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PATENT PROTECTION AND INNOVATION OVER 150 YEARS

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ABSTRACT

The paper seeks to understand the impact of the patent system on innovation by examining shifts in the strength of patent protection across sixty countries and a 150-year period. An examination of 177 policy changes reveals that strengthening patent protection appears to have few positive effects on patent applications by entities in the country undertaking the policy change, whether filings in Great Britain or the nation making the policy change are considered. Cross-sectional analyses suggest that the impact of patent protection-enhancing shifts were greater in nations with weaker initial protection and greater economic development, consistent with economic theory. I address concerns about the endogeneity of these changes by employing an instrumental variable approach.

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1. Introduction

The impact of intellectual property rights on innovation is one of the most persistent empirical questions in the economics of technological change. In a memorable formulation, Penrose [1951] noted:

> If national patent laws did not exist, it would be difficult to make a conclusive case for introducing them; but the fact that they do exist shifts the burden of proof and it is equally difficult to make a really conclusive case for abolishing them.

Nearly five decades later, a literature review by Mazzoleni and Nelson [1998] reached a similar conclusion, "our lack of knowledge here clearly limits our ability to analyze intelligently the current pressing issues of patent reform."

This paper addresses this question by examining the impact of major patent policy shifts in sixty nations over the past 150 years that enhanced the amount of patent protection provided (but not the scope of awards). I examine the changes in patent applications by residents of the nation undertaking the policy change. While I tabulate the filings that the residents made domestically, confounding factors may influence this measure. Thus, I focus on filings made by residents of the nation undertaking the policy change *in a nation with a relatively constant patent policy*, Great Britain. As a control, I also compute the changes of filings by foreign entities in the country undertaking the policy change. The policy shifts and their impact on patenting activity are determined from examinations of numerous guides to patenting activity, as well as the publications of the World Intellectual Property Office (WIPO) and the various national patent offices.

The basic patterns are striking. Consider, for instance, policy changes that strengthen patent protection. Once overall trends in patenting are adjusted for, the changes in patenting by residents of the country undertaking the policy change are negative, both in Great Britain and in the country itself. Subject to the caveats noted in the conclusion, this evidence suggests that these policy changes did not spur innovation.

The extensive theoretical literature on patenting suggests at least three predictions about when strengthening patent policy should particularly boost innovation. To explore these suggestions, I examine cross-sectional differences across these events. Consistent with theoretical suggestions, I find that patent protection-enhancing shifts have a lesser impact on innovation when the nation already has strong patent protection and when its per capita gross domestic product lags further behind other nations. These patterns continue to hold when I employ an instrumental variables approach, which partially addresses the concern that the timing of these policy changes is not exogenous.

This paper takes a considerably different tack than earlier works on this question, which have largely focused on understanding the impacts of a single patent policy reform. Examples include studies of the broadening of Japanese patent scope (Sakakibara and Branstetter [2001]), the establishment of the Court of Appeals for the Federal Circuit in the United States (Kortum and Lerner [1998], Hall and Ziedonis [2001]), and the strengthening of patent protection of pharmaceuticals in such nations as India (Lanjouw [1998]) and Italy (Scherer and Weisburst [1995]). These papers generally cast doubt on claims that enhancing patent policy changes spurs innovative

behavior. My results are largely consistent with the earlier work. But by aggregating a large number of episodes, I am able to reduce the problem of confounding effects that individual case studies often face.

This paper is also related to works in the international trade literature, which have sought to relate indexes of intellectual property protection (such as those developed by Ginarte and Park [1997] and Rapp and Rozek [1990]) to the volume of trade or foreign direct investment. (This literature is reviewed in Maskus [2000].) Reflecting the nature of these indexes, these papers have typically examined these relationships at a single point in time or over a very short time period. As a result, these analyses have found it challenging to disentangle the causal relationships: e.g., the possibility that countries could have greater intellectual property protection because they engage in more international trade, not *vice versa*.

The plan of this paper is as follows. The second section reviews the theoretical work that motivates the analysis. I discuss the construction of the data set in Section 3. Section 4 presents the analysis. The final section concludes the paper.

2. Theoretical Perspectives

In this section, I discuss theoretical predictions concerning the impact of enhanced patent protection on innovation and the implications for my analysis.

A. Impact of Enhanced Patent Protection

Much of the theoretical economics literature has assumed an unambiguous relationship between the strength of patent protection and the rate of innovation. To cite a few examples, in Gilbert and Shapiro [1990], Kamien and Schwartz [1974], Klemperer [1990], and Waterson [1990], an increase in the amount of patent protection offered unambiguously increases the rate of innovation. A crucial assumption behind such findings is that the nature of the patent award does not affect the incentives of subsequent researchers to pursue innovations.[1]

This assumption has been relaxed in a line of work on sequential innovation, beginning with Scotchmer and Green [1990]. When the nature of protection offered the initial innovator affects the incentives of subsequent researchers, the conclusions may change. The effects of such an adjustment are perhaps most starkly illustrated by Bessen and Maskin [2000], who assume that a firm must be actively competing in the product market in order to introduce a next generation product. In this case, a strong patent award has the effect of precluding other firms from pursuing a subsequent innovation. They suggest that strong patent protection may actually lead to significantly less innovation than no patent protection at all.[2]

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[1]Williams [1994] suggests that while an increase in patent protection may spur innovation, its effect may be very modest. His simulations suggest that a 10% increase in patent life will boost productivity by less than one-tenth of one percent.

[2]In addition to the theoretical rationales suggested above, there could be several other reasons why enhanced patent protection could lead to a (temporary) decline in patenting. One possibility is a "crowding out" effect. Case studies suggest, for instance, that foreign pharmaceutical companies aggressively expanded their operations in countries that enhanced pharmaceutical patent protection. In some of these cases, the new entrants hired many local researchers away from basic research positions with local firms. Often,

B. The Relative Effect of Patent Policy Shifts

Theorists have also focused on the question of *when* strong patent protection is likely to have a powerful effect on innovation. Researchers have examined the impact of differences along two dimensions: the strength of the patent protection in the nation and the technological standing of the nation relative to other countries.

The strength of existing patent protection in the nation. Gallini [1992] considers the impact of increasing patent life when rivals can "invent around" previous discoveries (at some cost). When patent awards are short, her model predicts that increasing the length of a patent award will lead to innovators enjoying increased rewards, and hence to them having a greater incentive to innovate: stronger patents will lead to more innovation. But above a certain threshold, increasing patent length leads rivals to seek to imitate the patent. The losses from the increased imitation may more than offset the gains from the longer patent protection: when patents are already strong, increasing patent length further may actually depress the level of innovation. This insight is refined in a series of subsequent models, such as Cadot and Lippman [1995] and Horwitz and Lai [1996]. These models similarly suggest that the relationship between patent length and innovation will display an "inverted U" shape.

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the foreign companies used the scientists for more applied roles (e.g., obtaining local regulatory approval for already-developed drugs). Since in many cases the local companies found it hard to replace these individuals, fewer domestic patents may have resulted. Alternatively, local companies may have initiated basic research programs after the policy change, but these may have taken many years to generate any patent filings.

The stage of the nation's development. Much of the economics research into the determinants of the optimal degree of patent protection has focused on the nation's stage of development. Initial analyses focused on a single-country setting. In the classic model of Nordhaus [1969], a policy-maker considered how to encourage an incremental (cost saving) innovation. The greater the degree of patent protection, he assumed, the greater the resources that a private firm will devote to pursuing the innovation and the greater the probability of a discovery (though the probability increases at a declining rate with the amount spent on R&D). The analysis suggests that the impact of changes in patent protection on innovation will be determined by the curvature of the R&D cost function, which may be interpreted as the ease of further discovery for a given additional expenditure. In settings where relatively modest investments are likely to lead to substantial discoveries but progress beyond a certain point is much more costly—which Nordhaus suggests will characterize nations who are technological followers—increased patent protection will have a limited impact on the pace of innovation.

