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Reaping what you sow: an empirical analysis of international patent harmonization

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Abstract

This paper extends analysis of the GATT Uruguay Round by quantifying the impact of international patent harmonization as implied by the TRIPs agreement. Patent harmonization has the capacity to generate large transfers of income between countries, the US being the major beneficiary. Developing countries are major contributors to these transfers, but Canada, the UK, and Japan also make sizable contributions. © 2001 Elsevier Science B.V. All rights reserved.

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The Uruguay Round of GATT negotiations were remarkable; not only did they secure a further reduction in trade barriers but they also overhauled the entire structure of the multilateral trading system. This new structure extends GATT principles to a range of issues that had previously escaped discipline. Included in these new issues was an agreement on the Trade Related aspects of Intellectual Property Rights (TRIPs). Despite its title, this agreement represents a comprehensive framework for the protection of intellectual property and effectively defines what rights an inventor is entitled to and what institutions should be available to enforce these rights. The striking thing about this agreement is that not only is it

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comprehensive in nature but the standards it sets are either in line with or exceed the practices of most industrialized countries.

Such a dramatic reform of the international system of intellectual property rights is controversial because it holds all members of the World Trade Organisation to the same standards. This harmonization of standards will require major reforms in most developing countries and has raised concerns over the redistributive consequences of the TRIPs agreement. Despite these concerns, a view has emerged that developing countries, and more generally technology importing countries, will gain substantially from the Uruguay Round package — any losses incurred by these countries from patent harmonization will be more than offset by the gains from market access in other areas (Chin and Grossman, 1990; Maskus, 1990; Eby-Konan et al., 1995; Gruen et al., 1996). However, no detailed analysis of the TRIPs agreement has yet been conducted, with much of what is known currently drawn from surveys of the owners of intellectual property. For example, the USITC (1988) reported that in response to a 1986 survey of US firms, 269 respondents estimated aggregate worldwide losses as a result of inadequate protection of *all* intellectual property at $23.8 billion in 1986. However, incentives to exaggerate the losses undermine the credibility of such survey evidence. It is precisely this lack of information that has confounded evaluation of the TRIPs agreement and qualifies any assessment of the Uruguay Round.

The objective of this paper is to clarify these issues by estimating the value of transfers of income between countries implied by the TRIPs agreement. To estimate these transfers a structural model of innovation in an international setting is estimated. The structural model allows the value of patent rights held by 29 countries to be estimated and provides a basis for the examination of how the value of these rights are affected by patent harmonization. These estimates are derived from a modified version of the model set out in Eaton and Kortum (1996). The basic framework relates innovations to productivity growth through a quality ladders model, with the source of innovations (domestic or foreign) related to patent applications. Importantly, the decision to seek a patent is modeled as one that is taken by a profit maximizing inventor, with a patent sought only in those countries which provide patent protection and whose protection is sufficiently valuable to warrant paying the cost of a patent.

An important feature of this paper is that it models the relationship between the value of patent rights and both the sectoral coverage of patent protection and the enforcement institutions offered by a country. By incorporating this level of detail, the model identifies the relationship between patent institutions and the rents associated with patent protection. Estimation of this relationship then enables the counterfactual experiment to be conducted in which all countries adopt standards consistent with the TRIPs agreement. This allows inferences to be drawn on the international redistribution of income due to the TRIPs agreement, and facilitates a more complete assessment of the Uruguay Round. However, it should be noted that this exercise is conducted for a given set of innovations. Consequently, the model does not include a link between the standards of intellectual property protection and R&D.

What emerges from this analysis is a picture of patent protection as an important method for appropriating the rents of an invention. Although it is not the primary method of rent appropriation, patent harmonization nevertheless has the capacity to generate large transfers of income between countries. The US is the major beneficiary with a net increase in the present value of patent rights of $4.5 billion (1988 dollars) on the patents applied for in 1988. Although developing countries contribute to these transfers, Canada ($1 billion), the UK ($0.5 billion), and Japan ($0.5 billion) also make sizable contributions. These transfers significantly alter the perceived distribution of benefits from the Uruguay Round trade liberalization measures. The net transfers the US receives from the TRIPs agreement is estimated to be up to 40% of the gains associated with trade liberalization, while the developing countries pay net transfers of up to 64% of the gains they receive from trade liberalization. It is important to emphasize that the analysis is conducted for a given set of innovations, so the benefits of any increase in innovation in response to the TRIPs agreement have not been included. Nevertheless, the estimates provide insight into the impact of the TRIPs agreement on the allocation of rents from an innovation and demonstrates the importance of this agreement for determining the distribution of benefits from the Uruguay Round package.

1. Calculation of patent values

The object of this study is to estimate the relationship between the value of patent rights and national patent institutions. However, a major difficulty arises in this calculation since patent rights are rarely traded. As a result, data on transactions that would allow the value of patent rights to be directly observed does not exist. Consequently, any attempt to assess the value of patent rights must be based on some method of imputation.

In order to impute the value of patent rights this paper adapts the framework set out in Eaton and Kortum (1996). The primary purpose of their model is to decompose the contribution that foreign and domestic innovations make to a country's productivity growth. In their framework international patenting provides information on the origin and diffusion of innovations. By assuming that these data are consistent with optimizing behavior of the inventors, inferences can be drawn about the size of innovations. It is the step size of an invention that an inventor uses to calculate the expected value of an invention and consequently the merit of patent protection. The estimated parameters allow these calculations to be reconstructed, revealing the value of patent protection.

While Eaton and Kortum's study implies a method for quantifying the value of patent protection, this was not the focus of their work. Instead they employed the model to conduct a growth accounting exercise for 19 OECD countries, finding that (except for the US) growth is largely determined by research done elsewhere. In contrast, this paper specifically examines the role that patent institutions play in determining the value of patent rights for both developed and developing countries. To derive these values Eaton and Kortum's framework is modified in two key respects.

First, the model is extended to incorporate a fuller description of national patent institutions. Eaton and Kortum summarize the institutional characteristics of each country by employing a single summary measure developed by Rapp and Rozek (1990). While there is some variation in the patent institutions of the countries considered by Eaton and Kortum, a single summary measure would seem appropriate for a relatively homogeneous group (such as the OECD). However, when considering countries with a more varied structure of intellectual property protection, this index becomes inadequate and the parameter estimates are subject to omitted variables bias. To overcome this problem, a range of variables are used to describe national institutions. These variables provide detailed information about patent institutions by summarizing the extent of coverage offered (e.g., are any sectors excluded from patent protection?), restrictions on the form of exploitation of patents (e.g., do imports satisfy working requirements?) and the availability of enforcement institutions (injunctions, burden of proof, etc.). Aside from mitigating omitted variables bias, a disaggregated specification can be mapped directly into the changes implied by the TRIPs agreement, allowing a counterfactual experiment to be conducted.

A second modification to the model is a simplification of the structure underlying the innovation production function. Eaton and Kortum use two approaches to proxy the flow of innovations: data on the employment of research scientists and engineers, and country dummies. However, data on research personnel are not available for a large number of countries. Therefore, this paper uses only dummy variables to account for differences in the level of inventiveness between countries. By adopting this simplified version of the model, a relatively large and diverse sample of countries is constructed.

