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Intellectual Property Rights and the Propensity to Patent

INTRODUCTION

SINCE 1989, the Canadian *Patent Act* has undergone extensive changes. Among these were: the conversion from a first-to-invent to a first-to-file system; an increase in patent duration from 17 years from the date of issue to 20 years from the date of filing; the adoption of disclosure rules requiring the publication of new applications within 18 months of the filing date; and the elimination of automatic examination of applications. Perhaps the most prominent reform was the repeal of the compulsory licensing system for pharmaceuticals in 1992.

The changes made to Canada's *Patent Act* are representative of a series of sweeping reforms in intellectual property that are taking place throughout the world. From the international arena came the Trade-Related Aspects of Intellectual Property Rights (TRIPs) Agreement that established minimum standards for the protection of intellectual property in all member countries of the World Trade Organization (WTO), as well as trade-related penalties for non-compliance. At the country level, extensive legislative and policy reforms have been implemented in the United States over the past two decades, including the establishment of the Court of Appeals for the Federal Circuit and the extension of patentability to business methods, software and genetic material. The widely-held view is that, on balance, these country-specific reforms and international agreements have strengthened the rights of patent holders.[1]

Around the time the Canadian reforms were taking place, the rate of patent applications in Canada from both domestic and foreign innovators began to increase, after having been constant throughout most of the 1970s and 1980s. Figure 1 shows total patent applications filed in Canada, disaggregated by domestic, U.S., European and Japanese applicants. During the years 1985-92, the average annual growth in patent applications rose to 6.44 percent from 1.37 percent over the previous seven years (Rafiquzzaman and Whewell, 1998). In addition to becoming a desirable destination for foreign patentees, Canada has developed into a fertile source of new products and processes over the past decade, as shown in Figure 2.

As was the case for reforms, the surge in patenting has not been unique to Canada. Patenting activity increased throughout the industrialized world. For example, patenting has been steadily climbing in the United States since the mid-1980s, particularly among domestic inventors who have increased their patenting activity at home and in foreign markets, as shown in Figures 3 and 4.

These facts — world-wide patent reform and an acceleration in patenting activity — have caught the attention of many academics and policymakers. And, the passage of time has provided an opportunity to examine a key question raised by these observations: Could the strengthening of patent rights be credited with the increase in patenting?

A growing literature sheds light on this question. The results from these studies are remarkably consistent in showing weak support, if any, for a causal relationship between the strengthening of patent protection and increased innovation.[2] However, several studies find evidence of a positive relationship between stronger patents and an increase in the *propensity to patent*, as measured by patenting per unit of research and development (R&D). [For example, see Hall and Ziedonis (2001) and Hicks, Breitzman, Olivastro and Hamilton (2001) for the United States; Rafiquzzaman and Whewell (1998) for Canada; Scherer and Weisburst (1995) for Italy; Arundel and Kabla (1998) for Europe.]

Measuring the impact of policy changes in the United States and the implications of the TRIPs Agreement for less-developed countries has occupied the research agendas of many academics and policymakers. In contrast, only limited attention has been devoted to recent patent reforms in Canada [Rafiquzzaman (1999), Rafiquzzaman and Whewell (1998), Pazderka (1999) and McFetridge (1999)][3]. Except for the repeal of compulsory licensing for pharmaceuticals, there is little systematic evidence to show whether the 1989 reforms have led, on balance, to a strengthening or a weakening of patent rights.[4] While the data available limit our ability to address this issue directly, we are able to provide some new insights on the determinants of patenting in Canada, particularly among foreign inventors, and the relevance of intellectual property rights for the decision to patent.

Total patent applications (or grants) may vary in response to a strengthening of patent rights because inventors have a greater incentive to develop innovations and/or because they patent a greater proportion of their inventions. It is the latter effect — the *propensity to patent* — that we are interested in explaining.

FIGURE 1

PATENT APPLICATIONS IN CANADA BY SOURCE, 1972-97

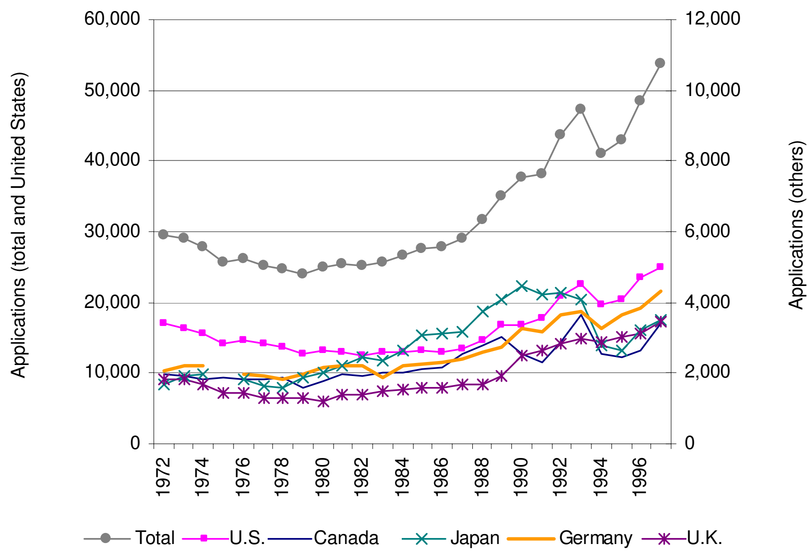


FIGURE 2

PATENT APPLICATIONS BY CANADIAN INVENTORS ABROAD, 1972-97

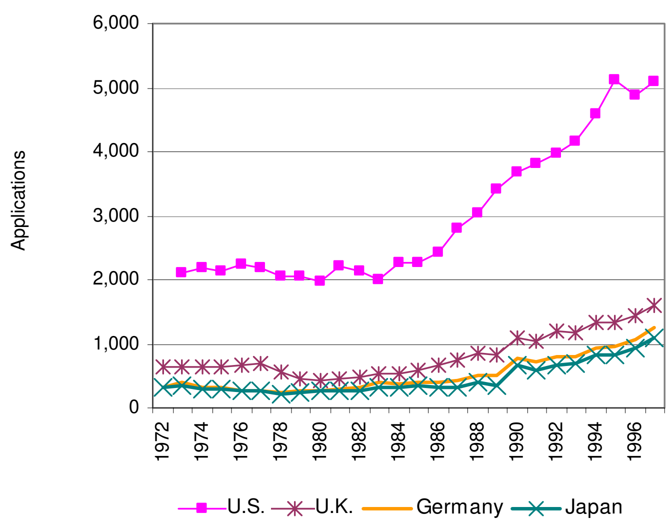


FIGURE 3

PATENT APPLICATIONS IN THE UNITED STATES BY SOURCE, 1972-97

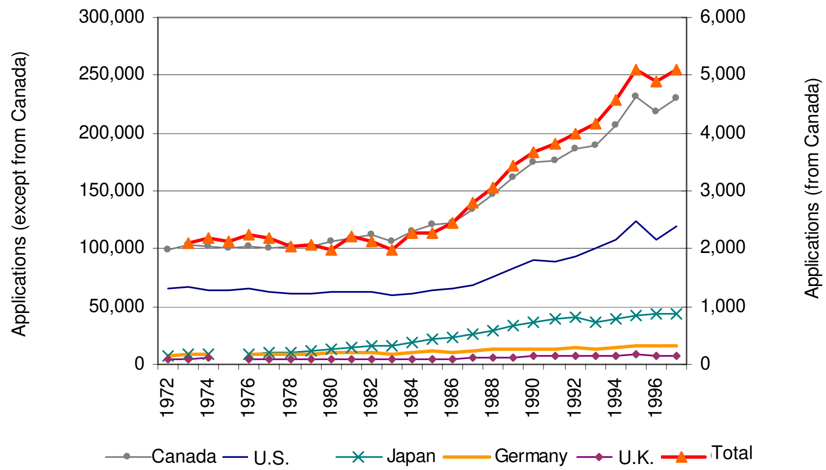
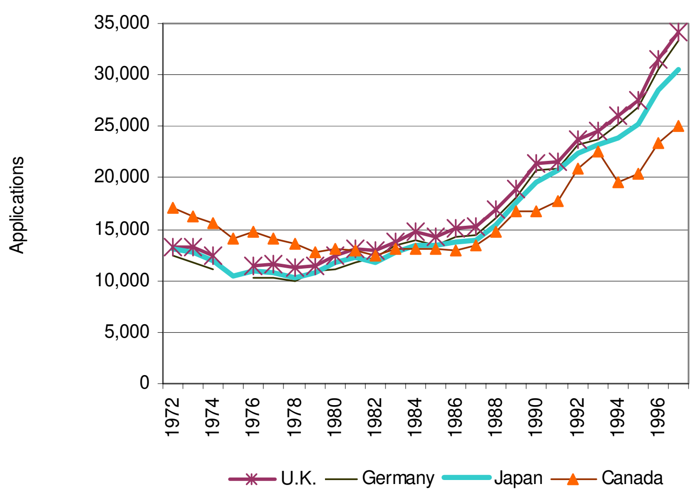


FIGURE 4

PATENT APPLICATIONS BY U.S. INVENTORS ABROAD, 1972-97



Why should we be interested in studying the propensity to patent in Canada? First, an increase in foreign patenting in Canada may simply reflect an increase in innovative activity in the foreign country that *spills over* into Canada, but may have little to do with incentives provided in Canada.[5] Focusing on the propensity to patent in Canada controls for this possibility. Second, while domestic patenting in Canada has increased significantly over the past decade, foreign patenting still accounts for 90 percent of total applications filed in Canada. Identifying the determinants of foreign patenting may inform policy directed toward attracting new technologies in Canada. Third, as Hall and Ziedonis (2001) suggest, some patenting may be socially wasteful. To determine whether patenting activity occurring in Canada is beneficial or costly requires an analysis of private incentives to patent. More broadly, understanding the determinants of the propensity to patent may guide current policy in Canada and identify whether further reforms are warranted.

We measure the propensity to patent in two ways: (1) the number of patent applications filed in a destination country *j* from a source country *i* per million dollars of R&D spent in *i* (i.e. conditional on *i*'s R&D input); and (2) the number of patent applications in destination country *j* from source country *i* per domestic patent application filed in *i* (i.e. conditional on *i*'s R&D output). With these two measures of the propensity to patent, we present two types of analyses. In the first, we estimate a model of the aggregate propensity to patent, in which data are aggregated across all industries for each of 17 countries (both source and destination) observed at four points in time that are distributed before and after the reform of the Canadian patent system.