This insight has been corroborated in subsequent models that depict a world with both a developed and developing nation. A number of papers (e.g., Chin and Grossman [1990], Deardorff [1992], and Helpman [1993]) suggest that mechanistically transferring the intellectual property practices in place in the developed world to developing countries is problematic. These works suggest that the spur to domestic innovation will be modest in these settings.[3]

[3]Diwan and Rodrik [1991], however, show that if the developing country has a need for innovations that differ from that of the developed nation, strong intellectual property protection may be desirable. Otherwise, it may not be able to induce the developed nation to undertake innovations in this area.

C. The Mapping Between Theory and Empirical Tests

These works discussed above focus on innovations by domestic entities. One way to test these models is to examine patenting by residents of a large number of nations making patent policy shifts. Patent applications by domestic residents can be examined both in the nation undertaking the policy change and in a nation with a relatively stable patent policy over this period.

The mapping between what I seek to measure (innovative activity) and the dependent variable in this analysis (patent applications) is, of course, not exact. It has long been recognized (see the discussion, for instance, Griliches [1990]) that many important innovations are not patented, while some patents are awarded for very modest discoveries. While it would have been desirable to assess the importance of the patents through the analysis of patent citation and renewal data, this information was not available for most countries and time periods.

It is worth emphasizing, however, that what I will be analyzing here is not the absolute level of patenting, but rather the changes in patenting associated with policy shifts. As long as the propensity to patent does not change, this measure will be a reasonable proxy for the shifting level of innovative activities. I also address this problem by examining not just patent applications filed by domestic entities in the country undergoing the policy change, but also activity in another country where patent

policy has been relatively constant. To control for patenting trends, I adjust patent counts by the overall growth in patenting.

It is also important to emphasize the fact that while I examine several types of policy changes that enhance patent holder rights, I do not include changes that altered the *scope* of patent protection. If shifts that broadened patent scope were included, the interpretation of the dependent variable would be problematic: for instance, did patent applications fall because a decline in the amount of innovation, or rather because single patent filings now encompassed discoveries that previously had to be protected through multiple filings?

The models discussed above generally do not discuss patenting by foreign entities. (Scotchmer [2001] is an important exception.) The impact of such a policy shift on foreign entities is likely to be very different. For a typical foreign entity, which is likely to sell only a small fraction of its products in the country making the policy change, the impact of the policy shift on the decision to pursue an innovation will be much smaller. But the patent policy shift may nonetheless influence the decision to pursue patent protection in that country. Even though an enhancement of patent protection is not likely to shift foreign firms' level of innovation, after such a policy change the companies may become much more likely to seek patent protection in that country for their inventions. If we see a shift in foreign patent filings around the same events, it helps reassure us that we have properly identified a set of significant policy changes.

3. Constructing the Data Set

In this section, I describe the process by which the data set was created. Because of the diversity of sources employed (a number of which have not been previously employed in economic research), I discuss this aspect of the research at some length.

A. Defining the Sample

I employed as my sample the sixty countries listed in the International Monetary Fund's *International Financial Statistics* [1999] with the highest total gross domestic product (GDP) in 1997.[4] This included many nations that experienced considerable economic growth, but also others (e.g., Argentina, Iraq) that underwent substantial reversals.

I included these nations in the sample back until 1850 or until the country ceased to be an independent political entity, whichever came later. My rationale for this approach was that most colonies did not have independent patent policies. Most did not grant patents at all: they simply registered patents granted by their colonial overseer without any formal review. If the colonies had patent systems, they usually closely mirrored those of their colonizers. As a result of these omissions, this sample is not

[4]In undertaking these rankings, if the country was missing GDP data for 1997, I used the GDP and exchange rate for the most recent year for which such data were available (inflation-adjusting the result to insure comparability). In one case (Iraq), the volume had no data for the past five years. In this case, a consensus estimate from press accounts was used. In the second case (Taiwan), a country was not listed owing to questions about its political status. In this case, data were obtained from government publications.

balanced: the number of observations increased over time, as more nations became independent.[5]

B. Identifying Patent Policy Changes

I then identified significant changes to the amount of patent protection offered. I determined this information using guidebooks to the world patent systems, which have been published frequently since the early nineteenth century. I also employed publications of the British Patent Office (*Commissioners of Patents' Journal*), the Patent Office Society (*Journal of the Patent Office Society* and related titles), the publisher Trade Activities (*Patent and Trade Mark Review*), and the WIPO (*Industrial Property* and *La Propriete Industrielle*), as well as legal monographs on individual nations' patent systems in the collections of Harvard University and the Max Planck Institute for Foreign and International Patent, Copyright and Competition Law. (The key data collected and sources employed are summarized at http://www.people.hbs.edu/jlerner/PatPolSum.pdf.)

Five principles guided my selection of events to include in the analysis. First, I wished to focus on episodes where the government consciously set out to shift its patent policy. I consequentially eliminated policy changes that occurred within five years of the establishment of a nation, its restoration after a period of being a part of another state, or

[5]Determining what constituted an independent country was not always a simple matter. In some cases, colonies underwent prolonged independence struggles, while in other cases, countries enjoyed a great deal of independence while under the official control or informal influence of another nation. In general, I sought to include a nation from the date that its independence was declared (conditional on its eventually becoming a widely recognized country). In cases where a country was divided into several political entities, I used the patent policy (and other characteristics discussed below) from the most economically significant portion.

a revolution that involved a change of the form of government. I also excluded policy changes that were designated as temporary measures during a time of war.

Second, I wanted to be sure that the events were precisely dated. I thus eliminated changes where I could not determine the year of the policy shift. For instance, some nations during the nineteenth century simply began issuing patents on chemicals, even though legislation remained on the books for many years thereafter indicating that these subjects were not patentable.

Third, I eliminated changes to the breadth of patent protection. In these cases, as noted above, the interpretation of one of my dependent variables (domestic patenting) would be problematic. I thus did not include changes in statuary patent scope or in the number of claims that could be included in the patent.

Fourth, I wanted to compare the reactions to the policy changes by domestic entities to those by foreign entities. I thus eliminated policy changes that happened at the same time as discriminatory provisions against foreign applicants were either imposed or relaxed.

Finally, I wanted to insure that the changes were substantive shifts in patent policy. I consequentially only not included shifts in the most visible and controversial areas of patent policy. These areas were as follows:

- Whether the country offered patent protection at all, either in general or for certain critical classes of discoveries. While by 1999, 59 out of the 60 largest countries had patent protection, during the nineteenth and early twentieth centuries patent systems were far from universal. Similarly, the decision to extend patent protection to chemicals, foodstuffs, and medicinals was highly controversial in many countries.

- The duration of the patents awarded to domestic applicants. Because in some cases, awards were measured from different starting points (e.g., application and award dates), I employed some assumptions in making these calculations. In making the computations, for 1950 and afterwards, I assumed that awards occurred two years after the application date (one year after publication date). Between 1900 and 1949, I assumed awards occurred one year after the application date (and publication date). Before 1900, I assumed awards occurred only a nominal period after application.

- The cost of the patent. Many nations adjusted their costs on a periodic basis, often to keep up with inflation. In order to insure that I just identified real policy shifts, I only included changes in the cost of patents if they entailed at least a 100% increase or a 50% decrease in patent cost.[6] Because in many cases, countries required a series of fees over the patent life, I compared the net present value of the payments associated with the patent of the longest duration normally granted, discounted back to the date of the original patent application using the U.S. 10-year treasury yield (or an estimated yield of government bonds in earlier years), and expressed in 1998 U.S. dollars.

