOURCES

- Bilateral Exports (in real 2000 U.S. dollars). Source: United Nations, *Comtrade* database.
- Bilateral Patent Filings. Source: World Intellectual Property Office, *Industrial Property Statistics*, various issues.
- Distance (Geographic distance between the capital cities of countries). Source: Centre D'Etudes Prospectives et D'Informations Internationales (CEPII)
- http://www.cepii.fr/anglaisgraph/bdd/distances.htm
- EPC an indicator variable (= 1 if both source and destination are members of the European Patent Convention (EPC) in a particular time period, and zero otherwise).

- GDP (in real 2000 U.S. dollars), Labor Force, and Population. Source: World Bank *World Development Indicators*.
- Inward and Outward Foreign direct investment (in real 2000 U.S. dollars). Source: United Nations Conference on Trade and Development (UNCTAD) *World Investment Directory*.
- IPR (Index of Patent Rights). Source: Ginarte and Park (1997) and Park (2008)
- Licensing Receipts and Payments of U.S. firms (in real 2000 dollars). Source: U.S. Department of Commerce, Bureau of Economic Analysis, *U.S. Direct Investment Abroad (USDIA)*. http://www.bea.gov/international/index.htm#iip
- NAFTA an indicator variable (= 1 if both source and destination are members in a particular time period, and zero otherwise).
- Patenting Cost: sum of official filing fees, translation costs, and agent fees (in real 2000 U.S. dollars). Source: Global IP Estimator (www.globalip.com) and World Intellectual Property Office, *PCT Applicant's Guide* (www.wipo.int/pct/guide/en).
- PCT an indicator variable (= 1 if both source and destination are members of the global Patent Cooperation Treaty (PCT) in a particular time period, and zero otherwise).
- Research and Development (in real 2000 U.S. dollars). Source: Organization for Economic Cooperation and Development (OECD) *Main Science and Technology Indicators*, and United Nations Education, Scientific and Cultural Organization (UNESCO) *Statistical Yearbook*, various issues.
- Scientists and Engineers (Number of). Source: Organization for Economic Cooperation and Development (OECD) *Main Science and Technology Indicators*, and World Bank *World Development Indicators*.

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