We find that the quality of patent protection offered by a destination country has a significant impact on the propensity of source country inventors to seek patents in that destination, especially if the destination country has a permissive antitrust policy or high imports from the source country. While performing well overall, the model over-predicts patent propensity for Canada as a destination country in the latter part of the sample. With this lesson from the aggregate analysis, we turn to a more disaggregated approach that attempts to identify differences in patent propensities from major industrial countries across a wide range of industries in Canada. In this analysis, we document changes in the patterns of patent grants across industries and countries prior to and after the patent reforms of 1989.

In the second section, entitled *The Propensity to Patent*, we describe an economic framework from which the two patent propensity measures are derived and review the relevant literature within this framework. In the third section, entitled *Aggregate Analysis*, we present the empirical results from the aggregate analysis and, in the fourth section, entitled *Applying the Model to Canada*, we examine the model's predictions for this country. The disaggregated industry analysis of the propensity to patent in Canada is presented in the fifth section, entitled *Industry-level Analysis*. The last section concludes and suggests directions for future research.

THE PROPENSITY TO PATENT

IN THIS SECTION WE DEVELOP AN ECONOMIC FRAMEWORK for the propensity to patent, which we estimate in the fourth section, drawing from the analysis of Eaton and Kortum (1996) and Kortum and Lerner (1998).

AN ECONOMIC FRAMEWORK

CONSIDER A SINGLE RESEARCHER IN COUNTRY i, contemplating research on multiple research projects at time t. N_i projects are directed toward patentable inventions; the time subscript is suppressed for convenience.[6] We assume that research on a patentable project is an independent draw from a distribution $f(q)$, with cumulative distribution $F(q)$ and support $(0,Q)$, that yields a technology of uncertain quality, q. The cost of researching N_i projects is given by $R(N_i)$, where $R'(N_i) > 0$. The researcher faces a two-stage problem. The first stage is the innovation decision in which the number of research projects is chosen; the second stage is the patenting decision in which the researcher decides which of the N_i projects to patent in country i (at home) and in country j (abroad).

We begin in the second stage, after the investment has been made and the research results are known. For simplicity, we assume that all N_i projects yield products or processes that are sold or used in independent and identical markets in each country and, furthermore, that the set of patentable subject matters is the same in both countries.[7] Suppose that if the technology is patented in country j, the gross return will be $v_p(s_j, x_j, z_{ij})$ per unit of quality q, where s_j represents the level of patent protection in country j; x_j are features of the economic environment in country j (e.g. market size, imitation costs, etc.); and z_{ij} are features that describe the relationship between the source and destination countries (e.g. bilateral treaties, trade between countries).[8] If an invention is not patented in country j, the firm earns $v_n(s_j, x_j, z_{ij})$ per unit of quality, which may also depend on s_j, x_j and z_{ij}.[9] The filing cost of a patent in country j is c_j.[10] Then a firm will patent an innovation with quality q in country j if $q[v_p(s_j, x_j, z_{ij}) - v_n(s_j, x_j, z_{ij})] > c_j$. The quality level that makes the researcher from country i indifferent between patenting and secrecy[11] in country j is:

(1) $$q_{ij}^* = c_j/[v_p(s_j, x_j, z_{ij}) - v_n(s_j, x_j, z_{ij})].$$

A parallel decision, made with respect to patenting in the home country, yields a reservation quality level for secrecy, q_{ii}*.

Next, consider the research investment decision in the first stage. The level of investment will depend on the return that the inventor expects to receive from patenting or secrecy, as outlined above. Without loss of generality, assume that $q_{ii}^* \leq q_{ij}^*$, which implies that if the invention is patented abroad, it will also be patented at home.[12] Then, the researcher maximizes expected profits over N_i, where expected profits are given by:

$$(2) \quad N_i \{ \int_0^{q_{ii}^*} q[v_n(s_i, x_i) + v_n(s_j, x_j, z_{ij})] f(q) dq + \int_{q_{ij}^*}^{q_{ij}^*} q[v_p(s_i, x_i) + v_n(s_j, x_j, z_{ij}) - c_i] f(q) dq + \int_{q_{ij}^*}^{Q} q[v_p(s_i, x_i) + v_p(s_j, x_j, z_{ij}) - c_i - c_j] f(q) dq \} - R(N_i).$$

The solution to the maximization problem reveals that the number of profit-maximizing research projects depends on the expected return from patenting which, through the patenting decision, depends on the strength of patent protection, the costs of patenting and other features of the economic environment in *both* countries. That is, the profit-maximizing number of inventions is given by:

$$(3) \quad N_i^* = N(s_i, s_j, c_i, c_j, x_i, x_j, z_{ij}).$$

To complete the model, we denote by ρ_{ij}^* the probability that an invention from country *i* will be of sufficiently high quality for patenting to be profitable in country *j*. So $\rho_{ij}^* = Pr(q > q_{ij}^*)$ or, from (1):

$$(4) \quad \rho_{ij}^* = 1 - F\{c_j / [v_p(s_j, x_j, z_{ij}) - v_n(s_j, x_j, z_{ij})]\} = \rho(s_j, x_j, z_{ij}, c_j).$$

Of course, the above model is a gross simplification of actual R&D processes. Among the apparent criticisms are that innovations are not, in reality, so easily classified as *patentable* or *non-patentable*, and the standards for patentability may not be the same across countries. But, in its simplicity, the determinants of patenting that enter our empirical analysis are easily gleaned. To see this, let P_{ij} be the number of patent applications (grants) in destination country *j* filed by researchers from source country *i*. Then, the expected P_{ij} equals the number of patentable inventions generated in country *i*, times the probability that an invention generated in country *i* will be patented in country *j*. That is,

(5) $E(P_{ij}) = N_i{}^*\rho_{ij}{}^* = N(s_i, s_j, c_i, c_j, x_i, x_j, z_{ij})\rho(s_j, x_j, z_{ij}, c_j)$.

Equation (5) highlights a direct and an indirect mechanism through which patent policy in a destination country impacts on the total number of patents filed in that country. First, stronger protection in destination country *j* may increase researchers' incentives to develop more patentable inventions if a higher return from patenting is anticipated (the *innovation effect*). Second, researchers may have a greater incentive to patent rather than keep inventions secret for a given number of patentable inventions in source country *i* (the *patent propensity effect*). So, if the relationship in equation (5) was estimated by a regression analysis, the coefficient on s_j would reflect *both* the direct (innovation) and indirect (patent) effects of changes in patent strength on the total number of patents.[13]

MEASURING THE PROPENSITY TO PATENT

IN ORDER TO ISOLATE THE IMPACT of intellectual property rights on the propensity to patent, which is our focus, we control for the innovation effect. If our data were disaggregated (by inventor), we could do this by estimating equation (4) directly. Since they are not, but P_{ij} [total patent applications (or grants) from country *i*, filed in country *j*] is observable, an alternative approach is to estimate equation (5) by controlling for the innovation effect ($N_i{}^*$). As the literature review below reveals, this is typically done by estimating the relationship in equation (5) after substituting a proxy for $N_i{}^*$, or by redefining the dependent variable as total patents per patentable innovation, in which case the relevant model becomes:

(6) $E(P_{ij}/N_i{}^*) = \rho(s_j, x_j, z_{ij}, c_j)$.

To proxy the total number of patentable inventions, which is unobservable (since inventions kept secret are not observed), a measure of R&D (dollars or number of scientists and engineers) is typically used. This measure of patent propensity — patents filed in country *j* by country *i* per million dollars of R&D invested in the source country — is the first of two measures we implement in this study. Since the priority country in which a patent is first filed is typically the source country, then when $i = j$, this *input-based* propensity measure gives the proportion of inventions that are disclosed rather than protected by secrecy.

As an alternative proxy for N_i*, we use the number of domestic patents filed in country *i*. So, the second propensity measure can be interpreted as the proportion of inventions already patented in source country *i* that are also filed in destination country *j*.[14] In contrast to the first measure, this *output-based* propensity applies only to foreign patenting (since it equals one when $i = j$) and reflects the diffusion, rather than the disclosure, of innovations.

The two propensity measures for Canada as a destination country, disaggregated for four source countries — the United States, Germany, the United Kingdom and Japan — are shown in Figures 5 and 6. Note that the U.S. propensity to patent in Canada in Figure 6 has been steady; the German propensity has been increasing, while Japan's has been steadily falling. A comparison of these results with those for the United States in Figures 7 and 8 suggests considerable variation in patent propensities between destination countries from a particular source, as well as variation among source countries toward a particular destination country.

We attempt to explain this variation with an empirical model based on the above framework. Before describing the specification of the estimated model and its results, we review briefly a subset of studies from the relevant literature.

