Who enjoys 'TRIPs' abroad? An empirical analysis of intellectual property rights in the Uruguay Round

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Abstract. Analysis of the Uruguay Round is extended by quantifying the impact of the TRIPs agreement. The static costs of raising the standards of patent protection are captured by the transfers of income between countries, with the majority of countries estimated to make net payments abroad, the United States being a major beneficiary. To offset these transfers the model provides estimates of the dynamic benefits from the greater incentive to innovate, revealing that there is potential for all countries to benefit from the TRIPs agreement in the long run. However, the distribution of these benefits is highly skewed towards developed countries. JEL classification: O34, F43

Qui tire profit des ADPICs à l'étranger? Une analyse empirique des droits de propriété intellectuelle dans la Ronde de l'Uruguay. On analyse les décisions de la Ronde de l'Uruguay en vue de quantifier l'impact de l'accord sur les droits de propriété intellectuelle qui touchent au commerce. Les coûts statiques de normes plus élevées pour la protection des brevets sont mesurés par les transferts de revenus entre pays. On estime que la majorité des pays effectuent des transferts nets vers l'extérieur, et que les Etats-Unis sont un bénéficiaire important de ces transferts. Pour compenser ces transferts, le modèle cherche à déterminer les avantages dynamiques qu'il y a à encourager ainsi l'innovation, et montre qu'il y a un potentiel de gains pour tous les pays découlant des accords sur les ADPICs à plus long terme. Cependant, la répartition de ces avantages est fortement biaisée en faveur des pays développés.

1. Introduction

The completion of the Uruguay Round of GATT negotiations resulted in fundamental changes in the way the multilateral trading system operates. The scope of these changes is so dramatic that they are overseen by a new

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international institution, the World Trade Organization (WTO). This new institution extends GATT principles to a range of issues that had previously escaped discipline. Included in these new issues is an agreement on the Trade Related aspects of Intellectual Property Rights (TRIPs).[1]

Despite a title that implies a focus on trade issues, this agreement effectively defines what rights an inventor is entitled to and what institutions should be available to enforce these rights. For instance, TRIPs requires that patent protection must be available for at least 20 years, that protection must be available for almost all areas of technology (including pharmaceuticals and plant varieties) and that the importation of patented products is consistent with proper exploitation of a patent (i.e., domestic production/working of a patent is not required).[2] Moreover, having intellectual property laws is not enough. They have to be enforced. The agreement says governments have to ensure that intellectual property rights can be enforced under their laws, and that the penalties for infringement are tough enough to deter further violations. In fact, TRIPS describes in detail how enforcement should be handled, including rules for obtaining evidence, provisional measures, injunctions, damages, and other penalties. The striking thing about this agreement is that not only is it 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 WTO to the same standards. This harmonization of standards requires major reforms in most developing countries and has raised a number of concerns over the consequences of the TRIPs agreement. Foremost among these concerns is the redistributive nature of the agreement, especially in the short run. This redistributive element carries particularly important political implications for countries making payments to foreign owners of technology. From this perspective, it is important to try to assess the size of these transfers, since speculation as to their size can seriously undermine the realization of the potential benefits of the TRIPs agreement. The benefits, however, will become apparent only in the long run, as firms respond to a changed set of incentives. Ultimately, the value of the TRIPs agreement must lie in the ability to raise income levels. However, no detailed empirical analysis of the long-run impact of the TRIPs agreement has been conducted, a situation that has contributed to the delay in pursuing further negotiations within the WTO.[3]

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1 For an overview of the TRIPs agreement see Maskus (2000) and Keely (2000).

2 Both an overview of the TRIPs agreement and its text can be found at www.wto.org.

3 See Subramanian (1999) for a discussion of the role that TRIPs has played in the delay of the Millennium Round. For theoretical models of various aspects of the TRIPs agreement see Chin and Grossman (1990), Deardorff (1992), Diwan and Rodrik (1994), Helpman (1993), Lai (1998), and Taylor (1994).