2. The model

Following Eaton and Kortum (1996), a quality ladders model of productivity growth is employed.[1] In any country, output is produced by combining a given set of intermediate inputs, subject to a constant returns to scale Cobb–Douglas production function. Output is assumed to be homogeneous and tradable across countries, while inputs are non-traded. The expansion of output over time is

[1] The presentation of the model will be brief with most of the details contained in Appendix A. A more detailed exposition can be found in Eaton and Kortum (1996).

related to improvements in the quality of inputs. The improvement in the quality of an input is described by the step size of the invention, where a step of q represents the percentage improvement in the quality of the input.

An important aspect of the model is that an innovation can come from either domestic or foreign inventors. If an invention comes from abroad, then the quality of the invention is scaled up or down depending upon the relative technology positions of the source and recipient countries. Specifically, it is assumed that the step size of an innovation is a random variable drawn from an exponential distribution with a parameter θ_{ni}. The average step size of an invention employed in country n, but originating in country i, is then equal to $1/\theta_{ni}$. Since the process of R&D is not directly modeled, it is assumed that the type of input to which an invention applies is a draw from a uniform distribution over the input range. The model also incorporates two parameters that describe the production of inventions and the diffusion of technology. It is assumed that country i produces a flow of inventions at a rate α_i, with the probability of an invention from country i diffusing to country n given by ε_{ni}.

Given the structure of the model and assuming that $\alpha_i$and ε_{ni} are constant overtime, the steady state involves each country's technology growing at a common rate (i.e., $g_n = g$). In addition, Eaton and Kortum show that under their assumptions about market structure there is a proportional relationship between labor productivity and the technology index:

$$y_n \equiv \frac{Y_n}{L_n^p} = \Gamma_n A_n, \tag{1}$$

with the factor of proportionality a function of α_i, ε_{ni} and θ_{ni}. The inclusion of this equation in the subsequently estimated system ensures that the estimated value of patent protection is in line with observed differences in labor productivity levels.

3. The patenting decision

An inventor earns rents generated by an invention in a country as long as it has diffused there and has been neither imitated nor rendered obsolete by a more advanced technology. The hazard of imitation depends in part on whether the invention has been patented in that country. The protection afforded by a patent, in turn, depends on the strength of national institutions. Let ι_{ni}^{pat} denote the hazard of imitation if an invention is patented, while ι_{ni}^{not} not is the hazard of imitation without a patent. The hazard of obsolescence is denoted by o_n, and depends upon the rate at which innovations flow into a country and the probability that they apply to a particular industry. Once the invention has been imitated or made obsolete, the rents of the inventor fall to zero.

The flows of rents are determined by the assumptions about market structure.

Suppliers of intermediate inputs are assumed to engage in Bertrand style competition under constant returns to scale technology. An innovator takes advantage of this competitive behavior by charging a price for the right to use the innovation (which may or may not be patented) that leaves the input suppliers just willing to use the new technology. Using the Cobb–Douglas structure the instantaneous rents extracted by the owner of an invention of size q are given by $\pi_n(q) = (1 - e^{-q})Y_n/J$, where Y_n is the value of the market in country n and J is the index of the range of intermediate inputs.

In assessing the benefits of patent protection an inventor compares the expected present value of the invention both with a patent (less any costs of obtaining the patent) and without.[2] To analyze the decision, consider the expected value at time t of an invention from country i of size q that has diffused to country n, $V_{ni}(q)$. Assuming constant rates of imitation, Eaton and Kortum derive the expected present value along the steady state growth path to be:

$$V^k_{ni}(q) = \frac{(1 - e^{-q})Y_n}{J(r + \iota^k_{ni} + o_n - g)} \tag{2}$$

where r is the discount rate which is assumed to be constant overtime and $k \in \{\text{pat}, \text{not}\}$ depending on whether or not the invention has been patented.

A patent gives the inventor the incremental benefits of a lower hazard of imitation, so is worth $V^{\text{pat}}_{ni}(q) - V^{\text{not}}_{ni}(q)$. Equating this difference with the cost of obtaining a patent, C_{ni}, implicitly defines a threshold level of quality, $\bar{q}_{ni}$, above which all inventions are patented, while those that are of a lower quality are not. The fraction of inventions which diffuse from country i to country n that are patented in country n can now be determined by combining the cut-off quality with the distribution function for the inventive step: $f_{ni} = \Pr[Q > \bar{q}_{ni}] = e^{-\theta_{ni}\bar{q}_{ni}}$. This setup has the property that the more effective the national patent institutions are at lowering the hazard of imitation, the higher is the fraction of inventions that are profitable to patent.

The reduction in the hazard of imitation due to patent protection is assumed to be related to the modes of legal redress that an inventor can access. Specifically, it is assumed that patent protection lowers the hazard of imitation in the following manner:

$$\iota^{\text{pat}}_{ni} = \begin{cases} \iota^{not}_{dom}\, e^{-\gamma PG_n} & \text{for } i = n \\ \iota^{not}_{for}\, e^{-\gamma PG_n} & \text{for } i \neq n \end{cases} \tag{3}$$

where PG_n is an index describing national enforcement institutions. Under this specification the critical elements affecting the hazard of imitation are the origin of

[2] Note that since imitation is not assumed to be instantaneous the expected present value of an invention without a patent is not zero.

the innovation and whether this innovation is patented. The hazard of imitation does not directly depend on the step size of the innovation.

In contrast to Eaton and Kortum, this specification allows the hazard of imitation to depend on whether the innovation being patented is of domestic or foreign origin. This is achieved by incorporating additional information on the hazard of imitation of non-patented innovations.[3] Note also that since the index employed is continuous, this specification allows for the estimation of one domestic and one foreign hazard of imitation rate associated with patents for each country, for a total of 58 in contrast to Eaton and Kortum's two.

Given the flow of inventions from country i, α_i, the fraction of these that diffuse to country n, ε_{ni}, and the fraction of these which it pays to patent, f_{ni}, the number of patents taken out in country n by inventors located in country i, P_{ni}, would then be given by $P_{ni} = \alpha_i \varepsilon_{ni} f_{ni}$. This derivation assumes that once an invention has diffused to another country the only relevant factor determining patenting behavior is the size of the innovation. However, a number of countries either exclude from patentability inventions in a particular field or require that the patents be worked within the country. It is therefore possible that inventions that satisfy the quality threshold are nonetheless not patented. To capture this possibility, the model is augmented by a parameter representing the sectoral coverage of patent protection, s_{ni}. This parameter is assumed to enter the bi-lateral patenting equation in a multiplicative manner.[4] The sectoral coverage parameter is interpreted as the fraction of inventions of patentable quality that are also applicable to an industry which is covered by patent protection.

The motivation for including extra information on the sectoral coverage of patent protection is 2-fold. First, one of the major changes required by the TRIPs agreement is that patent protection be offered to all inventions without regard to country of origin or how the patent is exploited. Therefore, by including information on the sectoral coverage of protection, the impact of this broadening of patent protection can be directly assessed. The second motivation is to overcome the possibility of omitted variables bias. The potential for this bias to arise is related to Eaton and Kortum's assumption that the role of national patent institutions affect patenting decisions solely through reductions in the hazard of imitation. However, if otherwise profitable patents are not taken out because they are excluded from patentability, then the estimated hazard rate for a patent will be biased upward. This will tend to understate the consequences of patent harmonization. Both of these reasons suggest that the sectoral coverage of patent protection plays an important role in the operation of the patent system and needs to be incorporated directly into the model.