FIGURE 5

PROPENSITY TO PATENT IN CANADA,
RATIO OF APPLICATIONS IN CANADA TO R&D BY SOURCE COUNTRY, 1974-97

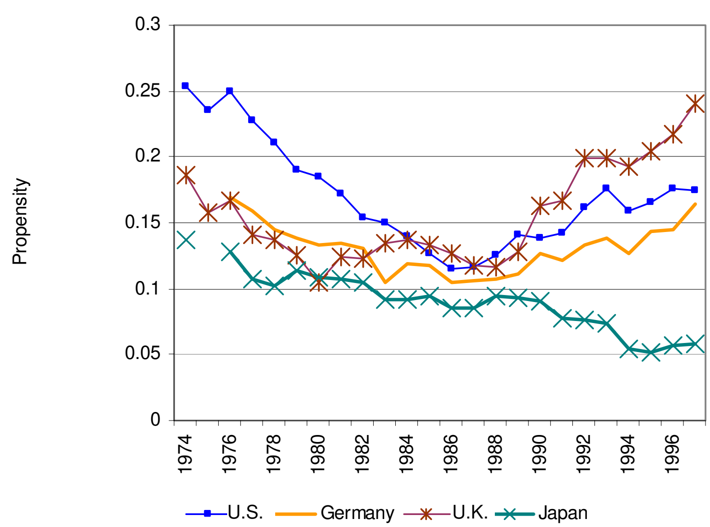


FIGURE 6

PROPENSITY TO PATENT IN CANADA
RATIO OF APPLICATIONS IN CANADA TO SOURCE COUNTRY PATENTS, 1973-97

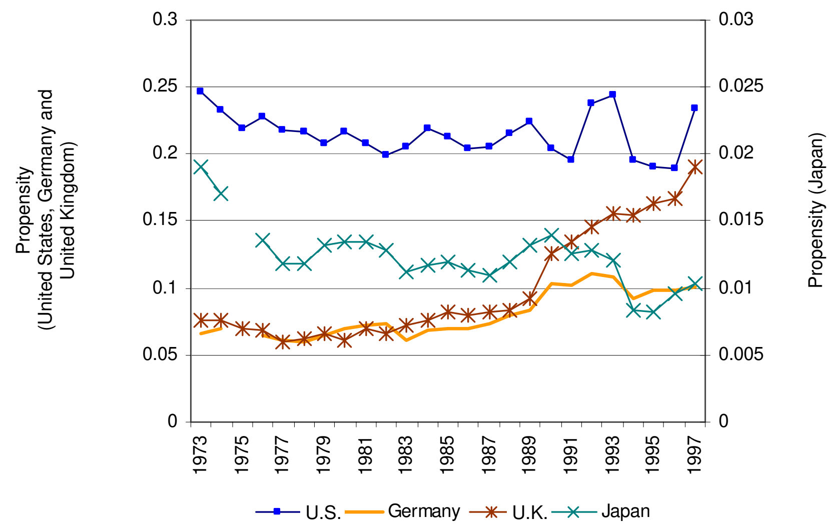


FIGURE 7

PROPENSITY TO PATENT IN THE UNITED STATES,
RATIO OF APPLICATIONS IN THE UNITED STATES TO R&D BY SOURCE, 1974-97

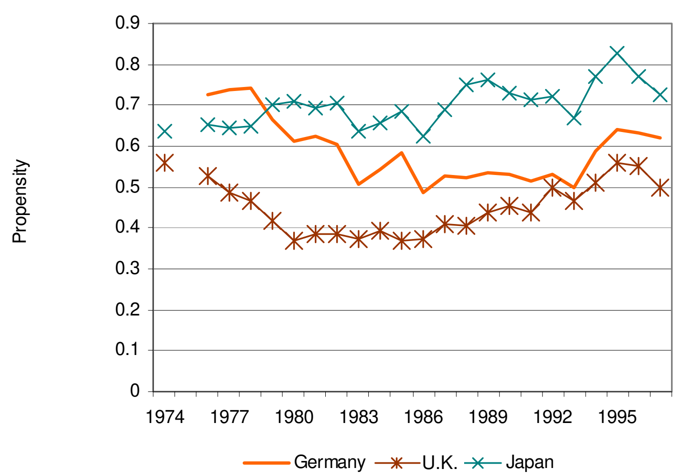
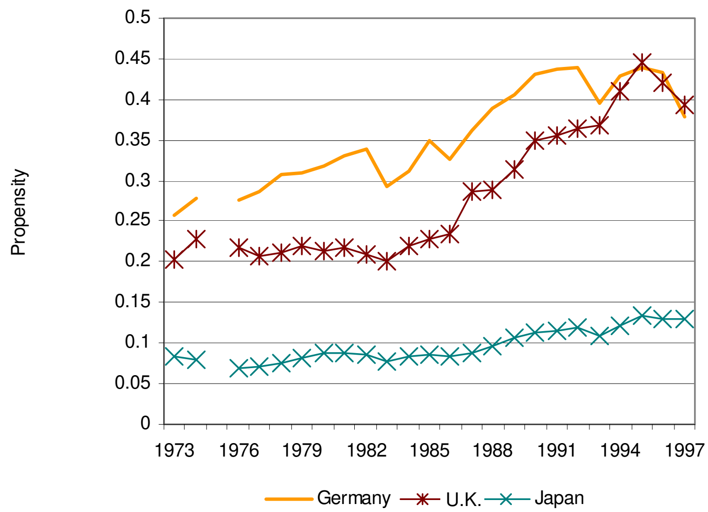


FIGURE 8

PROPENSITY TO PATENT IN THE UNITED STATES, RATIO OF APPLICATIONS IN THE UNITED STATES TO SOURCE COUNTRY PATENTS, 1973-97



LITERATURE REVIEW

WITH CHANGES IN THE U.S. PATENT REGIME providing a natural experiment, Kortum and Lerner (1998) set out to determine whether the recent rise in patenting into and out of the United States (Figures 3 and 4) can be attributed to pro-patent policy changes. If so, they hypothesize, the United States should have become an increasingly attractive destination for both domestic and foreign inventors, relative to other countries. They call this the "friendly court" hypothesis, in reference to the most prominent change, the creation (in 1982) of the Court of Appeals for the Federal Circuit (CAFC), which hears the appeals of all patent-related judicial decisions.[15] A related hypothesis, the "regulatory capture" hypothesis, explains the increased patenting activity by lobbying pressures from large firms. The "fertile technology" hypothesis explains the increase in patenting either by an expansion in the set of new patentable areas (e.g. biotechnology, software and business methods) or by an increase in the productivity of managing R&D that redirected research efforts toward more applied activities. According to Kortum and Lerner, the last hypothesis reflects changes that lie outside of the patent system.

Using aggregate data, they test a model similar to equation (5), where the destination and source countries, time and interaction effects are represented by a set of dummy variables. Based on evidence of a weak increase in foreign patenting in the United States relative to the increase by U.S. inventors at home and abroad, they reject the friendly court hypothesis. Also rejecting the regulatory capture hypothesis and the first part of the fertile technology hypothesis, Kortum and Lerner attribute the rise in U.S. patenting activity to a (primarily U.S.-based) productivity increase in the management of the R&D process that led to an increase or re-orientation toward applied research.

Kortum and Lerner's study provides an innovative analysis of patenting patterns into and out of the United States, but it raises some questions. In particular, the authors claim that the increase in U.S. patenting activity abroad is not consistent with the pro-patent hypothesis. However, as the expression in equation (5) implies, stronger patent rights may have induced more innovation in the United States, which may account for some of the increase in patenting abroad. (See also Hall and Ziedonis, 2001.)[16] Also, the *management* explanation, attributed to productivity effects outside of the patent system may, in fact, have been motivated by changes in patent policy.[17] As Hall and Ziedonis (2001) interpret the management hypothesis, firms may have harvested more of their R&D *output* (rather than redirected R&D *input* toward more applied research, as in Kortum and Lerner) in response to a more litigious environment brought about by a pro-patent regime.[18]

In their study on the semiconductor industry in the United States, Hall and Ziedonis (2001) argue that stronger patent rights have stimulated a *strategic* response: patenting to stave off costly litigation, especially for overlapping technologies that are common in this industry. Through detailed field interviews, they find that firms commonly accumulate portfolios of patents that are used as *bargaining chips* in cross-licensing agreements. Under the strategic view, patents are valuable assets that can be traded to avert costly court battles, rather than instruments for protecting one's investment against infringement, as under the traditional view. As a second hypothesis, they conjecture that strong patent rights facilitated vertical specialization by R&D-intensive entrants that contract out the manufacturing of their products.

Using firm-level data from the semiconductor industry, Hall and Ziedonis estimate a patent production function that relates patents to R&D and firm characteristics. Their model can be interpreted within the framework of equation (5) above, with the production function replacing N_i^* and the remaining explanatory variables corresponding to patent propensity. The latter variables are given by year dummy variables, which measure the growth of patent propensities over time that is not attributed to characteristics of the firm.[19] They find strong evidence of increased propensity to patent among manufacturing firms, although the specialized entrants appear to have also added significantly to the increase in patent propensity.

The Canadian experience is analyzed by Rafiquzzaman and Whewell (1998), who perform an analysis similar to Kortum and Lerner to examine the impact of policy changes that occurred over the past decade. As in Kortum and Lerner, they employ aggregate country patent counts and estimate a model based on Eaton and Kortum and similar to equation (5) above. Likewise, they control for the innovation effect with (aggregate) R&D in the source country. The remaining variables, which they attribute to the propensity to patent, include characteristics of the destination country and destination-source countries' effects. Rather than using year dummy variables to control for changes in patent policy, they include an index of patent strength in the destination country, which they find to be significant. They conclude that the sharp increase in patenting activity in Canada can be attributed to both the pro-patent hypothesis and the fertile technology hypothesis.

As an alternative to the approach in equation (5), the relationship in equation (6) has been estimated in several studies, with patents per unit of R&D as the endogenous variable [Scherer and Weisburst (1995), Arundel and Kabla (1998) and Hicks et al. (2001)]. In these studies, the strength of patent protection is found to impact significantly on the propensity to patent. Scherer and Weisburst (1995) find that the introduction of product patents for pharmaceuticals in Italy, while not generating more innovations, increased the propensity to patent abroad. Using survey data on European firms, Arundel and Kabla (1998) find that the propensity to patent is significantly higher among firms for which patents are effective instruments against infringement. Hicks et al. (2001) show that the propensity to patent in the United States between 1991-94 and 1995-98 increased by 70 percent in information technologies, but was stable for other technology categories which, they conjecture, may be explained by the strategic effect suggested by Hall and Ziedonis (2001).

Lessons from the Literature

As this brief review indicates, notable attempts have been made to disentangle the impact of policy changes from alternative explanations of the increase in patenting activity. Falling squarely under explanations attributed to patent reform would be more effective enforcement of patents and the extension of patentability to new classes of products. Less clear are hypotheses regarding changes in the management of the R&D process but, as Hall and Ziedonis (2001) insightfully note, a reorganization of the way in which firms conduct their R&D business may be attributed to changes in the patent regime. Arguably, a change in the *technical* production of R&D lies outside of the patent system but, even then, patents may play a role in facilitating licensing and alliances between research firms that permit them to re-orient their research toward more productive uses.[20] Not to consider this wider impact of patent changes would be to underestimate the role of policy, but crediting patent policy entirely with changes to the R&D process would grossly overestimate its impact.

With these lessons from the literature reviewed above, we proceed cautiously to our empirical analysis.

THE EMPIRICAL MODEL

WE ATTEMPT TO IDENTIFY THE VARIABLES that determine the propensity to patent, focusing on the Canadian experience. Our empirical model is based on equation (6) with a measure of patent propensity as the dependent variable, as in the second set of studies listed above. Because of data limitations, we employ aggregate country data, as in Kortum and Lerner (1998) and Rafiquzzaman and Whewell (1998), but for a larger number of countries over fewer time periods.