- The period of time after which patents could be revoked or compulsorily licensed if they were not reduced to practice ("worked") in a set period. Occasionally, when patentees could choose patents of different lengths, the minimum period in which the patent had to be worked differed. I examined the working period for the patent of the longest duration normally granted.

In total, I ended up with 177 events in 51 out of the 60 nations in the sample. The first change in the sample occurred in 1852 and the last in 1998. In many cases, the policy shift affected several elements of the patent system, or two closely related bills were

[6]In many cases, countries raised the price of a patent dramatically after a period of hyperinflation, but the change returned the real fee back to what it was before the inflationary episode. These changes did not appear to be real policy shifts. I eliminated changes that followed periods of hyper-inflation or deflation (*i.e.*, cases where the currency depreciated by 100% against the dollar or depreciated by 50%) unless the new cost of the patent was less than half or more than double the cost before the period in real terms.

passed in the same year. Consequentially, the number of distinct policy changes was larger, a total of 271.

The number of events and distinct policy changes occurring in each decade are depicted in Figure 1. Because the number of countries in the sample varies, I normalized the changes by the number of nations that were active at the beginning of the decade. The figure indicates that there have been five waves of patent policy changes, from the "Patent Controversy" of the 1850s and 1860s (Penrose [1951]) to the response to the changes triggered by the 1993 Uruguay Round agreements.

C. Identifying Patenting around the Policy Shifts

The next phase was to determine the patent applications filed around the time of the policy changes. I identified three distinct measures of activity: patent filings in Great Britain by residents of the country undertaking the policy change, patent applications by domestic entities in the country undertaking the policy change, and applications by foreign entities in that country. I chose Great Britain because its patent office has consistently tabulated the national identity of the patent applicants since 1884 (except during the years of World War I) and the relative constancy of its patent policy. In these tabulations, I sought to only include traditional patent awards, eliminating various weaker variants that nations have sometimes also offered to inventors. These included design patents, inventors' certificates, patents of addition, plant patents, and utility model patents.

I identified this information from a variety of sources. The WIPO has tabulated these filings since 1962 in *La Propriete Industrielle* and (subsequently) *Industrial Property*, and Great Britain has reported filings in the *Annual Report of the Comptroller General*. WIPO has also compiled older data in *100 Years Protection of Industrial Property* [1983]. Unfortunately, the WIPO data were in some cases inaccurate. In particular, during the early years of the European Patent Office, filings through the central office were not always properly credited to the individual countries selected. I corrected the data through an examination of the databases and publications of the European Patent Office and Organisation for Economic Co-operation and Development.

More problematic was the fact that the data were quite incomplete. In many cases, the WIPO publications did not present any information on applications prior to 1960, or failed to divide the applications between domestic and foreign filings. (While a few other compilations exist, such as Federico [1964], they were largely based on WIPO data and had similar failings.) Thus, I was forced to turn to publications of the various national patent offices to compile this information. I found the volumes in the Science Reference Library (formerly the Patent Office Library) of the British Library. This collection has had a policy of acquiring all patent office publications since its formation in the 1850s. The publications that contained the necessary data were identified through Rimmer and van Dulken [1992] and consultations with the reference librarian.

The data in the national publications were sometimes inconsistent. In some cases, the tabulations employed a different interval than the calendar year that I sought to use throughout. In these cases, I used the reporting year that corresponded most closely to the calendar year of interest. In other cases, certain other patent awards (e.g., utility model awards) were included in the total count of patent applications. I used the data as long as additional awards did not appear to constitute more than 10% of the patent applications in the total.[7]

I sought to collect the data for "event window" from five years before to five years after the policy change. In all, I was able to identify data on domestic and foreign patent filings in the country for 145 of the 177 event windows, and British application data for 171. (In some cases, the information was insufficient to compute the changes from two years before the policy change to two years afterwards, as analyzed below.) I also collected similar data for the "estimation period" from twenty to five years prior to the event.

D. Supplemental Data

I also collected a variety of additional information about the countries at the time of the shifts. This information was drawn from a wide variety of sources, but most

[7]In certain cases in the nineteenth and early twentieth century, nations (including the United States) reported the breakdown of the nationality of their patent awards, but just the number (not the breakdown) of applications. In many instances, a large fraction of applications were accepted, making it possible to impute the breakdown of applications quite accurately. In these cases, if the number of applications and awards (lagged one year) were within 25% of each other, I used the data at hand to impute the number of applications. In particular, I assumed that the applications in a given year were divided proportionately to the awards in the subsequent year.

important were Banks [1999], International Monetary Fund [1999], Maddison [1995], and Mitchell [1998]. The variables employed in this analysis included:

- Population of the country.
- Per capita gross domestic product. The variable was converted into current U.S. dollars using, if possible, a purchasing power parity-based deflator. It was then converted into 1998 dollars using the U.S. GDP deflator (back to 1889) or the U.S. consumer price index (for earlier years).
- The coincidence of the event window and a change in either the country's national borders (representing either at least 10% of its surface area or population) or a war within the territory of the country (lasting at least three months and affecting at least 10% of the nation's territory). These indicators were coded as +1 if there was a war in progress at the end of the period that was not present at the beginning or an expansion of territory. They were coded as –1 if there was a war in progress at the beginning of the period and not at the end or a contraction of territory.[8]

I sought to match the dates of these measures as closely as possible to the patent policy change, typically using the same calendar year. For the nineteenth century, however, I relaxed these requirements: I employed an observation as long as it was within five years of the patent policy change. This was particularly true of the estimates of gross domestic product, which were frequently only periodically available.

4. Analysis of Patent Protection

A. Summary Statistics

I began by simply summarizing the changing level of patent applications in the years before and after the policy shift. Panel A of Table 1 reports the changes in patent

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[8]In unreported regressions, I also used some additional control variables. These included the manner in which the effective ruler responsible for day-to-day governance of the country was selected (direct election, indirect election, or non-elective), whether the legislature was selected through an elective process, a ranking of the effectiveness of the legislative body, the mixture between agricultural, industrial, and services employment, and the legal family into which the nation's commercial laws fell.

applications filed from two years before to two years after the policy shift. In order to enhance the sample size, when the necessary observation was missing, I substituted data from either three years before or after the change or one year before or after.

I divided the observations by the type of policy change. Most shifts (64%) unambiguously increased patent protection. The remainder either unambiguously reduced patent protection (24%) or else contained both protection-enhancing and detracting elements (12%). In view of the small sample sizes, I treated the ambiguous and negative changes together in the reported analysis. (In unreported univariate and regression analyses, I undertook the same analyses without the ambiguous cases. The results were little changed.)

Domestic and foreign patent applications both increased in countries undertaking patent protection-enhancing shifts. The increase was larger, on both an absolute and percentage basis, among the foreign applicants. (In the sample as a whole, the mean number of British, domestic, and foreign patent applications during the year of the policy change were 739, 13,296, and 14,118 respectively.) No evidence appeared of a rise in British patent applications.

Panel A does not, however, control for changes in the overall propensity to seek patent protection over the period. In event studies of stock price returns, it is standard to present returns net of an appropriate market index. I similarly sought to control for the changing global patenting trends. Some periods, such as the depression years of the

1930s and the two world wars, saw a dramatic decline in patent applications across all nations, while others saw a substantial increase.