The objective of this paper is to clarify these issues by estimating the impact of the TRIPs agreement.[4] Estimates are derived from a multi-country model of (semi) endogenous growth. The basic framework relates innovations to productivity growth through a quality ladders model, with the source of innovations (domestic or foreign) related to patenting behaviour. Importantly, the decision to seek a patent is modelled as one taken by a profit-maximizing inventor, with a patent sought only in those countries that provide patent protection and whose protection is sufficiently valuable to warrant paying the cost of a patent. The structural model allows the value of patent rights held by 27 countries to be estimated and provides a basis for an examination of how the value of these rights are affected by the TRIPs agreement. By analysis of the affect of the TRIPs agreement on the incentives to conduct R&D, an assessment of both the short- and long-run implications of the TRIPs agreement can be derived, thereby facilitating a more complete assessment of the implications of the GATT Uruguay Round. The ability to offer an empirical analysis of the long-run implications of the TRIPs agreement is the main motivation and core contribution of this paper.

The results of the short-run analysis confirm the relatively bleak picture for the majority of countries from McCalman (2001), one in which the TRIPs agreement serves as a mechanism for foreign owners of technology to increase their ability to appropriate rents. However, these short-run estimates do not take into account the changed incentives that innovators face from the higher standards of protection implied by the TRIPs agreement. Allowing research effort to respond to these greater incentives (and using the baseline parameter estimates) reveals that the income levels of all countries are raised to a degree that is sufficient to offset any negative redistributive impacts, making the TRIPs agreement potentially beneficial to all members of the WTO. However, these benefits are not evenly distributed. The largest proportional gains accrue to Switzerland with an income level estimated to be 2.4% higher in steady state. In contrast, the TRIPs agreement delivers the smallest gains to India, which experiences a gain of only 0.08% in the level of steady-state income.

Sensitivity analysis reveals that the uneven distribution of benefits is a robust conclusion; however, it is possible to find plausible parameter values that return a negative long run prediction for India. This finding raises doubts about the sustainability of the TRIPs agreement and suggests that the current approach of allowing transition phases for developing countries may need to be extended beyond their current limits. Such an outcome raises the possibility of differential standards of patent protection persisting around the world. While this may lead some to predict that TRIPs cannot function in such an environment, analysis of the unilateral incentives countries have to adopt the TRIPs standards reveals that TRIPs may still produce long run benefits for all, even if only a subset of countries adopt the TRIPs standards.

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[4] For analysis of other aspects of IPR reform see McCalman (2004a) and McCalman (2004b).

To establish these results the paper is structured as follows. Section 2 provides an overview of the model and the sources of growth in a multi-country world. Section 3 relates the patenting decision to the parameters of the growth model and derives an equation that can be taken to the data to gain sight into the process of international technology diffusion. Section 4 sets out the estimation strategy and presents the parameter estimates. Section 5 describes the implications of the model for the pre-TRIPs set-up, while sections 6 examines the counterfactual exercises of implementing the TRIPs agreement both for short-run transfers of between countries and the long-run impact on steady-state income levels.

2. The model

To analyse the relationship between patents, innovation, and income a model of semi-endogenous growth is utilized. This framework employs a quality ladders setup similar to Helpman and Grossman (1991) and as extended by Eaton and Kortum (1996). Specifically, in any country it is assumed that output, Y, is produced by combining intermediate inputs subject to a constant returns to scale Cobb-Douglas production function,

$$\ln\ Y = J^{-1} \int_0^J \ln\ [Z(i)X(i)]dj,$$

where $X(j)$ is the quantity of input i. The range of inputs is fixed over time and the same across countries. Output is homogeneous and tradable across countries while inputs are non-traded. Output expands over time as the quality of inputs improve. The quality of inputs within country n is measured by

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

An important aspect of the model is that improvement in an inputs quality can come from an innovations from either domestic or foreign inventors. If an innovation of size q is adopted at home it makes the input e^q times better. The size of an innovation, q, is interpreted as the inventive step, and it is assumed that each innovation is a draw from an exponential distribution with parameter θ. Thus the average step size of a domestic innovation is $1/\theta$.

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. This reflects the notion that a given idea is likely to have a larger percentage impact the more backward is the country, with an idea from country i that represents an improvements of q at home generating an improvement of size $q(A_i/A_n)^{\omega}$.

While some inventions are widely applicable, others will only be useful to a small number of countries. Let ε_{ni} represent the fraction of ideas that are generated in country i and are adopted in country n. In the empirical application, these probabilities are related to the distance between countries, the level of bilateral imports and the level of human capital in the recipient country. (The exact specification is set out in the appendix.) Letting α_i denote the flow of innovation produced by country i, then ideas flow into country n from country i at rate $\varepsilon_{ni}\ \alpha_i$.