Our central hypothesis is related to Kortum and Lerner's *friendly court* and Hall and Ziedonis's *pro-patent* hypotheses that an increase in intellectual property rights in a destination country j impacts significantly on the propensity of source country i to patent in country j. We test this hypothesis with an empirical model based on the relationship depicted in equation (6) (taking logs and including the t subscripts), that is given by:

$$(7) \quad \log P_{ijt}/n_{it} = \alpha_0 + \beta s_{jt} + \gamma x_{jt} + \delta z_{ijt} + \eta c_{jt} + \alpha_t + \alpha_i + \alpha_{it} + \epsilon_{ijt}$$

where the dependent variable, P_{ijt}, is the number of patent applications filed in destination country j by source country i at time t; n_{it} is a proxy for N_{it} (either R&D or domestic patents); s_{jt} is the strength of patent protection in country j; x_{jt} is a set of variables describing the economic environment in country j; z_{ijt} are source-destination pair variables that may influence the decision to patent; and c_{jt} is the cost of filing a patent application in country j. Since we are particularly interested in explaining why countries may be attractive destinations for patenting, we include specific features of their environments rather than dummy variables as in Kortum and Lerner.

We also include time and source-country fixed effects, denoted by the α parameters. To capture idiosyncratic features of source countries, such as the level of patent protection and economic conditions that may influence the decision to patent abroad, we include α_i.[21] Global effects, such as international agreements bearing on patents, are captured by α_t. In some specifications, we include time-source country fixed effects to account for changes over time in the economic or legal environments of source countries that may impact on patenting decisions. Finally, ϵ_{ijt} is an error term.

We look to the estimated coefficient on s_{jt} for support of our central hypothesis. For this to be a persuasive test, we must be able to distinguish among the alternative hypotheses discussed above. First, consider a hypothesis related to Kortum and Lerner's *fertile technology* hypothesis, that the variation in patent propensity can be explained by changes in the productivity of the R&D process.

If the set of inventions patented abroad is a subset of inventions patented at home, then the second propensity measure (based on innovative output) will not be influenced by an increase in the productivity of the research process, either on the R&D input side [as in Kortum and Lerner (1998), or on the output side, as in Hall and Ziedonis (2001)].[22] However, a variant of Hall and Ziedonis's output hypothesis — that inventors have become more efficient at international patenting — might impact on the measure of this patent propensity. Since data are unavailable to estimate this effect, we simply include source country dummy variables, both by country and interacted with year effects.

A second alternative to the central hypothesis is that a change in the propensity to patent may be explained by policy changes in source countries. For example, as implied in equation (1) above, an increase in the economic value of patents in source country i may lower the *quality* of the marginal patent in country i (i.e. q_{ii}^* falls). But, if the quality level above which patenting is desirable in destination country j does not change, then the additional lower-quality patents in i will not be patented in j. Hence, the propensity to patent in country j, as given by the second propensity measure, may fall.[23] As noted earlier, the source-country and time-source-country dummy variables are used to control for these effects. Finally, global effects may alter patent propensities throughout the world. This may be attributed to international treaties or a reduction in the cost of patenting abroad, which we control for with year dummy variables.

Our study most closely resembles the aggregate analysis in Rafiquzzaman and Whewell (1998). As discussed in more detail in the next three sections, we extend their analysis in several directions. Most notably, we: (1) propose a second propensity measure, based on innovative output; (2) expand the set of destination variables to include a measure of antitrust strictness and ease of imitation in the destination country; and (3) evaluate the model for Canada. Lastly, using disaggregated industry patent and import data, we offer some insights on patenting activity in Canada by industrial sectors.

We now turn to the estimation results of the model corresponding to equation (7).

AGGREGATE ANALYSIS

EXPLANATORY VARIABLES

IN THIS SECTION, WE PRESENT THE ESTIMATION RESULTS for an empirical model based on equation (7). Our model contains several important explanatory variables, some of which are destination-specific (s_{jt}, c_{jt} and x_{jt}), while others correspond to source-destination pairs (z_{ijt}). We also include year and source-country dummy variables.

Country-specific Variables

As the central hypothesis highlights, countries that provide stronger protection of intellectual property should receive more patent applications; thus, there should be a positive relationship between the strength of patent protection (s_{jt}) and the propensity to patent.

The cost of obtaining patent protection in country j (c_{jt}) is also a determinant of the propensity to patent. We capture the cost effect in two ways. First, from Helfgott (1993), we classify countries according to whether their filing costs (the sum of application and agent's fees) are high, where we define high as above the mean level in 1992.[24] Second, as translation fees represent an important component of costs for foreign patentees, we include a dummy variable indicating whether translation is necessary, which will be the case when the source country and destination country do not share an official language. We expect these cost measures to be negatively related to the propensity to patent.

Next, we turn to additional destination-specific variables (x_j) which both our model and previous studies have shown to be important [Eaton and Kortum (1996) and Rafiquzzaman and Whewell (1998)]. Since larger markets are likely to be more attractive to foreign patentees, we include the log of the destination country's real GDP to control for market size.

A destination country with a highly educated population is expected to receive a higher share of patent applications, as such countries can more readily absorb or imitate technologies from abroad. We control for this by including a term based on the average number of years of schooling. Following Eaton and Kortum (1996), we use the negative reciprocal of the average number of years of schooling as our measure of human capital.[25]

A destination country that can easily imitate foreign technologies may be seen as a less desirable place in which to patent. Thus, while we expect destination country human capital to have a positive impact on the propensity to patent, we hypothesize that if imitation is a concern this positive effect should be driven largely by countries with strong patent rights. In contrast to Eaton and Kortum (1996), who posit the hazard of imitation simply as a function of destination country patent protection, we capture the threat of imitation by including an interaction term between destination patent strength and our measure of human capital. We hypothesize that if imitation is an important concern, specifications including this interaction should generate a negative coefficient on the human capital term and a positive coefficient on the interaction term.

Finally, the extent to which a destination country's antitrust policy constrains the ability of a patentee to exercise market power may influence the patenting decision. To capture this effect, we interact a measure of the strength of patent rights with a proxy for the effectiveness of antitrust policy in some specifications. We hypothesize that stronger patent rights increase the negative effect of antitrust policy on the propensity to patent, as patentees with stronger (e.g. broader) patents may be subject to closer scrutiny. The interaction of antitrust strictness with patent strength is thus expected to have a negative sign.

Destination and Source Country-specific Variables

Next, we turn to explanatory variables corresponding to specific pairs of source and destination countries (z_{ijt}). Exports from a source country to a destination country provide a mechanism for technology diffusion: trade in R&D-intensive intermediate goods helps diffuse technology internationally [Coe and Helpman (1995) and Eaton and Kortum (1996)]. We expect to see a positive relationship between the destination country's imports from the source country and the propensity to patent. We also explore a variant of this idea, based on findings by Maskus and Penubarti (1995) and Smith (1999) that a country's exports are influenced positively by the strength of patent rights in the importing country. Patents on technologies used with or embodied in highly-traded products are expected to be more valuable, the stronger is patent protection against imitation of those technologies. Therefore, the coefficient on the interaction term between destination country imports and patent strength is expected to be positive.

We control for the distance between the source and destination countries by including distance and distance squared terms to capture transportation and other distance-related transaction costs. Geographical features naturally act as barriers to the international diffusion of technologies (see also Eaton and Kortum, 1996).

Time and Country Fixed Effects

The explanatory variables discussed above are all specific to *j*, the destination country. Although we are primarily interested in these destination country-specific determinants of the propensity to patent, the framework discussed in the previous section suggests that source-country effects (such as the strength of domestic patent protection) may be important. To capture time-invariant source country-specific heterogeneity in the propensity to patent, we include source-country dummy variables in all of our specifications. In addition, globalization and participation in the General Agreement on Tariffs and Trade (GATT) and the TRIPs Agreement would imply an increase over time in the patenting activity abroad of all countries. To control for this, we also include year dummy variables. Lastly, we estimate specifications that include a full set of dummy variables for source country-time interactions to account for changing domestic patent policies or other economic changes.

DATA AND VARIABLE CONSTRUCTION

OUR AGGREGATE ANALYSIS COVERS 17 COUNTRIES: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States. We consider two ways of empirically measuring the propensity to patent. First, as discussed above, we could take the total amount of R&D performed domestically as a proxy for the country's innovative effort, and define a propensity measure as the number of patent applications filed in the foreign country per million dollars of domestic R&D (in the previous year).[26] We thus construct PROP1 = $P_{ijt}/\text{R\&D}_{it-1}$, where *i* indicates the source country and *j* the destination country. Alternatively, the propensity to patent is captured by the proportion of domestic applications that are also filed the following year in the (foreign) destination country. Our variable PROP2 = P_{ijt}/P_{it-1} corresponds to this definition.[27] If inventors in country *j* subsequently patent only a fraction of their inventions abroad, then PROP2 will vary between zero and one.[28]

Because our patent strength and human capital data are available only at five-year intervals, our study covers the years 1980, 1985, 1990 and 1995. Business expenditures on R&D (in U.S. dollars) are taken from the Organisation for Economic Co-operation and Development (OECD) ANBERD database, and are expressed in 1990 dollars. Patent application data are from the OECD *Basic Science and Technology Statistics* publications. GDP data are also from OECD publications. Bilateral trade data in U.S. dollars come from Robert C. Feenstra's *World Trade Flows, 1980-1997* database.

We use the Ginarte and Park (1997) index of patent rights (updated to include 1995, courtesy of Walter Park) to proxy for the strength of intellectual property rights (IPRs). The updated Barro-Lee dataset on educational attainment (discussed in Barro and Lee, 2000) contains average years of education at five-year intervals, which we use as our measure of human capital. Distances are in thousands of kilometres between capital cities and are taken from Fitzpatrick and Modlin (1986). As indicated above, we use as a cost measure Helfgott's (1993) estimates of the total costs involved in obtaining patent protection. The index of antitrust policy is taken from the 1994 issue of the *World Competitiveness Report*, and is the product of a survey of a large sample of managers in each country.[29] We were able to obtain these data for only one year, so we assume the values are constant across time periods for each country.