The sectoral coverage of patent protection, s_{ni}, is assumed to determine the

[3]For details on the different treatment of the hazard of imitation see Footnote 13.

[4]This specification is consistent with the model developed above as the type of input to which an invention applies is assumed to be drawn from a uniform distribution.

fraction of high quality innovations that receive patent protection. This fraction is directly related to the industries that a country excludes from patent protection. In addition many countries specify that patent protection brings with it an obligation to undertake production that employs the new technology within the country granting the patent. This restriction may deter inventors of high quality innovations from taking out a patent, preferring instead to serve that market by exports.[5] It is also the case that the sectoral coverage of patent protection can affect source countries differently. For example, a country which itself excludes chemicals from patent protection is unlikely to have an active R&D sector in chemicals. In this situation, the bi-lateral sectoral coverage of patent protection between two countries that both exclude chemicals is higher than the sectoral coverage of protection for a country that covers chemicals but its bi-lateral partner does not. This effect is captured by the interaction terms for the sectoral dummies in the specification set out in (4).

It is the combination of excluded industries and working requirements that is taken to define the sectoral coverage of patent protection offered by a country. To capture the variation in institutional arrangements, the following relates the sectoral coverage of patent protection to national policies:

$$s_{ni} = (1 - s^{\mathrm{ph}} D_n^{\mathrm{ph}}(1 - D^{\mathrm{ph}}{}_i))(1 - s^{\mathrm{fd}} D_n^{\mathrm{fd}}(1 - D_i^{\mathrm{fd}}))(1 - s^{\mathrm{ch}} D_n^{\mathrm{ch}}(1 - D_i^{\mathrm{ch}})) \times (1 - s^{\mathrm{wr}} D_n^{\mathrm{wr}}) \tag{4}$$

where the D values represent dummy variables that take on the value of one if patent protection is not provided in the pharmaceutical (ph), food (fd) and chemical (ch) industries or if there is a restriction that the working of a patent is not satisfied by imports (wr) into a country, while s^{ph}, s^{fd}, s^{ch} and s^{wr} are parameters to be estimated. This specification has the property that $s_{ni} = 1$ unless: (1) the destination country excludes a product from being patented and the source country does not, or (2) the destination country imposes a working requirement. If either of these two criteria are fulfilled then there is a proportional reduction in the number of patents sought in country n by inventors from country i.

Taking into account the sectoral coverage of patent protection, bi-lateral patenting is described by

$$P_{ni} = \alpha_i \varepsilon_{ni} f_{ni} s_{ni} \tag{5}$$

Bi-lateral patenting is then the result of the following process of elimination. Country i generates a flow of α_i inventions which diffuse to country n with probability ε_{ni}. A fraction of these diffused inventions, f_{ni}, are of a sufficiently high quality to make patenting profitable, with this fraction being higher the more

[5] Modeling a domestic working requirement in this way is admittedly ad hoc. To analyze the role of this restriction requires a model which includes a choice over how a market is served (licensing, exports or direct investment).

effective are the national patent institutions at lowering the hazard of imitation. However, only a fraction, s_{ni}, will apply to industries which are covered by patent protection. The inventions that survive this filtering process are the ones that are ultimately patented.

4. Empirical implementation

The above parameters of the theoretical model can be estimated by assuming that the data are generated by steady state equilibrium. The two basic equations investigated are the bi-lateral patenting equation and the labor productivity equation:

$$P_{ni} = \alpha_i \varepsilon_{ni} f_{ni} s_{ni}$$
$$y_n = \Gamma_n A_n$$

These two equations are jointly estimated in order to impose the restriction that patenting behavior, and the implied patent values, are consistent with relative productivity levels.[6]

To estimate this system assume that the bi-lateral patenting equation is subject to a multiplicative error, u_{ni}, which is taken to be independently and identically distributed with a variance of σ_u^2. This implies the following empirical relationship:

$$P_{ni} = \alpha_i \varepsilon_{ni} f_{ni} s_{ni} e^{u_{ni}}$$

As noted in Eaton and Kortum, a difficulty arises in estimating this equation when the predicted fraction of patentable inventions hits zero. In this situation the model should fit perfectly. Following Eaton and Kortum it is assumed that a fraction of inventions η that are not worth patenting (i.e., involve a step size below) are patented by mistake. The bi-lateral patenting equation then becomes:

$$P_{ni} = \alpha_i \varepsilon_{ni}[f_{ni} + (1 - f_{ni})\eta] s_{ni} e^{u_{ni}} \tag{6}$$

Consider next the relationship between labor productivity and the technology index. To gain a measure of this index, the dynamic system is solved with the eigenvector yielding the implicit value of the technology index. However, since the eigenvector is only defined up to a scalar multiple, the model only has

[6] Eaton and Kortum estimate the same two equations with the exception that the introduction of extra information on national patent institutions in this paper alters the definition of f_{ni} and introduces the sectoral coverage parameter, s_{ni}.

implications for relative productivity levels. Hence the following relative productivity equation is estimated:

$$\frac{Y_n}{Y_N} = \frac{\Gamma_n A_n}{\Gamma_N A_N} e^{v_n - v_N} \tag{7}$$

where each country's productivity is measured relative to that of the US. It is assumed that the error, ν_n, is independently and identically distributed with a variance of σ_ν^2.

5. Data

The sample consists of 29 countries, a mix of both developing and industrialized countries. This provides 841 bi-lateral patenting observations and 28 relative labor productivity observations. Table 1 provides a list of the countries. The dependent variables are bi-lateral patenting of inventions from country i in country n's market, P_{ni}, and country n's productivity relative to that of the US, y_n/y_N. The patent variable is patent applications by reporting country and country of residence of the inventor for 1988. These data are taken primarily from WIPO (1990), with additional data obtained directly from WIPO.[7] Table 1 summarizes the full matrix of patenting.[8] The productivity variable is real GDP per worker, averaged over 1986–88, from Summers and Heston (1991) in 1988 dollars.

The explanatory variables governing the return to patenting relate primarily to data on national patent institutions. Data on the sectoral coverage of patent protection are taken from WIPO (1988) and Baxter and Sinott (1989). These data consist of dummy variables taking on a value of unity if a sector is excluded from patent protection and zero otherwise. The sectors most subject to exclusion are pharmaceuticals (D^{ph}), foods (D^{fd}) and chemicals (D^{ch}). In addition, some countries do not consider importation of products as consistent with the exploitation of patent rights and impose a domestic working requirement (D^{wr}). The values of these dummy variables are listed in Table 1.

Once a patent has been obtained, its exploitation is dependent on the national enforcement institutions that protect a patent holder from imitators. Recall that patent enforcement is given by (3) and enters (6) through f_{ni}. Information on these institutions is contained in an index, adapted from Ginarte and Park (1997), that has a range from 0 to 5 (PG_n). This index summarizes information on the availability of injunctions, prosecution for contributory infringement, the possi-

[7] I would like to thank Lise Mcleod of WIPO for supplying the additional data.