To control for the changing patenting environment, I computed the "adjusted" difference: the difference in the number of patent applications filed in this interval, less the difference that would have been expected, had the applications grown at the same rate as in other countries. To determine the growth rate in other countries, I constructed an index using the ten nations with the longest time series of patent application data. These nations included some where patenting has grown dramatically (e.g., the United States) and others where it has not (for instance, Argentina). In Panels B and C, I report the analysis using two indexes, one assigning an equal weight to each of the ten nations, and one weighting each observation by the total patent applications filed. In each case, I compute:

$$A_{+2} - A_{-2} - \left[\frac{I_{+2} - I_{-2}}{I_{-2}} * A_{-2} \right]$$

where A_{+2} is the number of applications filed two years after the policy shift, A_{-2} is the number of applications filed two years before, I_{+2} is the level of the index two years after the policy change, and I_{-2} is the index two years before.[9]

[9]It might be wondered why I did not examine the percentage change in the number of applications filed. In some cases, countries had a very small number of applications before a policy change. Even a modest rise in the number of filings thus led to a huge percentage jump in applications. While the same patterns appear in the percentage tabulations, the presence of such extreme cases made the comparisons very noisy.

Once the adjustment for overall patent application growth was made, a stark difference appeared in the case of patent protection-enhancing changes. While the change in foreign patenting was positive, adjusted patent applications by residents of the country undergoing the policy change declined, whether British or domestic filings were considered. The response of foreign patenting was much more modest in magnitude in the case of protection-reducing and ambiguous changes. The table also reports similar tabulations for the three most frequently encountered classes of changes: enhancements to the subject matter covered by patent protection (56% of 177 events involved such a change), the length of patent protection (50%), and the length of the working period (21%).

I also report the statistical significance of these changes. In the financial event study literature, a standard procedure for computing test statistics for event studies has emerged. First, the standard deviation of returns during an estimation period, which does not overlap with the event window, is computed. Each observation is then weighted by the inverse of the standard deviation when undertaking univariate or regression analyses (see Brown and Warner [1980]). In this way, observations where the stock price is very volatile are assigned less weight. In the same spirit, I computed the standard deviation of the change in patent applications filed in the period from twenty years to five years prior to the policy shift. I weighted both the t-tests and the regression analyses by the inverse of the standard deviation.[10] Not only did the adjusted patenting by residents of the

[10]I undertook separate calculations when examining British, domestic, and foreign applications. When I was unable to find data on patent applications in the estimation period, or if the nation did not extend patent protection during this period, I assigned the observation a weight equal to that of the median event. Brown and Warner [1980] also

country undertaking the policy change not increase after patent protection-enhancing policy shifts, it actually fell by a significant amount. Foreign applications, however, reacted positively to protection-enhancing changes, suggesting that we had properly identified a set of significant policy shifts.

Figures 2 and 3 depict graphically the average changes in patent applications around protection-enhancing and other patent policy changes, net of the value-weighted index. Around protection-enhancing changes, the same striking pattern appeared: patent application by foreign entities increased dramatically, while filings by domestic entities (whether in Great Britain or in the country undergoing the policy change) fell on an adjusted basis.[11] The pattern was much more muted in the case of the ambiguous or patent protection-reducing changes. Domestic filings changed little and the growth of foreign patenting was much more modest.

One concern with the above analysis was that it might be inappropriate to use the same index for each class of patent applications. For instance, the propensity of applicants to file foreign patents may have grown much more quickly than the tendency

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suggest more complex ways to compute these weights, which correct for the cross-sectional correlation of changes in the estimation period. To introduce such refinements, I would have had to undertake much greater data collection on patenting outside the event windows. In light of the time and expense of this effort, I did not pursue these suggestions.

[11]The fact that these changes began in the years before the policy change may reflect lags in the policy process. In many instances, changes were discussed for years before being implemented, and hence at least partially anticipated. In a number of cases, in fact, there was a significant lag between the decision to change the policy and its actual implementation.

to file domestically. In this case, the adjustment process may lead to the growth of domestic patenting being understated, and that of foreign patenting overstated.

To address this concern, in an unreported analysis I explored the robustness of these patterns to the use of an alternative index based on just the same type of patenting. In other words, instead of using the index based on all applications in the ten countries to adjust the number of applications, I employed an index based on domestic filings in the ten nations to adjust the domestic filings, and so forth. The change had a very modest impact on the analysis. In some countries, such as the United States, the ratio of domestic to foreign filings fell sharply over the twentieth century. But in others, such as Japan, this ratio rose considerably. Thus, the effects of the change were small. For instance, in the case of patent protection-enhancing changes, the differences in domestic and British patenting remained negative and the foreign patenting difference remained positive. These shifts continued to be statistically significant, at least at the 10% confidence level.

In other unreported analyses, I adjusted the composition of the countries in the indexes. For instance, I was concerned that since many of the nations undertaking policy changes were developing ones, the index might be distorted by the presence of the most developed nations. I recomputed the index, restricting it at all times to nations whose per capita gross domestic product was below 75% of that of the wealthiest nation. The results were little changed.

B. Regression Analyses

The univariate analysis discussed in the previous section suggested that patent applications originating in the nation undertaking a patent policy shift (whether filed in Great Britain or domestically) did not increase significantly in response to policy changes. But the cross-sectional differences in the sample may nonetheless be of interest.

The theoretical literature discussed in Section 2 offered a number of predictions about when strengthened patent policy should be most efficacious in spurring innovation. In particular, it suggested that protection-enhancing changes would have less impact when patent protection was already strong, would have more of an effect when protection was weak, and would be less effective when countries were far behind the technological frontier. This section examines these suggestions.

Following the finance event study literature, I estimated regressions in which the "adjusted" growth in patenting by residents of the country undertaking the policy change was the dependent variable. (I considered both patenting in Great Britain and in the country undertaking the change.) As independent variables, I employed a dummy variable denoting whether the policy represented a patent protection-enhancing change and one of three alternatives: a dummy denoting whether protection prior to the policy change was particularly strong, a dummy denoting whether protection was particularly weak, and the per capita GDP of the country relative to that of the wealthiest nation at that time. In the reported regressions, I used the length of patent protection to designate countries with particularly strong (those where patents extended eighteen or more years

from the application date) or weak (those where patent life was ten years from the application date or less) protection. Of greatest interest was the interaction of the positive change measure with the three additional variables.

I also employed a variety of control variables. These included the type of policy change, the inception of a conflict on the territory of or a change in the boundaries of the nation during the event window, the number of patent applications filed two years before the policy change, and the population of the nation (in millions). I again weighted each observation by the inverse of the standard deviation of changes in patent applications during the estimation period.

Table 2 examines patenting by the residents of the country undertaking the patent policy change in Great Britain. The dummy variable indicating a patent protection-enhancing policy shift was not significantly positive on a consistent basis. But in two out of three cases, the interaction term took on the predicted sign and was significant at the 5% confidence level. In the first and second regressions, the interaction between the dummy variable denoting strong patent protection prior to the policy change and that denoting a protection-enhancing change was significantly negative. In the fourth regression, the interaction between the relative GDP measure and a protection-enhancing change was significantly positive. This suggests that enhancing patent protection was less effective when patent protection was already strong and in poorer countries. For instance, in a country whose per capita GDP was three-quarters of the richest nation, a patent policy-enhancing change stimulated 636 additional British patent applications than

an ambiguous or negative change. In a country whose per capita GDP was about one-quarter of that of the richest nation, such a change generated no additional patents.

The analysis of patent applications in the country undertaking the policy change, reported in Table 3, was disappointing. The only significant variables were two control variables. Policy changes in larger countries tended to lead to a greater growth in patenting, which was not surprising in light of the fact that most changes were patent protection-enhancing. The size of the reaction declined with the number of the patent applications at the beginning of the event period, consistent with suggestions that there may be diminishing returns to patenting (Griliches [1990]). Given the greater noisiness of this measure, however, the failure to discern significant patterns may not be that surprising.