EMPIRICAL RESULTS

TABLE 1 PRESENTS SUMMARY STATISTICS for the primary variables of interest. As discussed above, some of the values correspond to source or destination countries, while others relate to a pair of source-destination countries (for a given year). The average source country conducts $12.6 billion of business

TABLE 1

SUMMARY STATISTICS

VARIABLES	NUMBER	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM
PROP1	1,017	0.409	0.812	0.006	12.718
PROP2	1,121	0.259	0.27	0.001	1.41
Real R&D Expenditures	1,020	12,591.1	23,889.73	319.066	108,395.6
Distance	1,088	4.736	5.063	0.174	17.58
High Cost	1,156	0.294	0.456	0	1
Translation Required	1,156	0.824	0.381	0	1
IPR Index	1,156	3.752	0.431	2.76	4.86
Human Capital	1,156	8.922	1.615	5.15	12.18
Real GDP	1,156	881,115.3	1,270,844	90,014.9	6,149,520
Imports/GDP	1,088	0.012	0.022	0	0.221
Exports to Low IPR/GDP Countries	1,156	0.007	0.004	0.002	0.019
Antitrust Index	1,156	6.102	0.876	4.1	7.45

R&D per year. Because of the variability of R&D expenditures, PROP1 has a larger variance than PROP2. Approximately 26 percent of a country's domestic patent applications are also filed abroad. The mean distance between source and destination countries is over 4,700 kilometres. About 30 percent of our observations are from countries with high filing costs, while 82 percent of source-destination pairs require translation of the patent application. The imports/GDP ratio for a given source-destination pair is 1.2 percent on average.

Table 2 reports regression coefficients for our base specification using both log(PROP1) and log(PROP2) as the dependent variable. Robust standard errors are used to account for heteroscedasticity of an unknown variety. The specification in column (1) explains almost 80 percent of the variation in the propensity to patent. The signs of our variables of interest are as hypothesized. An increase of 0.1 points in the patent strength index for a destination country increases the propensity to patent by approximately 4 percent. The import term is also positive and significant, although small in impact: an increase in country *j*'s imports from country *i* (normalized by *j*'s GDP) of 10 percent raises *i*'s propensity to patent by 2 percent. Our control variables are also signed as expected and significant. The propensity to patent is decreasing with distance and cost (including both filing and translation costs) and increasing with destination market size and level of education. Because this specification includes observations for which the source and destination countries are the same, a dummy variable was included. Not surprisingly, the coefficient is positive, suggesting that more patenting takes place in the home country. [Eaton and Kortum (1996) and Rafiquzzaman and Whewell (1998) present a similar finding.]

TABLE 2

REGRESSION ESTIMATES: COMPARISON OF DEPENDENT VARIABLES

INDEPENDENT VARIABLES	(1) LOG(PROP1)	(2) LOG(PROP2)
Constant	–6.713***	–9.258***
	(0.331)	(0.298)
Distance	–0.073**	–0.079***
	(0.035)	(0.026)
Distance Squared	0.003*	0.004***
	(0.002)	(0.001)
High Cost	–0.154***	–0.209***
	(0.052)	(0.049)
Translation Required	–0.199***	–0.182***
	(0.042)	(0.037)
IPR Strength	0.414***	0.481***
	(0.045)	(0.042)
–1/(Human Capital)	2.184**	2.586***
	(0.947)	(0.827)
Log(GDP)	0.486***	0.487***
	(0.019)	(0.018)
Log(Imports/GDP)	0.201***	0.178***
	(0.038)	(0.030)
Dummy Variable (Source=Destination)	0.657***	
	(0.173)	
N	1,017	1,052
R^2	0.792	0.862

Notes: Robust standard errors appear in parentheses.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
Regressions include year and source-country dummy variables.

The coefficients in column (2) for PROP2 are quite similar in magnitude and significance, although the data used for estimation are slightly different: here, observations for which the source country is the same as the destination country are dropped. Even so, the similarity suggests that we can restrict our attention to one dependent variable without substantial loss of generality. Accordingly, for the remaining specifications we report only the results corresponding to the use of PROP2 in our dependent variable. Column (2) will be referred to as our *base* specification.

Table 3 presents results of our main hypothesis tests. In column (1), we add the proxy for the threat of imitation, the interaction between destination country human capital and patent rights. The results do not confirm our hypothesized imitation relationship. In fact, human capital influences patent propensity positively when patent rights are weak, and has a decreasing effect with

TABLE 3

HYPOTHESIS TESTING: DEPENDENT VARIABLE LOG(PROP2)

INDEPENDENT VARIABLES	(1)	(2)	(3)	(4)
Constant	–5.700***	–11.072***	–11.958***	–9.906***
	(0.631)	(0.639)	(1.514)	(0.659)
Distance	–0.080***	–0.096***	–0.088***	–0.240*
	(0.025)	(0.027)	(0.026)	(0.141)
Distance Squared	0.004***	0.004***	0.004***	0.011*
	(0.001)	(0.001)	(0.001)	(0.007)
High Cost	–0.160***	–0.173***	–0.205***	–0.205***
	(0.050)	(0.051)	(0.051)	(0.051)
Translation Required	–0.181***	–0.191***	–0.149***	–0.303***
	(0.036)	(0.038)	(0.040)	(0.113)
IPR Strength	–0.458***	0.949***	1.326***	0.492***
	(0.151)	(0.151)	(0.380)	(0.044)
–1/(Human Capital)	35.105***	3.295***	4.783***	4.214**
	(5.398)	(0.873)	(1.038)	(1.657)
Log(GDP)	0.487***	0.497***	0.503***	0.471***
	(0.018)	(0.019)	(0.020)	(0.022)
Log(Imports/GDP)	0.173***	–0.151	0.180***	–0.070
	(0.030)	(0.108)	(0.031)	(0.214)
–1/(Human Capital)*IPR	–8.612***			
	(1.374)			
Log(Imports/GDP)*IPR		0.084***		
		(0.026)		
Antitrust Stringency			0.445*	
			(0.234)	
Antitrust Stringency*IPR			–0.135**	
			(0.058)	
R^2	0.866	0.863	0.864	0.851
Chi-square Statistic				0.17

Notes: Number of observations = 1,052. Robust standard errors appear in parentheses.
Columns (1) through (3) are estimated by the ordinary least squares (OLS) method; column (4) is estimated by instrumental variables (IV).
All regressions include year and source-country dummy variables.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
Column (4) reports the results of a Hausman specification test; the test statistic is a distributed chi-square with 26 degrees of freedom.

stronger patent rights. This suggests that the channel through which imitation might operate is subtler than our proposed mechanism.[30]

In column (2) we further investigate our finding that imports have a positive effect on the propensity to patent, which previous studies have failed to find. [See, for example, Eaton and Kortum (1996) and Rafiquzzaman and Whewell (1998).] When the interaction between imports and patent strength is included, we find that as hypothesized the interaction term is positive while the import term is insignificant. To the extent that imports embody new technologies (Coe and Helpman, 1995), a larger amount of trade to the destination country enhances the value of strong patent rights.

Column (3) presents a specification incorporating our index of the effectiveness of antitrust policy. While the other coefficients remain essentially unchanged from the base specification, the interaction between antitrust and patent rights yields our anticipated result. This negative coefficient can be given the following interpretation: a foreign firm is better able to exploit strong patent rights when antitrust is relatively weak, since its potentially strong market position is less likely to be actively scrutinized.

In column (4) of Table 3 we address a potential concern with our specification of the basic patent equation, namely the possibility that imports are determined endogenously with patenting activity. For instance, random shocks to the error term of the propensity to patent equation may also affect the amount of imports into the destination country (as, for example, if the same foreign firms are responsible for filing patent applications and for exporting goods). Then, the coefficient on imports would be biased and inconsistent. To attempt to address this possibility, we adopt an instrumental variables (IV) approach. The gravity model of international trade (e.g. Bergstrand, 1989) posits that bilateral trade is a function of source and destination countries' incomes and populations, as well as other factors. Therefore, the logarithm of source country population might qualify as a suitable instrument, as it is likely correlated with trade, but uncorrelated with disturbances to the patent propensity equation.

The results of the IV regression suggest that when this potential endogeneity is accounted for, imports are not an important predictor of international patenting, as the coefficient is not significantly different from zero. However, most of the other coefficients remain relatively precisely estimated, and comparable to the estimates in column (2) of Table 2. This lack of significance parallels similar results in Eaton and Kortum (1996) and in Rafiquzzaman and Whewell (1998). Whereas these studies found imports to be insignificant in OLS regressions, we find that this can only be established if endogeneity is believed to be a serious problem. In fact, a Hausman test does not allow us to reject the null hypothesis that the OLS specification is consistent, so we retain column (2) of Table 2 as our base set of estimates, and thus the finding that imports appear to help predict the propensity to patent.

ROBUSTNESS TESTS

WE PERFORM A VARIETY OF ADDITIONAL ROBUSTNESS TESTS on our base specification, a selection of which are reported in Table 4. To control for the possibility that source country characteristics might be changing over time (and thus not be adequately captured by source country dummy variables), we include in

TABLE 4

ROBUSTNESS TESTS

INDEPENDENT VARIABLES	(1) OLS[1] LOG(PROP2)	(2) WLS[2] LOG[PROP2/(1–PROP2)]
Constant	–9.601***	–9.162***
	(0.316)	(0.264)
Distance	–0.082***	–0.111***
	(0.025)	(0.021)
Distance Squared	0.004***	0.004***
	(0.001)	(0.001)
High Cost	–0.210***	–0.121***
	(0.049)	(0.032)
Translation Required	–0.184***	–0.083**
	(0.037)	(0.039)
IPR Strength	0.486***	0.509***
	(0.041)	(0.036)
–1/(Human Capital)	2.618***	2.816***
	(0.799)	(0.584)
Log(GDP)	0.486***	0.512***
	(0.017)	(0.013)
Log(Imports/GDP)	0.173***	0.140***
	(0.029)	(0.028)
Year Dummies	Yes	Yes
Source Country Dummies	Yes	Yes
Year*Source Country Dummies	Yes	No
N	1,052	1,040
R^2	0.875	0.887

Notes: [1] OLS: Ordinary least squares method.
[2] WLS: Weighted least squares method.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

equation (1) a full set of source country-year interaction dummy variables. While these improve the fit of the equation somewhat, the other estimated coefficients remain almost exactly the same as in the base regression. As an alternative control for time-variant source country characteristics, we estimate an (unreported) specification including source country per-capita real R&D expenditures (in the previous year) and find that while the R&D coefficient is positive and significant, the other coefficients are essentially unchanged.[31]

As an additional test of our specification, we exploit the fact that PROP2 is theoretically a proportional measure and varies between zero and one. We estimate in column (2) a logit model for grouped data; again, the coefficients are found to be significant in the same pattern as specification (2) of Table 2.[32]

APPLYING THE MODEL TO CANADA

THE PREVIOUS SECTION'S RESULTS ESTABLISH that equation (2) of Table 2 provides a fairly robust explanation of international patenting activity patterns. However, these results reflect data from all 17 countries. In this section, we briefly examine how well the predictions of the empirical model apply to Canada, exploring in particular some of the model's properties when attention is restricted to Canada as a destination country.