[8] Following Eaton and Kortum (1996) the data from Japanese domestic application has been adjusted to account for the idiosyncratic domestic patenting of the Japanese. The adjustment involves translating 4.9 Japanese domestic patent applications to be equivalent to one from somewhere else.

Table 1
Number of patent applications, patent protection and patent exclusions by country

	Domestic patents[a]	Foreign patents[b]	Patents abroad[c]	*PG* index[f]	Pharmaceuticals excluded[d]	Food excluded[d]	Chemicals excluded[d]	Imports excluded[e]
US	75 633	69 097	177 529	4.00	0	0	0	0
Japan	63 053	35 219	96 952	3.75	0	0	0	0
Germany	31 981	51 140	117 131	4.00	0	0	0	0
UK	20 903	58 448	47 353	2.00	0	0	0	0
France	12 438	52 343	47 822	5.00	0	0	0	0
Australia	6573	15 399	10 567	2.80	0	0	0	0
Korea	5699	11 618	897	4.75	1	1	1	0
South Africa	4829	4870	1323	3.00	0	0	0	1
Israel	4829	2835	2223	3.00	0	0	0	1
Sweden	3413	34 076	16 872	4.00	0	0	0	0
Switzerland	3251	33 151	25 483	3.90	0	0	0	1
Canada	2773	28 295	8780	3.00	0	0	0	1
Brazil	2343	9803	508	0.75	1	1	1	1
Italy	2290	41 900	22 454	5.00	0	0	0	0
Austria	2228	29 626	6578	4.00	0	0	0	1
Netherlands	2162	37 667	18 879	5.00	0	0	0	1
Finland	2039	7191	6160	4.00	1	1	0	1
Spain	1817	23 963	2526	4.00	1	0	1	0
Denmark	1332	9693	5923	4.00	0	1	0	1
India	1034	2737	134	2.00	1	1	1	1
Norway	929	8400	2600	4.00	1	1	0	1
New Zealand	804	3607	711	2.80	0	0	0	1
Mexico	733	4459	177	1.82	1	1	1	1
Ireland	728	3157	921	0.80	0	0	0	1
Belgium	637	32 377	5663	4.00	0	0	0	1
Greece	375	13 118	223	2.75	1	0	0	1
Columbia	85	195	178	2.50	1	1	0	1
Portugal	55	2407	156	2.88	1	1	1	1
Panama	10	60	128	1.88	0	0	0	1

[a] Patent applications by residents of each country for 1988, from WIPO (1990) and unpublished data.
[b] Applications from residents of other 28 countries.
[c] Applications by residents of a given country for patent protection in one of the other 28 countries.
[d] Dummy variable which is assigned a value of one if the sector is excluded from patent protection in a given country, WIPO (1988).
[e] Dummy variable which is assigned a value of one if the granting of a patent is associated with a requirement that the patent be worked within the country, Baxter and Sinott (1989).
[f] An index ranging from 0 to 5 which summarizes the national enforcement institutions associated with patent protection, adapted from Ginarte and Park (1997).

bility of criminal prosecution, the burden of proof procedures, and the duration of patent protection.[9] The cost of applying for a patent, (C_{ni}), which includes official application fees, agent's fees, and translation fees, are constructed from Helfgott

[9]I would like to thank Walter Park for providing these data.

(1993).[10] Recall that C_{ni} enters (6) through the definition of f_{ni}. These costs range from a minimum of $460 in India, for an application that does not require translation to English, to $4772 in Japan, for one which does require translation.[11] GNP taken from the World Bank (Y_n) scales these costs (see (5)). The modeling of diffusion follows that of Eaton and Kortum (for the exact specification, see Appendix A). Data on the determinants of diffusion are distance in kilometers, KM_{ni}, bi-lateral imports as a share of GNP, IM_{ni} (International Monetary Fund, various years) and human capital, HK_n (Barro and Lee, 1996).[12]

Finally, a number of parameters have been pre-determined due to difficulties in identifying all the parameters of the model. These are domestic and foreign imitation rates of non-patented technology ($\iota_{\text{dom}}^{\text{not}}$, $\iota_{\text{for}}^{\text{not}}$), the real rate of interest (r) and the growth rate (g). The foreign imitation rate of non-patented material is based on estimates of Mansfield and Romeo (1980) about the rate at which technology 'leaks out' from US firms to non-US competitors. This hazard rate is set at 0.25. Comparable numbers for the domestic market are reported in Mansfield (1985), which imply a domestic hazard of imitation of 0.8.[13] Finally, the model is solved to attain a steady-state growth rate of 2.8%, which is the average of the countries in the sample over the period 1985–90, and the real interest rate is set at 7%.[14]

6. Parameter estimates[15]

Table 2 contains the parameter estimates. All the parameters are significant except for the catch up parameter, ω, and the sectoral coverage parameters for the

[10]The existence of the European Patent Office (EPO) and the Patent Cooperation Treaty (PCT) have been ignored in the construction of these costs. Both of these options allow an inventor to defer the decision about which countries to file in until after a claim has been examined. For example, in Europe an inventor has a choice between filing in individual European countries or filing with the EPO and subsequently nominating in which European countries protection is sought. The complications introduced by this latter option are not considered in the analysis.

[11]Costs reflecting the annual renewal fees for patents have been ignored (see discussion in Section 1).

[12]This measure of human capital differs from that used in Eaton and Kortum and was adopted due to its wider country coverage.

[13]The treatment of the foreign hazard of imitation follows that of Eaton and Kortum, while the domestic hazard is calculated differently. It was decided for the sake of consistency that foreign and domestic imitation parameters would be taken from comparable sources.

[14]At each iteration of the model during the estimation routine, growth is constrained to equal 2.8%. This is achieved by calibrating the J parameter, conditional on all the estimated parameters, to generate a growth rate of 2.8% (see Appendix A for details).

[15]I would like to thank Sam Kortum for supplying the gauss code from Eaton and Kortum. Aside from the modifications cited already, the numerical routine was changed from the amoeba algorithm to the routines contained within optmum.

Table 2
Nonlinear least-squares coefficients and standard errors

	Symbol	Estimate	S.E.		
Enforcement parameter	γ	0.03	0.004		
Pharmaceutical coverage	s^{ph}	0.19	0.124		
Food coverage	s^{fd}	0.51	0.071		
Chemical coverage	s^{ch}	0.03	0.148	$u'u$	795.60
Working requirement	s^{wr}	0.48	0.049	$v'\Omega_v^{-1}v$	1.201
Step size parameter	θ	3.73	0.782		
Catch up parameter	ω	34.93	75.12		
Mistaken patents	η	0.02	0.004		
Diffusion coefficients:					
Imports	ε_{imp}	0.15	0.043	Number of	869
Human capital	ε_{hk}	3.67	0.687	observations	
Home bias	ε_{dom}	1.21	0.245		
Distance	ε_{km}	−0.23	0.029	σ_u^2/σ_v^2	29.1
Squared distance	ε_{km^2}	0.001	0.0002		
Innovation coefficients:					
Australia	α_{al}	9.76	0.291		
Austria	α_{as}	8.21	0.306		
Belgium	α_{be}	7.99	0.263		
Brazil	α_{br}	6.37	0.340		
Canada	α_{ca}	8.12	0.279		
Columbia	α_{co}	5.36	0.389		
Denmark	α_{dn}	8.01	0.302		
Finland	α_{fi}	8.12	0.306		
France	α_{fr}	10.00	0.244		
Germany	α_{ge}	10.40	0.218		
Greece	α_{gr}	5.10	0.367		
India	α_{in}	4.84	0.403		
Ireland	α_{ir}	6.38	0.330		
Israel	α_{il}	7.72	0.326		
Italy	α_{it}	9.39	0.257		
Japan	α_{jp}	10.26	0.223		
Korea	α_{kr}	5.53	0.320		
Mexico	α_{mx}	4.84	0.364		
Netherlands	α_{ne}	9.10	0.256		
New Zealand	α_{nz}	7.19	0.303		
Norway	α_{nr}	7.04	0.370		
Panama	α_{pa}	4.66	0.535		
Portugal	α_{pr}	4.53	0.366		
South Africa	α_{za}	8.08	0.336		
Spain	α_{sp}	7.41	0.300		
Sweden	α_{sw}	9.03	0.272		
Switzerland	α_{swi}	9.56	0.265		
UK	α_{uk}	9.87	0.234		
US	α_{us}	11.03	0.193		