In supplemental unreported analyses, I explored the robustness of these results. The use of longer event windows made little difference, as did adding more detailed controls for the nature of the policy change, the employment mixture of the country, its political system, or its legal family. I also explored the robustness of the results to employing an alternative definition of the initial strength or weakness of patent protection. I used a measure based on the presence or absence of restrictive provisions on patent holder rights (e.g., compulsory licensing provisions, prior user rights, provisions allowing the government to revoke patents at its discretion, working periods of under three years). Again, patent protection-enhancing changes had significantly less of an impact on patent applications filed in Britain from countries that already had strong

protection. I also employed the alternative indexes discussed in the previous section to adjust the change in patent applications and estimated Heckman sample selection regressions, which controlled for the fact that data were missing for some policy changes. The results were little changed.

C. Addressing Concerns about Causality

One concern with the above analysis was that patent policy changes might not be exogenous. For instance, a nation may enhance patent protection at times when its domestic industry is becoming particularly innovative. While the same concern has not deterred academics from pursuing hundreds, if not thousands, of event studies using stock price data (see, for instance, the discussion in Eckbo, Maksimovic, and Williams [1990]), I can at least partially address this issue by exploiting the history of the patent policy.

In order to address endogeneity problems, a standard approach is to identify an instrumental variable. Such a variable ought to be positively correlated with the explanatory variable of interest, but not correlated with the potentially confounding factor. I sought an instrument for the measure of whether the patent policy change was a positive one or not.

I used as an instrument another dummy variable, which indicated whether the policy change took place in the aftermath of the Paris Convention of 1883 or the TRIPs agreement of 1993.[12] The rationale for the use of this instrument was that these

[12]I defined the aftermath as the years 1883 to 1893 and 1992 to 1998 (the end of the sample). I included 1992, even though the agreement was signed in 1993, because a

agreements compelled nations to make protection-enhancing changes to their patent systems. This measure had a strong positive correlation with the indicator of protection-enhancing policy changes. Fully 90% of the policy changes in these years were protection enhancing, as opposed to 57% in other periods, a difference significant at the one percent confidence level. But because the impetus to adopt these changes was largely exogenous to the country, the endogeneity problem should be reduced. (Of course, some nations, such as Ecuador in the 1885, chose to resign from the International Union rather than make the required changes, or did not join the Union in the first place.)

Helping underscore the reasonableness of this instrument was that fact that the initial patent policies of many nations were quite diverse, and influenced by many factors other than economic considerations. Case studies of patent policy make clear that many of the aspects of patent policy were determined by a wide array of actors with very narrow agendas in mind. Furthermore, as Lerner [2001] highlights, many varied factors influenced the initial allocation of patent policies, such the family in which the nation's commercial legal system originated (consistent with La Porta, Lopez-de-Silanes, Shleifer, and Vishny [1998]).

The results reported above continued to be robust when this instrumental variable was used. Table 4 presents two representative regressions each from Tables 2 and 3, with the reform period dummy now used as an instrument for the protection-enhancing dummy. The results discussed above continued to hold: for instance, the interaction

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detailed draft of the Uruguay Round agreement was released in December 1991 (Wegner [1993]).

between positive changes and strong protection was again significantly negative in the British applications regression.

5. Conclusions

This paper examined the impact of changes in patent policy on innovation. Rather than analyzing a single case study, I studied 177 of the most significant shifts in patent policy across sixty countries and 150 years. Adjusting for the change in overall patenting, the impact of patent protection-enhancing shifts on applications by residents was actually negative, whether filings in Great Britain or domestically were considered. The cross-sectional differences in the impact of these shifts were largely consistent with the predictions of economic theorists. These findings are consistent with earlier case studies of individual policy changes.

This analysis had two limitations, which suggest the need for further research. The first of these is to understand the interaction between patenting and other forms of technology policy. As highlighted in papers by Kremer [1998], Shavell and van Ypersele [2001], and Wright [1983], in a number of historical instances nations have offered prizes or recognitions to discoverers of important inventions. To what extent did these or other policy tools—such as trade secrecy and government subsidies and procurement—change at the same time as shifts in patent policy? On a related note, did shifts in judicial doctrine mirror those in statutory protection, or serve to dampen their impact?

The second limitation relates to the crudeness of my measures of innovative output. Due to the broad scope and long time frame of this analysis, I was required to use patent-based measures of innovation. In an ideal world, I would have been able to examine a wide variety of measures, including R&D spending, total factor productivity growth, and counts of innovations. Other effects might have also been identified had I examined changes over longer event windows, since some of the policy changes could have taken more than five years to impact innovation. (Of course, the noisiness of the measures would have also increased substantially.) Despite these caveats, the failure of domestic patenting to respond to enhancements of patent protection, and the particularly weak effects seen in developing nations, were quite striking.

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Figure 1. Number of changes in patent policy over time. The sample consists of the sixty largest countries (by gross domestic product) at the end of 1997, observed from 1850 (or the date of inception as an independent entity) to 1999. The chart presents the number of policy reforms, as well as that of distinct policy shifts, in each decade, normalized by the number of active countries in the sample at the beginning of the decade.