Figure 9 plots the difference between actual and predicted propensities to patent from specification (1) as a function of time, with Canada as the destination country, for each of the five primary technology-exporting countries. This graph strongly suggests that as a destination, Canada's characteristics have changed over time in ways that our regression model does not entirely capture. It appears that the model initially under-predicts the propensity of each of these countries to patent in Canada, while over time this under-prediction disappears; for the United States, Germany and France, there is a high degree of over-prediction by the final year of the sample. Thus, by 1995, it seems that factors which accurately predict patent flows for the full set of countries in the aggregate tend to overestimate the propensity of foreign inventors to patent in Canada.

FIGURE 9

RESIDUALS WITH CANADA AS DESTINATION COUNTRY, 1980-95

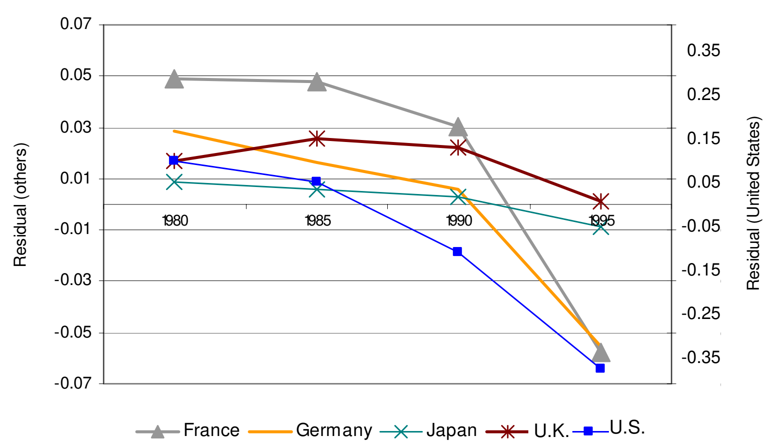


FIGURE 10

PROPENSITY TO PATENT, GERMANY, 1990-1995

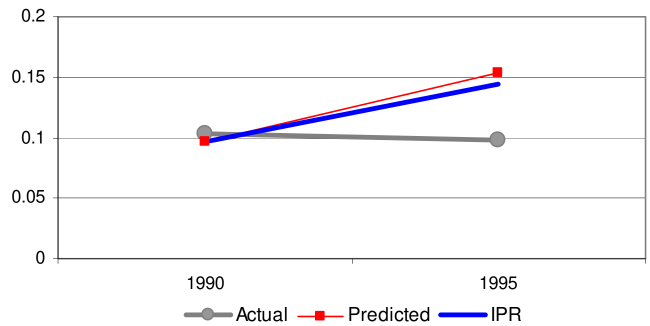


FIGURE 11

PROPENSITY TO PATENT, UNITED KINGDOM, 1990-1995

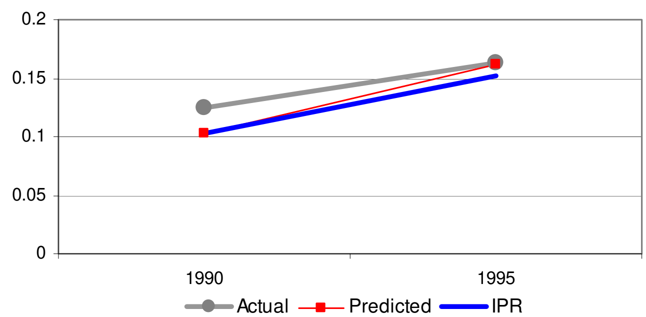
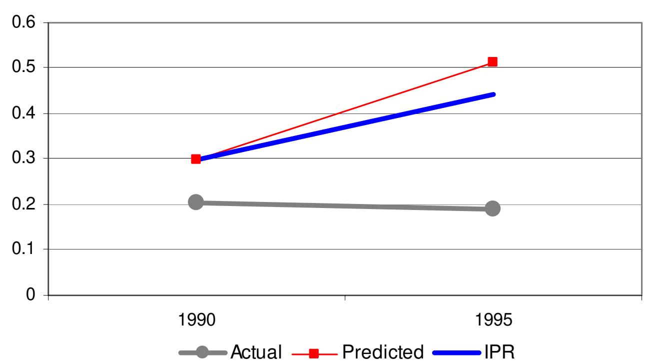


FIGURE 12

PROPENSITY TO PATENT, UNITED STATES, 1990-1995



Why might this be the case? Figures 10-12 plot actual and predicted propensities to patent for Germany, the United Kingdom and the United States. The figures also show the contribution of patent rights to the change in the predicted propensity, holding all other factors constant at their 1990 levels. The Ginarte and Park data indicate that Canada's score on the patent rights index increased from 2.76 prior to 1995 to 3.57 in 1995. The index increases in Canada's case due to the enhanced patentability of pharmaceuticals, and Canada's participation to the Patent Cooperation Treaty (simplifying administrative procedures) and to the International Convention for the Protection of New Varieties of Plants (allowing for plant breeders' rights). Therefore, according to that index, Canada was providing significantly stronger protection of intellectual property rights in 1995 than previously. Our regression estimates suggest that this should have a major impact on foreign patent applications in Canada. Specifically, holding other factors constant, the propensity for each source country to patent in Canada should increase by $\exp[(3.57–2.76)*0.481]–1 = 47.6$ percent.

As presented in Figures 10-12, the predicted propensities to patent in Canada indeed increased from 1990 to 1995 for these countries, with the change in the patent strength index accounting for the majority of the increase. However, in unreported plots of the eight most active patenting countries in Canada in 1995, five countries exhibited either a decrease or no significant change in the *actual* propensity to patent in Canada between 1990 and 1995. Because our predicted propensities are largely driven by the change in the patent strength index, these results suggest that the index may be overstating the degree of change in intellectual property protection, at least for Canada.

This over-prediction may be attributed to two types of aggregation in our analysis. First, the data are aggregated across industries. This may confound potentially significant industry-specific responses to patent policy, or systematic changes in the industrial composition toward low- or high-propensity industries. Second, the patent strength index is a broad combination of regime changes that occurred contemporaneously in Canada, some of which may not be as important as the weights imply, either in the aggregate or for particular industries. These suggestive findings motivate our analysis in the following section in which we disaggregate patenting activity by industry and offer some speculations on the importance of industry-level changes in patent policy.

INDUSTRY-LEVEL ANALYSIS

IN THIS SECTION, WE APPLY THE FRAMEWORK developed in the second section to data disaggregated by industry in order to determine whether patent policy may have differential effects across technologies in Canada, as documented in previous studies for the United States based on survey data (e.g. Cohen, Nelson and Walsh, 2000).[33] Estimates of the distribution of patent value at the industry level likewise suggest a considerable amount of heterogeneity among industries [e.g. Lanjouw (1998) and Schankerman (1998)], although these studies do not take account of industry-specific economic activity or other variables that might affect patent value. In our model, we control for the level of industry economic activity, measured by industry imports, to isolate differences in the propensity to patent across manufacturing industries.

Following the reduced-form specification discussed in the previous sections, we estimate the propensity to patent as a function of year, source-country and industry effects, and industry imports. For this estimation, we need to construct measures of the propensity to patent at the industry level. This is a challenging task, since patents are not classified by industry, but rather by field of technology. Because industries are both sources and users of many types of technology, there is no good one-to-one map from patent counts (which are classified by technology type) to industry. One approach to this problem has been to construct a probabilistic *concordance* among industries and technologies. The most widely used of these concordances is based on data originally collected in Canada, which for many years classified its patents by technology, industry of origin and industry of use.

The concordance has also been applied to other countries, but its usefulness may be limited by unobserved differences in the joint distribution of industries and technologies between Canada and other countries. Kortum and Putnam (1997) offer alternative means of constructing a concordance based on Canadian data and test the stability of such concordance by source country and time period.[34] We employ the Johnson-Evenson data to construct estimates of the propensity to patent in Canada at the industry level for patents originating from four countries: the United States, France, the United Kingdom and Germany. The data are then aggregated to the approximately 2½-digit level of the International Standard Industrial Classification in order to match them to standard industry-level trade data.

Not surprisingly, the data have some significant limitations. First, patent grants (rather than applications) are observed. This implies that propensity measures can only be approximately correct, since we cannot ascertain the exact application dates in the source and destination countries.[35] Also, as Rafiquzzaman (1999) points out, Canadian patent grants have fallen dramatically over our sample period, both absolutely and relative to applications. While we can control for this to some extent by using year dummy variables, we do not know whether the use of grant data involves any additional biases.[36] Second, the Johnson-Evenson data do not permit propensities to be constructed prior to 1993, which limits our ability to directly address the reforms adopted from 1989 to 1992. We can, however, describe cross-sectional variation at the industry level and, by constructing two cohorts (for 1993 and 1995), increase the efficiency of the estimation.

TABLE 5

ANALYSIS OF VARIANCE: INDUSTRY DATA

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	F–TEST STATISTIC	P–VALUE
Year	0.072	1	42.70	0.000
Country	0.072	3	14.11	0.000
Industry	0.174	16	6.42	0.000
Model	0.317	20	9.39	0.000
Residual	0.194			
Total	0.512			
R^2	0.620			

Notes: Number of observations = 136.
The dependent variable is the number of patents granted in Canada divided by the number of patents granted in the source country.

The analysis of variance results in Table 5 show that, as one might expect, industry-level variation dominates source country variation in patenting propensity, accounting for one-third of the total sum of squares. Interestingly, cohort effects figure as prominently as source-country effects in this sample, which likely reflects the sharp drop in the number of Canadian patents granted between the two periods.