exclusion from patent protection of the chemical and pharmaceutical industries, s^{ch} and s^{ph}. Taking account of the differences in the size of the sample and the characterization of national patent institutions, the remaining parameters generally conform to those found by Eaton and Kortum.

Turning to the role of patent institutions, the coverage variables reveal that restrictions on both sectoral coverage of patents and how they are worked has a substantial impact on patenting behavior. For example, a country that excludes pharmaceuticals, foods, and chemicals from patenting while requiring that the remaining patents be worked locally, only grants patent protection to 20% of the ideas of patentable quality that diffuse there from a country that offers full sectoral coverage (calculated using Eq. (4) and assuming $D_n^{ph} = D_n^{fd} = D_n^{ch} = D_n^{wr} = 1$ and $D_i^{ph} = D_i^{fd} = D_i^{ch} = 0$). However, it should be noted that only three countries in the sample (India, Mexico, and Portugal) offer such limited sectoral coverage. A clearer sense of the importance of the sectoral coverage of patent protection is given below when the results of Table 4 are discussed.

The parameter on the index of enforcement institutions, γ, shows that these institutions also play a significant role. This parameter implies that the most stringent enforcement institutions lower the risk of imitation by 10% compared to a non-patented outcome (calculated using Eq. (3)). However, to appreciate fully the role of patent institutions, the present value of protection that is offered by these institutions needs to be derived.

7. Patents and rent appropriation

A major concern associated with the adoption of the TRIPs agreement is that technology-importing countries are likely to be exploited by the owners of technology. However, studies of the utilization of the patent system reveal that patent protection is not the sole method used to appropriate the benefits from an invention. Other appropriation strategies based on secrecy, lead time, learning curves and sales/service efforts have all been identified as prominent determinants of the ability to appropriate rents.[16] This suggests that any analysis of the TRIPs agreement must attempt to isolate the role of patent protection in rent appropriation, or risk overestimating the role of patents in rent appropriation.[17]

The parameter estimates reported in Table 2 are used to derive the private value of patent protection based on the institutions that were in place prior to the TRIPs agreement. This value is defined as the increase in the present value of rents accruing to the inventor due to the lower hazard of imitation associated with patent protection, conditional on the estimated flow of innovations. Calculation of this

[16] See Levin et al. (1987).

[17] The static models of Maskus, Subramanian (1994) and others do not allow for alternative rent appropriating methods and equate market power solely with the existence of patent protection.

quantity involves a comparison of the present value of rents appropriated both with and without patent protection (i.e., with these values derived from (2)). The value of patent protection is then the present value of the incremental rents that an inventor appropriates from their extended tenure as technology leader due to the lower hazard of imitation associated with patent protection.

At the bi-lateral level, the private value of patent protection is calculated by multiplying the mean present value of patent rights by the number of patent applications. Combining the exponential distribution of the quality of the invention and the quality threshold for profitable patents identifies the mean value of patent rights as:

$$\int_{\bar{q}_{ni}}^{\infty} [V_{ni}^{\text{pat}}(Q) - V_{ni}^{\text{not}}(Q)]\, f(Q|Q\rangle\bar{q}_{ni})\, \mathrm{d}Q \equiv PV_{ni}^{\text{prof}}$$

The empirical model also allows for the possibility that a certain fraction of inventions with a step size below $\bar{q}_{ni}$ are also patented in country n by residents of country i. The mean present value of patent rights associated with these mistakes is given by:

$$\int_{0}^{\bar{q}_{ni}} [V_{ni}^{\text{pat}}(Q) - V_{ni}^{\text{not}}(Q)]\, f(Q|Q \le \bar{q}_{ni})\, \mathrm{d}Q \equiv PV_{ni}^{\text{mistake}}$$

Hence, the aggregate present value of rents appropriated from patents in country n held by inventors in country i is given by:

$$\varepsilon_{ni}\alpha_i s_{ni}[f_{ni}PV_{ni}^{\text{prof}} + \eta(1 - f_{ni})PV_{ni}^{\text{mistake}}] - \hat{P}_{ni}C_{ni}$$

Table 3 reports these values aggregated to give the present value of patent rights applied for in 1988 under the pre-TRIPs system for each country. The most striking feature of this column is the value of rights held by US residents. The aggregate value of US owned patent rights are not only calculated to be greater than any other country's, but are in fact greater than all other countries taken as a whole. This is a reflection of both the large number of patents held by US residents and the substantial home bias in patenting behavior.

Columns 3 and 4 of Table 3 help to put these numbers into perspective and provide a check on their plausibility. Column 3 provides a general measure of the importance of patent protection by comparing the present value of patent rights to R&D expenditures by business enterprises. This ratio provides a measure of the importance of patent protection as a rent appropriating mechanism. For example, with free entry into the R&D market we would expect this ratio to be approximately one if patents represented the sole source of rent appropriation. With no country recouping more than a quarter of R&D expenditures through patent protection, these predictions are in line with qualitative work which

Table 3
Patent values for Pre-TRIPs regime ($US Millions 1988)

	Present value of patent rents[a]	S.E.[b]	PV of patent rents / R&D expenditure[c]	Share of patent rents from abroad[d]
US	15 329	(2287)	0.15	0.36
Germany	3092	(545)	0.15	0.61
Japan	2554	(333)	0.07	0.18
France	1558	(268)	0.14	0.53
UK	1223	(245)	0.10	0.81
Switzerland	690	(140)	0.24	0.91
Italy	666	(118)	0.12	0.48
Netherlands	465	(89)	0.17	0.84
Sweden	313	(63)	0.12	0.90
Australia	297	(81)	0.22	0.71
Canada	180	(37)	0.05	0.77
Belgium	142	(28)	0.08	0.91
Austria	117	(23)	0.12	0.89
Denmark	104	(21)	0.16	0.98
Finland	93	(19)	0.12	0.95
Spain	58	(11)	0.04	0.74
Israel	41	(9)	NA	0.96
Norway	40	(8)	0.06	0.97
South Africa	24	(1)	NA	0.81
Ireland	17	(4)	0.12	1.00
New Zealand	10	(4)	0.08	0.97
Brazil	9	(1)	NA	0.85
Korea	7	(1)	NA	0.76
Greece	3	(1)	0.04	0.99
Columbia	2	(1)	NA	1.00
Mexico	2	(1)	0.01	0.92
India	1	(0.3)	NA	0.64
Panama	1	(0.2)	NA	1.00
Portugal	1	(1)	0.01	0.99