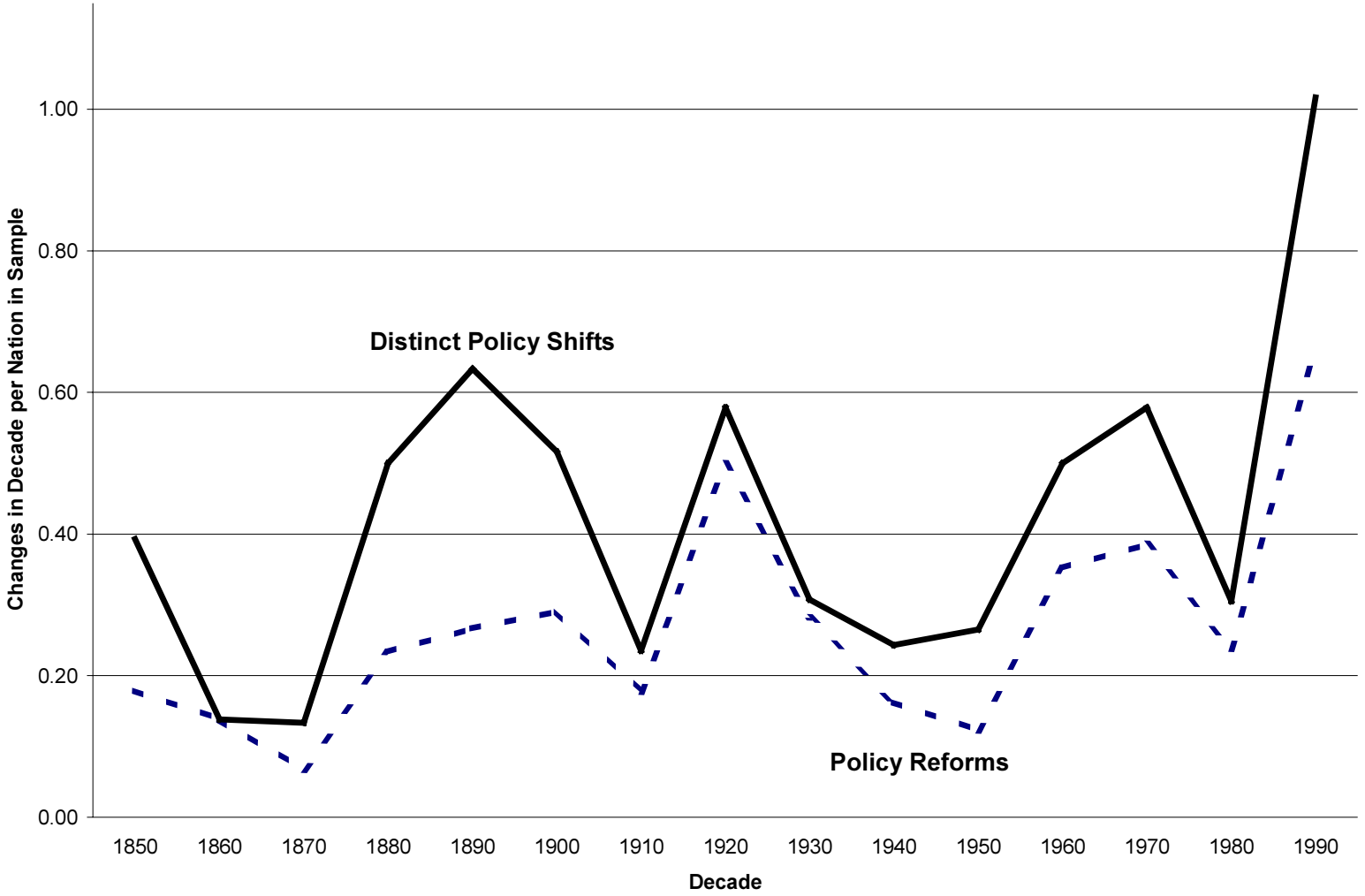

Figure 2. Patenting changes around the time of patent protection-enhancing policy changes. The sample consists of 177 changes in patent policy between 1852 and 1998 in the sixty largest countries (by gross domestic product) at the end of 1997. The figure displays the change in the number of patent applications filed between five years before the event and five years after the event by domestic entities filing in the country undertaking the change, foreign entities filing in the country undertaking the change, and residents of the country undertaking the policy change in Great Britain. These changes are shown net of a value-weighted index of patenting in the ten nations with the longest time series of application data.

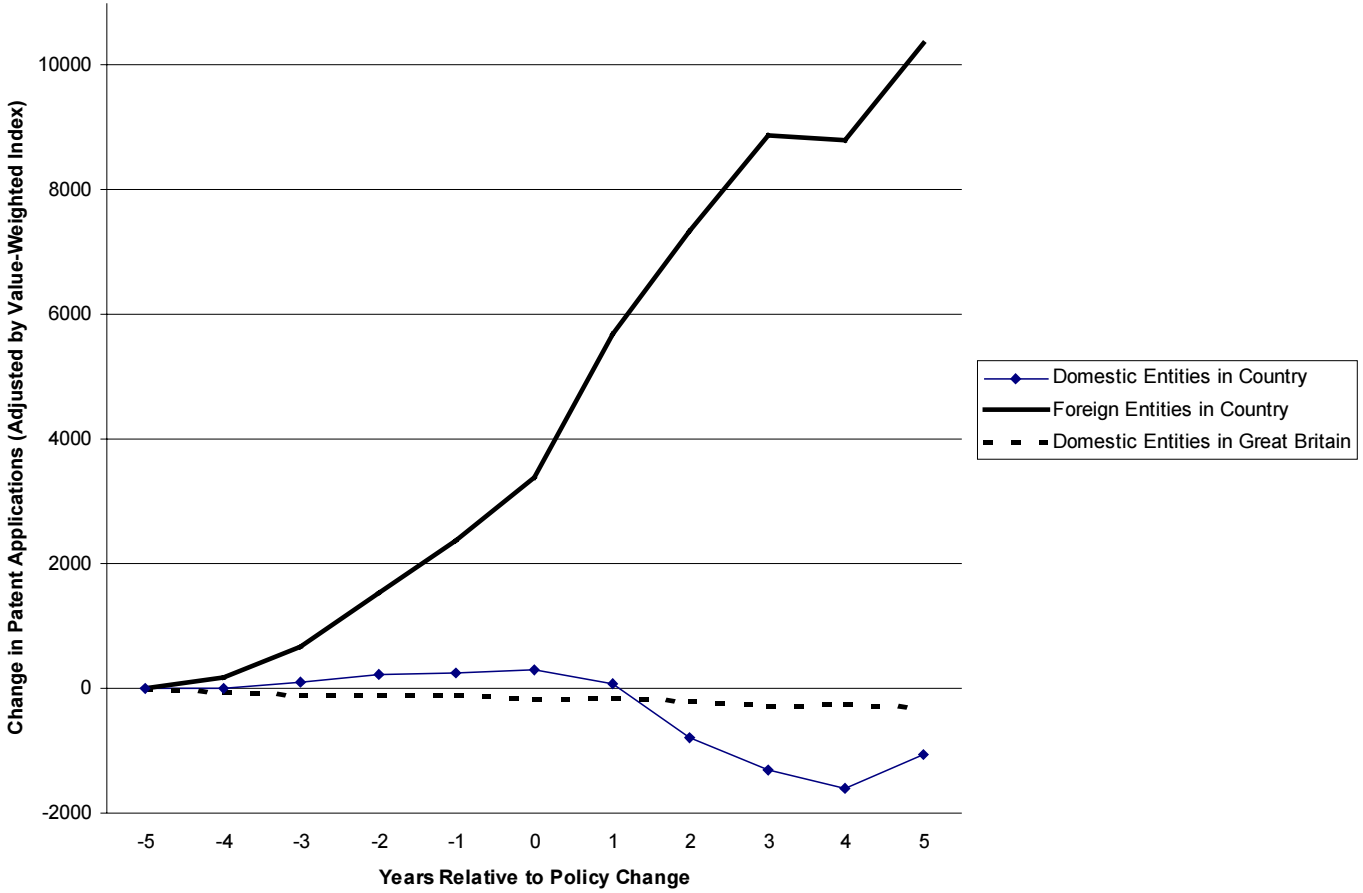

Figure 3. Patenting changes around the time of patent protection-reducing or ambiguous policy changes. The sample consists of 177 changes in patent policy between 1852 and 1998 in the sixty largest countries (by gross domestic product) at the end of 1997. The figure displays the change in the number of patent applications filed between five years before the event and five years after the event by domestic entities filing in the country undertaking the change, foreign entities filing in the country undertaking the change, and residents of the country undertaking the policy change in Great Britain. These changes are shown net of a value-weighted index of patenting in the ten nations with the longest time series of application data.