In addition to the variables used in the analysis of variance, we obtained data on industry-level Canadian imports from each source country. To isolate the effects of industry economic activity on the rate of patenting, we regress the propensity to patent on the level of industry imports into Canada, in addition to source-, year- and industry-level dummy variables. Because the propensity to patent is a proportional measure, we use logit estimation for grouped data. The dependent variable is thus the log of the odds ratio. The results are shown in Table 6.[37]

As in the aggregate analysis presented in the third section, we find that the level of imports significantly affects the propensity to patent. The U.S. dummy variable is negative, suggesting that the U.S. propensity to patent in Canada is lower than that of France (the omitted country), controlling for other factors.[38] Among European exporters, inventors from the United Kingdom patent relatively more frequently in Canada, while those from Germany patent relatively less frequently, than those from France, holding the level of imports constant. This ranking corresponds to the degree of language similarity between these countries and Canada, and reflects, in part, the cost of translation, shown to be a significant predictor of the propensity to patent in the aggregate analysis. Since we focus on a single destination country, all such pairwise-specific terms (e.g. distance and language) are absorbed into the source country intercepts.

TABLE 6

WLS LOGIT ESTIMATES: INDUSTRY DATA

INDEPENDENT VARIABLES	(1)
Constant	–3.484***
	(0.346)
Log(Imports)	0.323***
	(0.112)
Year 1995	–0.707***
	(0.048)
Germany	–0.667***
	(0.134)
United Kingdom	0.267**
	(0.129)
United States	–1.005**
	(0.442)
Electrical and Electronics	–0.694**
	(0.349)
Chemicals	–0.073
	(0.257)
Drugs	0.323
	(0.198)
Petroleum	0.838*
	(0.432)
Transportation	–0.932**
	(0.410)
Rubber and Plastics	–0.115
	(0.407)
Non-ferrous Metals	0.168
	(0.479)
Fabricated Metals	–0.224
	(0.213)
Instruments	–0.001
	(0.194)
Other Machinery	–0.739**
	(0.372)
Food	1.221***
	(0.272)
Textiles	0.388*
	(0.230)
Rubber and Plastics	–0.118
	(0.223)
Non-metallic Minerals	0.046
	(0.264)

TABLE 6 (CONT'D)

WLS LOGIT ESTIMATES: INDUSTRY DATA

INDEPENDENT VARIABLES	(1)
Paper	–0.044
	(0.283)
Wood	0.013
	(0.269)
R^2	0.772

Notes: Number of observations = 136.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
Standard errors appear in parentheses.
The dependent variable is *log[p'/(1–p')]*, where *p*' indicates the number of patents granted in Canada as a proportion of the number of patents granted in the source country.

Unsurprisingly, the rate of patenting varies substantially across industries; an F-test decisively rejects the equality of intercepts across industries. Several of the individual coefficients are also significant and can be given intuitive interpretations. In most countries, one might expect that the rate of patenting in the pharmaceutical industry is higher than in other industries. Our estimated pharmaceutical coefficient shows that indeed, immediately after Canada repealed compulsory licensing, the rate of foreign pharmaceutical patenting was higher than average, although the standard error of the estimate is large. However, this policy change did not affect other important determinants of the value of pharmaceutical patents, such as the precision with which pharmaceutical claims are specified in chemical formulae, or regulatory barriers to entry that retard the ability of imitators to invent around the patent. In this sense, the relatively large pharmaceutical fixed effect is likely not due to the regime change but rather to the technological and regulatory features inherent in pharmaceutical inventions.

Among other industries, the results show much higher than average patenting for petroleum, food and textile inventions, perhaps reflecting Canada's comparative advantage in resource-based industries. It should be noted that our reduced-form model and data cannot distinguish the *supply side* effects of relatively high imitation by domestic Canadian firms, from the *demand side* attributes like relatively inelastic demand for patented products in industries such as pharmaceuticals where these effects are relevant. At the other end of the spectrum, the electrical and electronics industry exhibits a relatively low rate of patenting, probably reflecting the relatively rapid rate of technological obsolescence. The "other machinery" industry, which encompasses mechanical inventions that are relatively easy to imitate, and transportation also exhibit relatively low propensities.[39]

The primary finding of this section is the considerable degree of heterogeneity among industries in their propensity to patent in Canada. This heterogeneity illustrates the inherent difficulty in assuming that the efficacy of patent rights is the same across industries (as in the aggregate analysis). Apart from the fact that patent reform may target industry-specific practices, such as compulsory licensing, the factors that influence the value of patents may vary across industries along a number of other dimensions. Among these are technology (e.g. the ease of specifying claims), industry practices (e.g. established licensing practices) and unrelated regulatory requirements (e.g. pharmaceutical safety and efficacy).

Thus, although the results presented in the section entitled *Aggregate Analysis* indicate that the strength of patent protection positively influences the propensity to patent in the aggregate, this section suggests that, at a more micro level, a multinational firm's decision to patent abroad must incorporate a richer set of determinants. These results accord with our conjecture in the section entitled *Applying the Model to Canada* that industry effects may account for the aggregate model's weak performance with Canada as the destination country. Even if a broad index of patent strength accurately reflects IPR policy, a trend in the industrial composition of patenting away from high-propensity industries could dominate the patent strength effect. Providing accurate empirical evidence of such trends remains an important task for future research.

CONCLUSIONS

IN THIS STUDY, WE HAVE ATTEMPTED TO DETERMINE whether a causal link exists between the 1989 patent reforms in Canada and the acceleration in foreign patenting activity over the past decade. By focussing on the propensity to patent, we control for the possibility that increased foreign innovation, unrelated to Canadian policy changes, may be the driving force behind the recent surge in patenting.

The study is only a first step in carrying out this objective. Although the data used are primarily at the aggregate level, we have been able to make some new observations. Most striking is the robust significance of patent strength in explaining a source country's propensity to patent in a destination country, especially when the latter's antitrust laws are weak or trade flows with the source country are large.

While the model has a good fit overall, it over-predicts the propensity to patent in Canada following the most recent patent reforms. A second analysis, employing disaggregated patent and import data for 17 industrial sectors in Canada, provides evidence that the over-prediction is likely attributed to heterogeneity in the value of patenting across industries. An extended time series and data on a wider set of explanatory variables (as in the aggregate analysis) would allow for a richer exploration of these sectoral responses to changes in patent protection.

In such an analysis, it would be useful to consider separately the influence of the various policy changes, rather than to package them into a composite index, as in the aggregate analysis.[40] As noted earlier, the effect of individual policy changes may vary across industries (e.g. strengthening plant breeders' rights is not likely to have much significance in the electronics industry). Moreover, if policy changes have *opposing* effects on patent protection, an index may yield biased results. For example, if two such reforms are weighted equally, the level of the composite index may stay constant but the joint impact may result in an increase in the number of patents observed.[41] So, if the respective effects of policy changes cannot be identified in the data (perhaps because they occurred simultaneously, or because theoretical predictions on their joint effect are ambiguous), one may incorrectly under-estimate the role that policy may play in influencing patent decisions.

Some studies have examined empirically the impact of isolated policy changes; for example, conversion to multi-claim patents in Japan (Sakakibara and Branstetter, 2001) and the granting of product patents in Italy (Scherer and Weisburst, 1995). Where policy changes occur contemporaneously, as they did in Canada, or where the impact of a policy is not obvious, we must turn to economic theory for guidance.

Unfortunately, testable predictions are not always evident, especially when innovation is cumulative. For example, a strengthening of patents, defined by a broadening of patent scope, may: (1) reduce innovation if early inventors can *hold-up* later researchers [Merges and Nelson (1990) and Bessen and Maskin (2000)]; (2) incite costly litigation, thus lowering the economic value of patents [Lanjouw (1994), Lerner (1995) and Lanjouw and Schankerman (2001)]; or (3) facilitate coordination of future research if contracting over R&D is possible, increasing the likelihood that subsequent research will be developed (Green and Scotchmer, 1995). In an ambitious empirical study, Lerner (2001) collects these results and hypothesizes an inverted U-shaped relationship between patent strength and patenting activity. Categorizing 177 policy changes over 150 years in 60 countries into those that clearly strengthen, clearly weaken, and have an ambiguous effect on patent strength, he tests his hypothesis and finds that strengthening patents increases patenting activity if patents are initially weak, and reduces patenting if protection is initially strong. As the study by Hall and Ziedonis (2001), Lerner's analysis is particularly valuable in linking together theoretical results and empirical testing.

The time is ripe for continuing this trend, especially given the growing theoretical literature on specific patent reforms [e.g. conversion to first-to-file from first-to-invent (Scotchmer and Green, 1990), public disclosure of patent applications (Aoki and Spiegel, 1998) and changes in the standards for patentability (O'Donoghue, 1998)]. Attaining a better empirical understanding of these aspects of patent policy would undoubtedly lead to further theoretical refinements, and more importantly would provide some guidance to policy-makers regarding the practical decisions that must be made.

ENDNOTES

1 Patent strength is not a clearly defined concept in the literature. Economists would consider a change in policy as having strengthened patents if it increased the value of patents. Three instruments of the patent system that can affect the value of patents are: the standards for patentability (novelty, non-obviousness), the scope of a patent and enforcement of a patent against infringement. Generally, whether patents are *strong* (higher-valued) depends on a mix of policies offered both ex ante (via patentability standards) and ex post (via enforceability in court). Although it seems plausible that an increase in (or broadening of) any of the three patent components will make patents more valuable, this may not necessarily be the case especially in a cumulative context, as cautioned by the recent theoretical works (e.g. Green and Scotchmer, 1995). See the last section for further discussion of this point.

2 For example, in a study of patent reform in Japan, Sakakibara and Branstetter (2001) show that the addition of multiple-claim patents to the prior *single-claim-only* regime in Japan did not result in any perceptible increase in innovation. Baldwin, Hanel and Sabourin (2000) find only a weak relationship between innovation and the effectiveness of patents. Bessen and Maskin (2000) show that the extension of patent protection to software has not induced an increase in R&D relative to sales in the United States. Kortum and Lerner (1998) identify an increase in innovative output, as measured by patents, but do not attribute this increase to the reforms. Jaffe (2000) rejects the hypothesis that the increase in patenting is attributed to increased R&D investment since the significant increases in R&D occurred prior to the reforms.

3 Several studies have examined more generally the determinants of innovation in Canada. See, for example, Baldwin, Hanel and Sabourin (2000), Tepperman (2001a), Baldwin (1997), Baldwin and Da Pont (1996) and Caves, Porter, Spence and Scott (1980).