[a] Expected present value of rents from the lower imitation rate associated with a patent.
[b] Derived using the delta method, see Greene (1993, p. 297).
[c] The R&D variable is expenditure by business enterprises for 1988, taken from OECD (1994, Table 22).
[d] Share of the value of patent rights held by residents of a country that come from patents held in the other 28 countries.

suggests that patents are not the primary method used by inventors to appropriate rents (Levin et al., 1987). They are also similar to predictions from patent renewal models that report ratios with a close resemblance to those in the third column for France, Germany, and the UK (see Lanjouw, 1993; Schankerman, 1991; Pakes, 1986; and Schankerman and Pakes, 1986). These ratios are also consistent with survey evidence for the US which finds that patents tend to raise imitation costs by a median of 11% (Mansfield et al. 1981). Schankerman (1991) interprets this 11%

as an approximate return to a patent holder. This is derived by assuming that without a patent, entry based on the new technology will occur until normal profits are made. However, if a patent raises the entry costs of imitators by 11%, then the patent holder will be able to make pure profits by avoiding these extra costs. The estimated return for the US is 15%, with a standard error of 2.3%, and 11% falls within the associated confidence interval.

The third column of Table 3 also shows that the most developed countries (US, France, Germany, UK, and Italy) rely on the patent system more than less-developed countries (Mexico and Portugal). Such a ranking is consistent with the notion that R&D efforts of less developed countries are directed primarily towards adaptive ends rather than purely innovative ends (Evenson, 1984). However, two elements of this ranking are somewhat surprising, the low ranking of Japan and the highest ranking of Switzerland. As noted previously, an adjustment was made to the number of domestic patents that the Japanese apply for. This adjustment is a crude way of dealing with the idiosyncratic patenting behavior of the Japanese, with an associated tendency to distort the value of Japanese held patent rights if it is incorrect. On the other hand, the highest ranking of Switzerland does seem a plausible result. Nearly 50% of Swiss business R&D expenditures are devoted to chemicals and drugs, in comparison to only 10% for the US. Given the higher than average reliance of chemical and drug firms on patents to appropriate rents (Mansfield, 1986), this suggests that the Swiss ranking is indeed appropriate.

As a final check on the calculated size and distribution of the value of patent rights under the pre-TRIPs system, the forth column of Table 3 provides a breakdown between the rents appropriated from the domestic market and foreign markets. As is to be expected, all but the largest countries appropriate most of their rents from abroad. The breakdown for the US is particularly encouraging, given that Mansfield et al. (1979) find that approximately one-third of the returns to US R&D projects are expected to come from abroad. Taken together, the evidence presented in Table 3 suggests that the approach adopted in this paper captures important elements of what is known about the value and distribution of patent rights under the pre-TRIPs system of patent protection.

Since the estimated parameters contain information on how inventors respond to different institutional settings when evaluating patent protection, this framework can be used to address the question: What are the transfers of income between countries implied by the TRIPs agreement? This question can be answered by setting the institutional parameters in line with those required by the TRIPs agreement. It should be emphasized that an important caveat to the results derived from this experiment is that the level of innovation is assumed to be constant. This restriction limits the ability of this model to characterize fully the welfare outcome of the TRIPs agreement since only the costs of higher standards of patent protection can be evaluated but not the potential benefits it achieves through greater innovation.

Compliance with the TRIPs agreement requires all countries to adopt the same broad sectoral coverage of protection.[18] This requires that coverage be extended to the pharmaceuticals, food and chemical industries. The TRIPs agreement also allows a patent holder to service a market through imports without fear of revocation of patent rights.[19] Finally, the TRIPs agreement requires that a basic enforcement infrastructure be erected to allow patent holders to defend their intellectual property.[20] The implication of these changes can be approximated by setting the sectoral coverage dummies (D^{ph}, D^{fd}, D^{ch} and D^{wr}) to zero and the enforcement index (PG_n) to five. Under these assumptions, the experiment being conducted is equivalent to asking what would the present value of patent rights have been in 1988 if all countries adopted the standards set by the TRIPs agreement in that year.

Representing patent harmonization in this way is subject to a number of qualifications, the most important being the construction of the enforcement index. The enforcement index is constructed by awarding a value of one to a country if a particular aspect of enforcement infrastructure is in place and a zero otherwise. The final total for a country is derived by adding up the number of ones received, together with the duration of protection offered by a country as a fraction of 20 years. An implication of this method of construction is that each enforcement institution is given the same weight, which is not necessarily a true reflection of the relative importance of each institution in lowering the hazard of imitation. If the different enforcement institutions effect the hazard of imitation in a way that is not uniform, then the results are likely to overstate the net transfers for some countries and understate then for others.

Table 4 presents the transfers induced by harmonization. The first column sets out the net transfers associated with the TRIPs agreement, which are defined as the increase in the present value of patent rights held by residents of a country less the increase in the present value of patent rights granted by that country in 1988. This column can be used to provide a ranking of the winners and losers from the TRIPs agreement. On this basis only six countries stand to benefit from the TRIPs agreement: US, Germany, France, Italy, Sweden, and Switzerland. All other countries experience a net loss from raising their standards of patent protection. The US stands out as the major beneficiary, gaining nearly 6 times as much as the second largest beneficiary. Somewhat surprisingly, Canada is the largest loser — over \$1 billion — but this is consistent with Canada's alignment with developing countries in the negotiation of the TRIPs agreement (Cottier, 1991). While the size of Canada's projected loss is surprising, it is still plausible. The potential for this transfer lies in Canada's proximity, size and shared language with the US, factors that combine to make Canada the largest trading partner for the US. However,

[18]See TRIPs Article 27(2) and (3).
[19]See TRIPs Article 27(1).
[20]On term of protection see Article 33, for burden of proof see Article 34(1), injunctions see Article 44 and criminal procedures see Article 61.

Table 4
Transfers associated with TRIPs

	TRIPs net transfer[a] (in $US millions)	S.E.[b]	Net transfer as % of GDP	TRIPs gross transfer[c] (in $US millions)	% of Gross transfer from broader coverage[d]
US	4553	(874)	0.09	73	0.00
Germany	788	(280)	0.07	384	0.00
France	568	(117)	0.06	0	0.00
Italy	231	(47)	0.03	0	0.00
Sweden	71	(39)	0.04	104	0.00
Switzerland	22	(79)	0.01	288	0.60
Panama	0.3	(0)	0.01	0	0.00
Australia	−22	(13)	0.01	166	0.00
Ireland	−48	(7)	0.14	58	0.00
New Zealand	−54	(4)	0.12	60	0.27
Israel	−66	(10)	0.14	89	0.32
Columbia	−77	(9)	0.20	78	0.37
Portugal	−87	(7)	0.18	87	0.34
Netherlands	−96	(67)	0.04	313	1.00
South Africa	−113	(12)	0.13	123	0.40
Greece	−118	(13)	0.22	119	0.35
Denmark	−174	(28)	0.16	227	0.68
Austria	−176	(32)	0.14	229	0.64
Finland	−198	(27)	0.19	238	0.73
Norway	−206	(24)	0.23	226	0.71
Belgium	−224	(40)	0.15	293	0.64
Korea	−326	(31)	0.18	328	0.92
Spain	−345	(98)	0.10	367	0.45
Japan	−439	(204)	0.02	896	0.00
Mexico	−444	(60)	0.26	445	0.29
India	−526	(51)	0.19	526	0.34
UK	−541	(191)	0.06	1044	0.00
Brazil	−926	(95)	0.28	930	0.11
Canada	−1023	(166)	0.21	1107	0.41

[a] The difference between the increase in the value of patent rights held by residents of a country and the increased value of rights granted by that country. Both quantities increase due to the higher patent standards required by the TRIPs agreement.