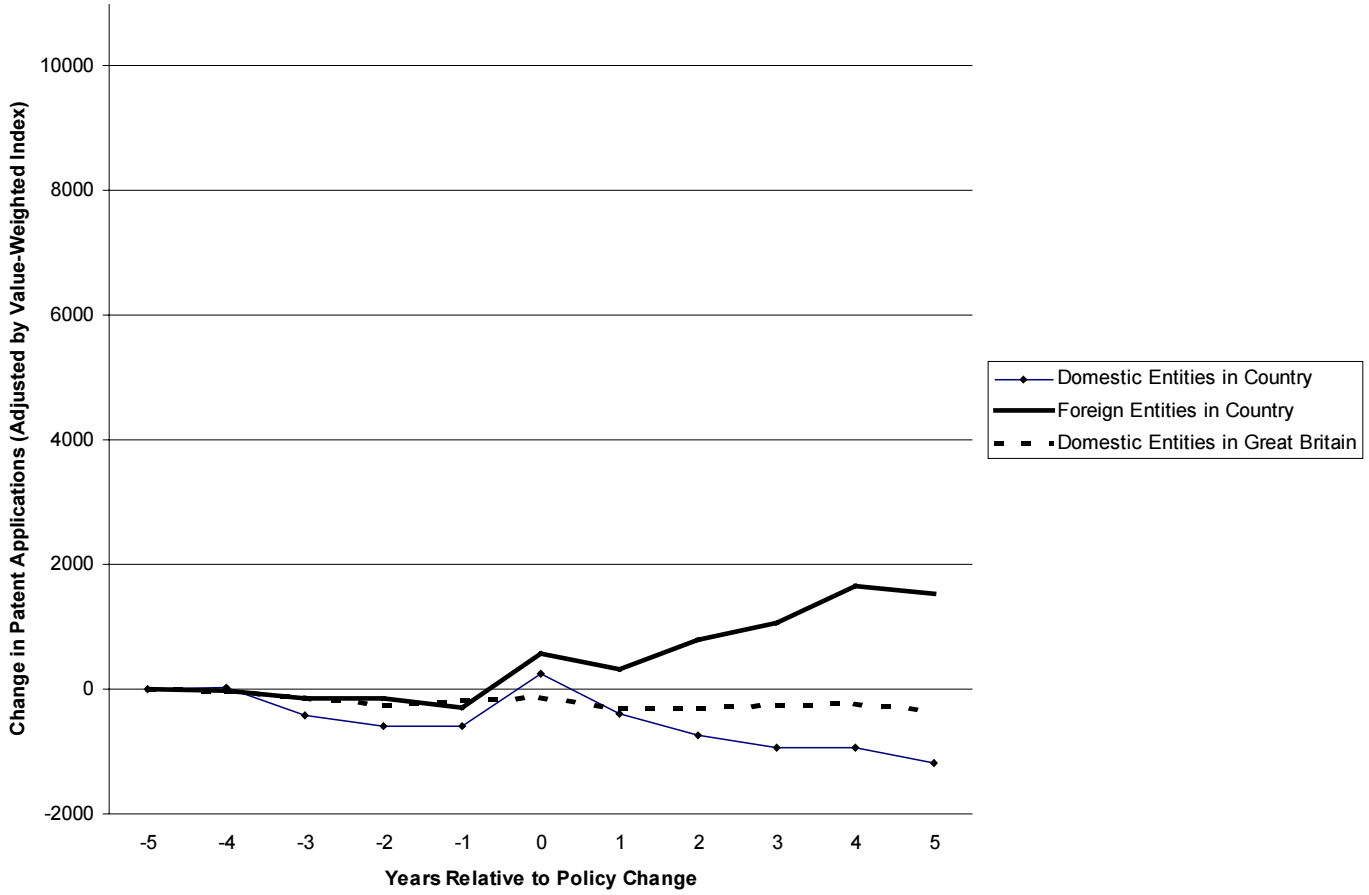

Table 1. Impact of a change in patent policy on patenting activity. The sample consists of 177 changes in patent policy between 1852 and 1998 in 60 nations. Panel A displays the change in the number of unadjusted patent applications filed from two years before the event to two years after the event by domestic entities residents of the country undertaking the policy change in Great Britain and in the country undertaking the change, and foreign entities filing in the country undertaking the change. In Panels B and C, these changes are shown net of equal-weighted and value-weighted indexes of patenting in the ten nations with the longest time series of application data. Underneath each adjusted change, the absolute t-statistic of the difference of the change from zero is displayed. In all tests, each observation is weighted by the inverse of its standard deviation of the annual change in patenting from 20 to five years before the policy change.

Panel A: Unadjusted Changes in Patenting Around Policy Changes			
	Residents' Patenting in United Kingdom	*Domestic Entities Patenting in Country*	*Foreign Patenting in Country*
Positive Patent Policy Changes	-27	+2424	+8662
Ambiguous/Negative Changes	+210	+529	+1401
Positive Changes Involving Coverage	-63	+2233	+9739
Positive Changes Involving Duration	-80	+2399	+10957
Positive Changes Involving Working Periods	-34	-1081	+3191
Panel B: Changes in Patenting Around Policy Changes, Adjusted by Equal-Weighted Index			
	Residents' Patenting in United Kingdom	*Domestic Entities Patenting in Country*	*Foreign Patenting in Country*
Positive Patent Policy Changes	-101	-1617	+4979
	***[4.61]	*[1.86]	**[2.41]
Ambiguous/Negative Changes	-217	-525	+390
	***[3.19]	[0.34]	[1.28]
Positive Changes Involving Coverage	-98	+1915	+7704
	***[5.13]	[1.03]	**[2.58]
Positive Changes Involving Duration	-190	-4714	+5699
	***[4.68]	**[2.22]	*[1.84]
Positive Changes Involving Working Periods	-27	-1239	+2772
	[1.33]	*[1.84]	[1.31]
Panel C: Changes in Patenting Around Policy Changes, Adjusted by Value-Weighted Index			
	Residents' Patenting in United Kingdom	*Domestic Entities Patenting in Country*	*Foreign Patenting in Country*
Positive Patent Policy Changes	-100	-932	+5617
	***[4.52]	*[1.69]	***[2.85]
Ambiguous/Negative Changes	-137	-408	+501
	**[2.40]	[0.07]	[1.65]
Positive Changes Involving Coverage	-111	+1781	+7963
	***[5.12]	[0.94]	**[2.57]
Positive Changes Involving Duration	-186	-3347	+6690
	***[4.63]	**[2.14]	**[2.36]
Positive Changes Involving Working Periods	-27	-1289	+2809
	[1.29]	*[1.89]	[1.27]

* = Significant at the 10% confidence level; ** = significant at the 5% level; *** = significant at the 1% level.

Table 2. Weighted least squares regression analyses of patenting in Great Britain by residents of the countries that underwent patent policy changes around the time of the changes. The sample consists of 177 changes in patent policy between 1852 and 1998 in the sixty largest countries (by gross domestic product) at the end of 1997. The dependent variable is the change in the number of patent applications filed by residents of the country undertaking the policy change in Great Britain from two years prior to the policy change to two years afterwards, net of either of a value-weighted (VW) or equal-weighted (EW) index of patenting in the ten nations with the longest time series of application data. The independent variables are dummy variables denoting whether the policy change entailed an unambiguous increase in protection and the aspects of patent policy that the change covered, variables denoting whether during the period the country began or ended a conflict on its territory or expanded or contracted its territory (with the former instance being coded as +1, the latter as –1, and all others as zero), the number of patent applications by domestic entities in Great Britain two years before the policy change, and the population of the nation at the time of the change. In addition, the various regressions include dummy variables denoting whether the country had a particularly strong or weak patent policy before the change, the nation's per capita gross domestic policy relative to the leading nation at the time, and the interaction of these measures with the dummy variable indicating an increase in patent protection. Each observation is weighted by the inverse of the standard deviation of the annual change in patent applications in Great Britain from twenty to five years before the policy change. Absolute t-statistics in parentheses.

	Dependent Variable: Change in U.K. Patent Applications Net of			
	VW Index	*EW Index*	*VW Index*	*EW Index*
Positive Patent Policy Change?	165.94 [0.87]	***598.53 [3.24]	19.13 [0.11]	-333.42 [0.88]
Strong Protection Prior to Change?	-249.34 [0.96]	86.93 [0.35]		
Weak Protection Prior to Change?			273.22 [0.32]	
GDP as Percent of Leading Nation				***-1561.76 [2.92]
Strong Protection * Positive Change	**-602.57 [1.99]	***-980.07 [3.34]		
Weak Protection * Positive Change			-133.66 [0.14]	
Relative GDP * Positive Change				**1292.27 [2.15]
Change Involving Coverage?	50.74 [0.37]	216.92 [1.65]	32.63 [0.22]	61.80 [0.42]
Change Involving Duration?	-199.37 [1.41]	-79.30 [0.58]	-171.04 [1.06]	-135.68 [0.91]
Change Involving Cost?	***1014.88 [4.42]	***1137.36 [5.12]	***1059.91 [4.24]	***1252.63 [5.26]
Change Involving Working Periods?	*-335.37 [1.78]	-192.88 [1.06]	-249.62 [1.22]	-117.16 [0.61]
Inception of Conflict?	-10.97 [0.04]	-332.82 [1.09]	80.75 [0.24]	-118.82 [0.36]
Change in Territory?	***-1058.54 [3.37]	130.20 [0.43]	***-1042.61 [3.03]	-118.22 [0.35]
Applications Two Years before Event	***-0.12 [11.63]	***-0.13 [13.14]	***-0.12 [10.13]	***-0.12 [10.03]
Population of Nation	0.07 [0.07]	0.27 [0.29]	-0.14 [0.14]	-0.96 [0.94]
Constant	21.18 [0.09]	-523.10 [2.21]	-117.27 [0.50]	428.65 [1.10]
Number of Observations	159	159	159	159
F-Statistic	17.10	23.14	12.06	18.08
p-Value	0.000	0.000	0.000	0.000
Adjusted R^2	0.53	0.61	0.44	0.54

* = Significant at the 10% confidence level; ** = significant at the 5% level; *** = significant at the 1% level.