4 See Binkley (1998) for further discussion of the Canadian patent system.

5 As Lerner (2001) suggests, if a country's market is modest relative to an invention's total market (as the Canadian market is likely to be for many countries), then changes in patent protection in that country are not likely to guide a foreign inventor's research agenda. However, they may very well alter incentives to seek patent protection in Canada, which is captured by the propensity to patent.

6 By "patentable" we mean inventions whose subject matter is patentable and that satisfy patentability standards. The latter typically include novelty, non-obviousness and usefulness. Research may also be conducted on non-patentable projects, which may include some forms of basic research, as well as development and other types of technical know-how. For simplicity, we treat the benefits and costs of these two research programs as separable and focus only on the former type of research.

7 In reality, the set of patentable subject matter and the standards for patentability may not be the same in both jurisdictions. For example, business methods are patentable in the United States but not in Canada. This assumption is made for convenience; relaxing it would not alter the qualitative results.

8 Note that the value of patenting does not depend on characteristics of country i, except through interaction terms. However, this would not be the case if some of the assumptions of the model were relaxed, as is explained below.

9 For example, if patent protection is strong, firms may be more inclined to enforce their rights; thus, the return from not patenting may be less than if patents are weak.

10 We adopt the simplifying assumption that costs are independent across countries. In reality, the applicant may incur fixed costs of filing a patent application (regardless of the number of countries in which protection is sought), along with an incremental cost for each additional country. This cost structure induces dependence in the decision to file across countries. The effects of introducing this dependence on the applicant's filing decisions are examined in Putnam (1996).

11 We use "secrecy" as short-hand for non-disclosure of the patented invention in country j. Obviously, if the inventor draws a q greater than the minimum required to justify filing in the home country, the initial decision to seek patent protection at home destroys secrecy worldwide.

12 This may not always be true. For example, in some years the number of patent applications filed in the United States by Canadian researchers exceeded the number of patent applications they filed in Canada.

13 In a more elaborate model, the coefficient on s (ignoring subscripts) in the propensity relationship may also reflect an *innovation effect*, but of a different type than noted above. That is, ρ may depend on N if firms can direct their research toward projects that have a higher chance of being patented (e.g. because it is more likely to pass the novelty requirement or to satisfy the cut-off quality). To see this, suppose that the firm faces a three-stage decision: first, it chooses total patentable inventions, N; second, it chooses λ, the proportion of projects that will be patented with probability 1; third, for the $1-\lambda$ projects with random quality, it decides whether to patent, after observing quality. Then, the solution to the firm's maximization problem will yield an expected number of patents equal to $N(s)[\lambda(s) + (1-\lambda(s)]\rho(s)$ implying that when patent strength, s, increases, more of the uncertain projects may be patented; the mix of projects may change toward a larger proportion of certain projects; and the total number of inventions may increase. The propensity in this case will be $\lambda(s) + [1-\lambda(s)]\rho(s)$, which reflects an innovation effect attributed to a change in the mix of research projects toward patented ones, as well as a propensity effect (as before) in which a smaller proportion of

uncertain projects are kept secret due to a reduction in the cut-off quality. Then, the coefficient on s in a regression based on equation (5) would reflect the three effects on innovative output, mix of research projects and propensity.

14 In reality, the inventions patented in country j may not be a subset of those patented in country i.

15 Among the other changes were: an expansion in the set of patentable products to include life forms (1980), software (1978-84) and business methods (1996); and the enactment in 1984 of the *Bayh-Dole Act* (which gave universities and non-profit institutions title to patents on inventions made with the use of public funds). See also Merges (1997) and Jaffe (2000) for a discussion of the changes. Jaffe (2000) reports that, after the creation of the CAFC, the proportion of cases that resulted in a finding of infringement and validity rose from 62 percent to 90 percent.

16 Solving for N_i* from equation (2) and differentiating with respect to s_j reveals that under reasonable conditions, $\partial N_i/\partial s_j > 0$; that is, a strengthening of patent rights increases innovative output. In a context of cumulative innovation, this may not be true, as discussed in more detail in the last section. Whether this relationship holds empirically has been the subject of a great deal of research. Sakakibara and Branstetter (2001) hypothesize that if the reforms in Japan had resulted in more innovation, some may have appeared in the United States in the form of increased patenting. But, after adjusting patent counts for quality, they find no evidence to support that hypothesis.

17 For example, the management explanation is consistent with a pro-patent hypothesis in the extension of the model described in note 13.

18 If firms are harvesting more of their marginal patents, then a reduction in quality would be expected. Hall and Ziedonis (2001) test this hypothesis against no change that would be consistent with Kortum and Lerner's input interpretation of the hypothesis. Note that this prediction is consistent with the framework in equation (1) above; in particular, if $\partial v_p/\partial s_j > 0$ and $\partial v_n/\partial s_j < 0$, then the quality cut-off, q_{ij}*, will fall. They find only weak support for that hypothesis, although they emphasize that quality is measured with error.

19 Sakakibara and Branstetter (2001) model the relationship between patent applications and patent reforms in Japan, particularly the conversion from single-claim to multiple-claim patents. Like Hall and Ziedonis (2001), they estimate a patent production function and, in addition to variables that enter the production function, they include year dummy variables to measure the impact of the reforms. However, they interpret the latter parameters as growth in innovative output rather than growth in the propensity to patent, as in Hall and Ziedonis (2001). Their study is thus more about the response of innovation than of patent propensity to changes in the patent regime. Lerner (2001) also estimates the impact of the patent system on innovation by examining 177 policy changes in 60 countries over a 150-year period. The propensity to patent is assumed to be stable, in which case patenting activity is a reasonable proxy for innovation. Lerner finds that a strengthening of patent protection has a stronger impact on patenting activity by foreign inventors than by residents of the country undergoing the change.

20 For example, see Merges (1998), Tepperman (2001b) and Gallini and Scotchmer (2001) for discussions on the impact of strengthening intellectual property rights on firms' incentives to reorganize those rights through integration, licensing and other forms of alliances.

21 The theoretical framework in equation (6) and in Kortum and Lerner (1998) assumes that features of the source country will not impact on the propensity to patent in a destination country. However, there are reasons why source-country characteristics may, in fact, influence the propensity to patent abroad (for example, if the standards for patentability are not identical in the two countries, as noted in note 7 for Canada and the United States). If R&D and domestic patent decisions depend on patentability standards in the source country, then the variation in patentability standards will impact on the propensity to patent abroad.

22 The propensity measure will be less than one if the home country is the priority country for most of their inventions. In that case, the patents filed in a foreign country will be a subset of the patents filed at home. This is not true for Canada since the United States is the priority country for many Canadian inventions.

23 Offsetting this may be a reduction in the marginal cost of filing in a destination country after the invention has been patented in the source country, since the fixed cost of prior art searches has already been incurred (Scherer and Weisburst, 1995). If the increase in domestic value is large enough to overcome this fixed cost, filing abroad may become feasible even if the marginal cost of filing has not changed, leading to an increase in the propensity to patent abroad (Putnam, 1996).

24 We only observe application fees for a single year, but we assume that countries that are classified as high cost in 1992 remain so over our sample period.

25 Our results do not depend qualitatively on this construction.

26 Hausman, Hall and Griliches (1984) show that contemporaneous R&D is the best predictor of current patents. But, because most of our observations are from foreign countries which file inventions in the home (priority) country one year earlier, we lag R&D by one year.

27 The lag on patents in the source country reflects the Paris Convention that gives inventors 12 months to file in other countries after filing in the priority country (which we take to be the source country).

28 As a practical matter, this variable presents a construction challenge for Canada in particular, as the majority of Canadian patent applications are filed first in the United States. For example, out of 3,056 (ultimately successful) patent applications filed by Canadian inventors in the United States in 1994, only 404 were previously filed in Canada (U.S. Patent and Trademark Office database). We therefore use patent applications in the United States for Canada's *domestic* applications. See Putnam (1996) for details about patent priority and the correct definition of the *home* country.

29 The precise question corresponding to this index was the extent to which managers agree with the statement "Antitrust laws do prevent unfair competition in [my] country." Countries are assigned a value ranging from 0 to 10 based on these responses.

30 We also estimated specifications including destination-country R&D expenditures as a proxy for the threat of imitation, with similar results.

31 One further concern might be that unobserved bilateral (i.e. source-destination countries specific) heterogeneity causes a mis-specification of our model. To address this possibility, we run unreported regressions in which the 1980 values of our dependent and independent variables are subtracted from the 1995 values. This differencing sweeps out any time-invariant unobservables. With this specification, we find that the patent rights coefficient is essentially unchanged, while other coefficients are imprecisely estimated.

32 The logit model for grouped data estimates weighted least squares for the equation where log[PROP1/(1-PROP1)] is the dependent variable.

33 Rafiquzzaman (1999) also presents some descriptive statistics on patenting by industry in Canada.

34 The data have subsequently been updated by Dan Johnson of Wellesley College and used by both Johnson and Robert Evenson; see http://www.wellesley.edu/economics/johnson/jeps.html.

35 For example, patents granted in Canada to German inventors in 1995 may not correspond to the 1995 cohort of German domestic patent grants, as we assume here, if the lag between application date and grant date differs across countries.

36 The drop in the number of patents granted may have been due to the change from a mandatory to an elective examination system. If some industries exhibit a higher ratio of applications to examination requests than others, our propensities constructed with grant data would be biased. The extent to which this is a problem remains an issue for future research.

37 The reference year is 1993, the reference country is France and the omitted industry is 'Other manufacturing'.

38 Interestingly, in an unreported regression excluding the import term, the U.S. effect is strongly positive. This suggests that trade between Canada and the United States accounts for a great amount of the existing technology diffusion.

39 The latter includes the U.S.-dominated automobile industry, which has evolved a fairly stable set of licensing practices that do not depend on patenting in Canada, despite extensive intra-industry trade between the two countries.

40 See Tepperman (2001a) for further discussion of this point.

41 See, for example, Scherer and Weisburst (1995) for an empirical analysis of pharmaceutical patent protection, and O'Donoghue (1998) for a theoretical analysis of patentability standards. More precisely, O'Donoghue predicts that R&D will fall with a reduction in the non-obviousness requirement but that more low-quality inventions will be patented.

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