[b] Derived using the delta method.

[c] The increase in the expected present value of patent rights granted by a country to residents of the other 28 countries.

[d] The share of the gross transfer attributable to the increase in industry coverage of patent protection and abolition of working requirements.

Canada ranks only fifth in terms of destination for US owned patents. In addition, in 1988 US inventors sought only 14 687 patents in Canada while seeking over 75 000 domestically. In contrast, Canada seeks more patents in the US than any other country (including Canada itself). Consequently, the harmonizing of patent standards at a high level of protection provides ample incentive and opportunity for US inventors to seek patents in Canada, without a corresponding opportunity for Canadian inventors. In particular, the TRIPs agreement requires Canada to improve the enforcement of patent rights by making infringement subject to criminal action and by providing for preliminary injunctions to be granted. In addition, the requirement that patents granted in Canada be worked in Canada will be removed under the TRIPs agreement.

Other significant losers are Brazil, UK, India, Mexico, Japan, Spain, and Korea. Of these, the poor performance of the UK and Japan is somewhat unexpected. While the estimated net transfers for both these countries is subject to relatively high standard errors, their ranking is a reflection of the higher standard of enforcement that TRIPs requires of them. Prior to the TRIPs agreement, the UK ranked twenty-fourth on the basis of enforcement, yet still managed to be the second most popular destination for seeking patents among foreign innovators. Under the TRIPs agreement the UK will be required to provide for the granting of preliminary injunctions when infringement of a patent is suspected, along with the reversal of the burden of proof in certain cases involving process patents. In addition, the UK is required to make the infringement of a patent subject to criminal action. These factors combine to generate a substantial increase in the value of UK patent protection, a rise that is not matched by the increase in value of foreign patents held by UK inventors. A similar, though less pronounced, story lies behind the ranking of Japan.[21]

The third column of Table 4 helps to put the size of these transfers into perspective by comparing them to GDP. It is clear that the absolute size of transfers is relatively small, with no country's net transfer being larger than a third of a percentage point of GDP. This column also provides an alternate view of the ranking of net contributors, with Brazil making the largest relative sacrifice and the net contributions of Japan and the UK being relatively minor.

Table 4 also decomposes transfers into those associated with a broadening of the sectoral coverage of protection and a raising of the enforcement efforts. Since most countries end up paying, the focus is on the gross transfers abroad and the share of these transfers attributable to the broadening of the sectoral coverage of protection. The fifth column reveals that transfers from developing countries are generally associated with an increase in the standard of enforcement rather than a widening of the sectoral coverage of protection. For developed countries the relative importance of transfers deriving from sectoral coverage or enforcement changes is divided roughly fifty–fifty. Overall, this breakdown provides some insight into the source of future tensions over intellectual property protection, especially for developing countries. Since the transfers from the developing countries are primarily determined by an increase in enforcement efforts, this suggests that these countries will be more willing to extend the coverage of patent protection as

[21] A full breakdown of bilateral transfers is available in McCalman (1999).

required by TRIPs, but may be less willing to devote adequate resources to enforcement. Hence, future North–South tensions over intellectual property rights are likely to be centered around enforcement issues rather than the sectoral coverage of protection offered.

Given the distribution of benefits from patent harmonization, it is interesting to try to evaluate the relative importance of the TRIPs agreement compared to other aspects of the Uruguay Round. There have now been a large number of studies trying to evaluate the benefits of the Uruguay Round as they relate to liberalization of goods trade.[22] Columns 1 and 2 of Table 5 report the results from a representative study by Harrison et al. (1995) that was performed on a sufficiently disaggregated level to enable comparisons to be made at a country level.[23] The work of Harrison et al. evaluated the market liberalization consequences of the following three policy changes: (i) tariff reductions on manufactured goods; (ii) liberalization of agricultural protection; and (iii) the elimination of the Multifibre Arrangement. While caution should be applied to the interpretation of comparisons made across models, it appears that the TRIPs agreement does play a prominent

Table 5
Distribution of gains from trade liberalization and patent harmonization ($US millions 1988)

	Efficiency gains			
	From trade liberalization		Net of TRIPs transfer	
	Short run[a]	Long run[a]	Short run	Long run
Australia	1017	2745	994	2722
EU	33 117	42 020	32 768	41 671
Canada	1088	2199	65	1176
Japan	14 220	19 127	13 780	18 688
New Zealand	336	1204	281	1149
US	11 185	22 458	15 738	27 011
Brazil	1215	3593	288	2666
South Asia[b]	3130	5677	2604	5151
Mexico	129	1931	−316	1486
Korea	4036	6270	3710	5944
LDC	16 298	46 437		
DEV	64 459	97 167		
World	80 757	143 603		

[a] Adapted from Harrison et al. (1995).
[b] South Asia includes a number of countries other than India. However, the efficiency gain net of TRIPs transfers only includes the transfer made by India.

[22] See Francois et al. (1995) for a survey.
[23] The short run setting reported by Harrison et al. (1995) and reported in Table 5 refers to a situation in which the capital stock is fixed. In contrast, the long run outcome allows for the capital stock to be adjusted in response to changes in relative prices. This long run outcome ignores adjustment costs and therefore serves as an upper bound on the welfare gains of the Uruguay Round.

role in shaping the outcome of the Uruguay Round.[24] Columns 3 and 4 report the estimates of Harrison et al. net of the transfers implied by TRIPs. Taking account of the TRIPs agreement, the US finds that its gains from the Uruguay Round are substantially enhanced by patent harmonization (an increase of 40% in the short run and increase of 20% in the long run). For Mexico, Canada, and Brazil patent harmonization also plays a large role in determining the outcome of the Uruguay Round. All of these countries now find that the Uruguay Round is of questionable benefit in the short run and that patent harmonization reduces substantially the magnitude of any long run gains.