Table 3. Weighted least squares regression analyses of domestic patenting by residents of nations undergoing patent policy changes. The sample consists of 177 changes in patent policy between 1852 and 1998 in the sixty largest countries (by gross domestic product) at the end of 1997. The dependent variable is the change in the number of patent applications filed by domestic entities in the country undergoing the policy change from two years prior to the policy change to two years afterwards, net of either a value-weighted (VW) or equal-weighted (EW) index of patenting in the ten nations with the longest time series of application data. The independent variables are dummy variables denoting whether the policy change entailed an unambiguous increase in protection and the aspects of patent policy that the change covered, variables denoting whether during the period the country began or ended a conflict on its territory or expanded or contracted its territory (with the former instance being coded as +1, the latter as –1, and all others as zero), the number of patent applications by domestic entities two years before the policy change, and the population of the nation at the time of the change. In addition, the various regressions include dummy variables denoting whether the country had a particularly strong or weak patent policy before the change, the nation's per capita gross domestic policy relative to the leading nation at the time, and the interaction of these measures with the dummy variable indicating an increase in patent protection. Each observation is weighted by the inverse of the standard deviation of the annual change in domestic patent applications from twenty to five years before the policy change. Absolute t-statistics in parentheses.

	Dependent Variable: Change in Domestic Patent Applications Net of			
	VW Index	*EW Index*	*VW Index*	*EW Index*
Positive Patent Policy Change?	1862.87 [0.76]	2361.31 [0.82]	2727.11 [1.32]	2887.20 [0.59]
Strong Protection Prior to Change?	-1079.46 [0.30]	-717.08 [0.17]		
Weak Protection Prior to Change?			-2018.17 [0.12]	
GDP as Percent of Leading Nation				4630.29 [0.63]
Strong Protection * Positive Change	1657.97 [0.42]	1230.48 [0.27]		
Weak Protection * Positive Change			-611.87 [0.04]	
Relative GDP * Positive Change				-615.17 [0.08]
Change Involving Coverage?	1153.91 [0.63]	1311.54 [0.61]	1423.43 [0.80]	1861.75 [0.88]
Change Involving Duration?	-373.71 [0.21]	-566.56 [0.27]	-746.30 [0.41]	-387.44 [0.19]
Change Involving Cost?	1979.52 [0.59]	1872.51 [0.48]	1580.56 [0.48]	1226.20 [0.32]
Change Involving Working Periods?	1485.56 [0.53]	1620.48 [0.50]	1473.81 [0.53]	1758.43 [0.54]
Inception of Conflict?	-1639.60 [0.41]	-1523.63 [0.33]	-1999.77 [0.51]	-2125.00 [0.46]
Change in Territory?	-1231.93 [0.36]	-934.01 [0.23]	-1215.29 [0.35]	322.75 [0.08]
Applications Two Years before Event	***-0.23 [16.53]	***-0.31 [18.95]	***-0.24 [16.65]	***-0.32 [18.64]
Population of Nation	***25.20 [3.05]	***26.56 [2.74]	***26.46 [3.22]	***30.19 [2.94]
Constant	-1449.71 [0.43]	-1500.72 [0.38]	-1756.58 [0.60]	-4797.64 [0.88]
Number of Observations	132	132	132	132
F-Statistic	27.83	36.82	28.05	37.29
p-Value	0.000	0.000	0.000	0.000
Adjusted R^2	0.69	0.75	0.69	0.75

* = Significant at the 10% confidence level; ** = significant at the 5% level; *** = significant at the 1% level.

Table 4. Instrumental variable regression analyses of patenting in Great Britain and domestically by residents of nations undergoing patent policy changes. The sample consists of 177 changes in patent policy between 1852 and 1998 in the sixty largest countries (by gross domestic product) at the end of 1997. The dependent variable is the change in the number of patent applications filed in Great Britain and domestically by residents of the nation undergoing the policy change from two years prior to the policy change to two years afterwards, net of a equal-weighted index of patenting in the ten nations with the longest time series of application data. The independent variables are dummy variables denoting whether the policy change entailed an unambiguous increase in protection and the aspects of patent policy that the change covered, variables denoting whether during the period the country began or ended a conflict on its territory or expanded or contracted its territory (with the former instance being coded as +1, the latter as –1, and all others as zero), the number of patent applications by domestic entities in Great Britain and domestically two years before the policy change, and the population of the nation at the time of the change. In addition, the various regressions include dummy variables denoting whether the country had a particularly strong patent policy before the change, the nation's per capita gross domestic policy relative to the leading nation at the time, and the interaction of these measures with the dummy variable indicating an increase in patent protection. A dummy variable denoting that the policy change took place in the ten years following the signing of the Paris Convention of 1883 and the preliminary version of the TRIPs agreement of 1993 is used as instrument for the measure of positive patent policy changes. Each observation is weighted by the inverse of the standard deviation of the annual change in patent applications in Great Britain and domestically from twenty to five years before the policy change. Absolute t-statistics in parentheses.

	Dependent Variable: Change in Patent Applications, Net of Equal-Weighted Index			
	Applications in Great Britain		Domestic Applications	
Positive Patent Policy Change?	***7737.47 [3.00]	-3342.62 [0.87]	-7243.45 [0.37]	6075.96 [0.19]
Strong Protection Prior to Change?	**4546.50 [2.28]		-3062.68 [0.16]	
GDP as Percent of Leading Nation		**-9152.71 [2.48]		15135.62 [0.57]
Strong Protection * Positive Change	**-6671.86 [2.48]		1621.90 [0.07]	
Relative GDP * Positive Change		**10667.92 [2.06]		-18925.80 [0.49]
Change Involving Coverage?	**1137.27 [2.15]	-115.15 [0.31]	202.25 [0.07]	1569.60 [0.56]
Change Involving Duration?	133.54 [0.29]	-529.23 [1.50]	-1912.28 [0.86]	-926.64 [0.39]
Change Involving Cost?	**2655.75 [2.12]	**2128.94 [2.56]	-2480.94 [0.44]	-1792.07 [0.28]
Change Involving Working Periods?	**3322.78 [2.26]	1438.40 [1.57]	-5693.91 [0.58]	-4964.26 [0.77]
Inception of Conflict?	*-2221.32 [1.79]	-202.12 [0.23]	-104.44 [0.02]	-627.54 [0.11]
Change in Territory?	-1380.91 [1.17]	**-2111.38 [2.14]	1875.57 [0.29]	4339.82 [0.66]
Applications Two Years before Event	-0.12 [3.52]	***-0.08 [2.79]	***-0.24 [9.49]	***-0.24 [9.84]
Population of Nation	3.45 [1.08]	-4.12 [1.55]	22.52 [1.41]	30.62 [1.64]
Constant	***-7283.29 [2.94]	2883.99 [1.01]	8720.00 [0.47]	-3886.16 [0.16]
Number of Observations	159	159	132	132
F-Statistic	3.08	5.34	11.29	11.34
p-Value	0.001	0.000	0.000	0.000

* = Significant at the 10% confidence level; ** = significant at the 5% level; *** = significant at the 1% level.