8. Conclusion

This paper extends the analysis of the Uruguay Round by quantifying the impact of international patent harmonization as implied by the TRIPs agreement. What emerges from this analysis is a picture of patent protection as an important method for appropriating the rents of an invention. Although it is not the primary method of rent appropriation, patent harmonization has the capacity to generate large transfers of income between countries, with the US being the major beneficiary. The developing countries are not alone in financing transfers, with Canada, the UK, and Japan also making sizable contributions. These transfers significantly alter the perceived distribution of benefits from the Uruguay Round, with the US benefits substantially enhanced, while those of developing countries and Canada considerably diminished. However, dynamic efficiency gains from increased innovation may go some way to offsetting the negative impact of these transfers, which is an issue for future research.[25]

A number of restrictive assumptions were made when deriving the estimates of this paper. In particular, the model precluded from consideration both the role of trade in patented inputs and the role of multinationals. By precluding trade in inputs, possible efficiency enhancing aspects of the TRIPs agreement may have been overlooked. If an inventor finds that the requirement to produce locally is accompanied by an increase in costs, which may be the case if there are increasing returns to scale in production, then there will be additional efficiency gains under TRIPs from the removal of 'working requirements'. On the other hand, the inclusion of multinationals may have a more ambiguous effect on the predicted outcome. The modeling of multinationals would allow the link between foreign direct investment and technology transfer to be studied more directly. In particular,

[24] One precaution that has been taken is the selection of a study that reports simulations for 1992, which are then discounted to 1988 to make the numbers comparable. Other studies report implications for 2005 when the Uruguay Round will be fully implemented, which includes the benefits of projected growth between 1992 and then.

[25] See Eaton et al. (1998) for a framework with endogenous R&D.

the concern that developing countries have expressed over the removal of the working requirement can be evaluated. Their concern is that without a local production requirement, multinationals will only set up plants to assemble imported components, thereby reducing both the amount of technology transferred and the spill-over benefits associated with that technology. Such an effect will further undermine the productivity differential and has implications for both the distribution of income and global efficiency.

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Appendix A

Output is derived from the following production function:

$$\ln Y = J^{-1} \int_0^J \ln[Z(j)X(j)]\,\mathrm{d}j$$

where Y is the quantity of output, $X(j)$ is the quantity of input j and $Z(j)$ is the quality of input j. A measure of the level of technology in country n is:

$$\ln A = J^{-1} \int_0^J \ln Z(j)\,\mathrm{d}j$$

The improvement in the quality of an input is described by the step size of the invention, with an invention of size q applicable to input j raising the quality of that input from $Z(j)$ to $Z(j)' = e^q Z(j)$. The step size of an innovation is a random variable drawn from an exponential distribution; $\Pr[Q < q] = 1 - e^{-\theta_{ni} q}$, where $\theta_{ni} = \theta(A_i/A_n)^{-\omega}$ and the catch up parameter, ω, is assumed to be strictly greater than zero.

To solve the model begin by defining: $\mu_n = A_n^{\omega}$. This implies $(\mathrm{d}\mu_n/\mathrm{d}t) = (\mathrm{d}A_n^{\omega}(t)/\mathrm{d}t) = \omega A_n^{\omega-1}(\mathrm{d}A_n/\mathrm{d}t) = \omega A_n^{\omega-1}\dot{A}_n = \dot{\mu}_n$. Noting that $g_n = (\dot{A}/A) = (1/J\theta) \sum_{i=1}^{N} \varepsilon_{ni}\alpha_i(A_i/A_n)^{\omega}$, then $\mu_n = (\omega/J\theta) \sum_{i=1}^{N} \varepsilon_{ni}\alpha_i \mu_n$. This defines a system of linear differential equations $\dot{\mu} = (\omega/J\theta)\,\Delta\mu$. Under a wide range of parameter values this system has a single, strictly positive eigenvalue, λ^F, with a corresponding eigenvector, μ^F, which satisfies $(\omega/J\theta)\lambda^F\mu^F = (\omega/J\theta)\,\Delta\mu^F$. This allows the range of inputs, J, to be calibrated, conditional on all the estimated parameters, to achieve the desired growth rate, g (i.e., $J = \lambda^F/g\theta$). From the eigenvector the relative technological indices are given by:

$$A_i/A_N = (\mu_i/\mu_N)^{1/\omega}.$$

Using this index and the parameter values the predicted bi-lateral patenting behavior is:

$$\hat{P}_{ni} = \alpha_i \varepsilon_{ni} s_{ni}[f_{ni} + (1 - f_{ni})\eta] \quad i, n = 1, \ldots, 29$$

where

$$\varepsilon_{ni} = \exp[\varepsilon_{\text{dom}} DH_{\text{ni}} + \varepsilon_{\text{km}} KM_{\text{ni}} + \varepsilon_{km2} KM^2 - \varepsilon_{\text{hk}}(1/HK)] IM_{ni}^{\varepsilon \text{imp}}$$

$$s_{ni} = (1 - s^{\text{ph}} D_n^{\text{ph}}(1 - D_i^{\text{ph}}))(1 - s^{\text{fd}} D_n^{\text{fd}}(1 - D_i^{\text{fd}}))(1 - s^{\text{ch}} D_n^{\text{ch}}(1 - D_i^{\text{ch}})) \times (1 - s^{\text{wr}} D_n^{\text{wr}})$$

$$f_{ni} = \left(1 - \frac{J(r + \iota_{ni}^{\text{pat}} + o_n - g)(r + \iota_{ni}^{\text{not}} + o_n - g) C_{ni}}{(\iota_{ni}^{\text{not}} - \iota_{ni}^{\text{pat}}) Y_n}\right)$$

$$\iota_{ni}^{\text{pat}} = \begin{cases} \iota_{\text{dom}}^{\text{not}}\, e^{-\gamma PG_n} & \text{for } i = n \\ \iota_{for}^{not}\, e^{-\gamma PG_n} & \text{for } i \neq n \end{cases}$$

$$o_n = \frac{1}{J} \sum_{i=1}^{N} \varepsilon_{ni} \alpha_i$$

$$\theta_{ni} = \theta \left(\frac{A_i}{A_n}\right)^{-\omega}$$

The relative technology index also generates a predicted value for relative labor productivity.

$$\frac{\hat{y}_n}{y_N} = \frac{\Gamma_n A_n}{\Gamma_N A_N} \quad n = 1, \ldots, 28$$

where

$$\Gamma_n = \frac{\exp\left(-\sum_{i=1}^{N} \phi n_{ni}/\theta_{ni}\right)}{\sum_{i=1}^{N} \phi_{ni}\theta_{ni}/(1 + \theta_{ni})} \quad \text{and} \quad \phi_{ni} \equiv \varepsilon_{ni}\alpha_i \left[\sum_{j=1}^{N} \varepsilon_{nj}\alpha_j\right]^{-1}$$

The errors are given by

$$u_{ni} = \log(P_{ni}) - \log(\hat{P}_{ni}) \qquad n, i = 1, \ldots, 29$$
$$v_i = \log\left(\frac{y_n}{y_{us}}\right) - \log\left(\frac{y_n}{y_{us}}\right) \qquad n = 1, \ldots, 28$$

The objective function is to minimize $u'u + \sigma_u^2/\sigma_v^2\ (v'\Omega_v^{-1}v)$ where $\Omega_v = [I_{N-1} + e_{N-1}e'_{N-1}]$ and e_{N-1} is a $N-1$ vector of ones. Estimation employs a two-step feasible generalized nonlinear least-squares procedure. The first step imposes a value on the ratio of σ_u^2/σ_v^2. To obtain efficient estimates the residuals are used to calculate estimates of $\hat{\sigma}_u^2$ and $\hat{\sigma}_v^2$ which are then used in the minimization routine.

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