To generate a flow of ideas, one must invest in R&D. To keep the model tractable, the specification that links R&D and innovations is chosen to generate semi-endogenous growth, following Jones (1995). In this framework an explicit link between the expected value of an innovation and the resources devoted to R&D can be developed. This is the key difference between the specification used by McCalman (2001) and the model used in this paper. In McCalman (2001), it was assumed that the level of innovation was given. Consequently, that framework could not be used to address issues relating to the changed incentives to undertake R&D. In contrast, the general equilibrium structure of the current model can be exploited to assess the long-run implication of changes in patent policy.

The R&D equation is assumed to take the following form:

$$\alpha_i = \frac{a_i(r_i L_i)^{\beta}}{\overline{A}^{\phi}}, \tag{1}$$

where L_i is the labour force of country i, r_i is the fraction of the labor force devoted to research and $\overline{A}$ is the average level of technology in the world. This specification captures the notion that as a country's research effort increases, less able researchers are called upon. This decline in the talent of researchers is reflected in the parameter β. Allowance is also made for the possibility that as technology advances, coming up with new inventions gets more difficult (represented by the term $\overline{A}^{\phi}$). One consequence of this specification is that the steady-state growth rate is constant, and any change in resources devoted to R&D reflected is in income levels and not growth rates.

Combining the above elements, the growth rate of country n can be related to innovations from around the world according to

$$g_n = \frac{\dot{A}_n}{A_n} = \frac{1}{J\theta}\sum_{i=1}^{N} \varepsilon_{ni}\alpha_i \left(\frac{A_i}{A_n}\right)^{\omega}, \text{ n} = 1, \ldots, \text{N}.$$

Note that as a destination country lags further behind, the ideas that arrive have a bigger percentage impact on productivity. If ε_{ni} and α_i are strictly positive and constant, this force eventually brings all countries to a common steady-state growth rate, although relative productivities permanently differ due to differences in ability to adopt innovations.

One implication of the equilibrium of this model is that there is a proportional relationship between labour productivity and the technology index:

$$y_n \equiv \frac{Y_n}{L^p_n} = \Gamma_n A_n. \tag{2}$$

This proportionality factor is a function of the number of inventions produced by a country (i.e., equation (1)), the probability of diffusion, ε_{ni}, and the strength of patent protection. The assumptions that are made about pricing behaviour are an important factor that determines the details of this proportionality factor. This paper differs from McCalman (2001) in that it allows for both obsolescence and imitation to change markups[5], while McCalman (2001) allowed only obsolescence to change markups.[6] Allowing for a more complicated pricing strategy generates a more complex proportionality factor, Γ_n.[7]

3. The patenting decision

Once in possession of an innovation, an inventor must decide whether it is sufficiently valuable to patent and, if so, in which countries to patent. This decision is modelled like that in McCalman (2001), resulting in the following bilateral patenting[8] equation:

$$P_{ni} = \alpha_i \varepsilon_{ni} f_{ni} s_{ni} \tag{3}$$

where

$$f_{ni} = \left(1 - \frac{J(r + \iota^{pat}_{ni} + o_n - g)(r + \iota^{not}_{ni} + o_n - g)C_{ni}}{(\iota^{not}_{ni} - \iota^{pat}_{ni})Y_n}\right)^{\theta_{ni}} \tag{3a}$$

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

$$s_{ni} = \Pi_j (1 - s^j D^j_n (1 - D^j_i)). \tag{3c}$$

The bilateral patenting equation (3) captures the following process: country i generates a flow of α_i inventions (given by equation (1)) which diffuse to country n with probability ε_{ni}. The cost-benefit analysis surrounding the decision to patent is based on the difference in the expected present value of rents

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[5] This follows the pricing assumption of Eaton, Gutierrez, and Kortum (1998).

[6] McCalman (2001) employs the same pricing assumptions as Eaton and Kortum (1996).

[7] The details of Γ_n are contained in the appendix.

[8] Note that under this formulation the number of patents is taken to be a continuous variable. However, since most patent values are quite large, there is little gain from adopting a probability model that ensures integer valued realizations.

that an inventor receives with and without a patent.[9] Since a patent lowers the hazard of imitation (from ι_{ni}^{not} to ι_{ni}^{pat}), it increases the expected flow of rents from a market where a patent is held.[10] An allowance is made for the hazard of imitation to differ between domestic (*dom*) and foreign (*for*) innovations (see equation (3b)). In either case, the stronger the protection offered in a market, the higher the expected flow of rents. However, seeking a patent in a market also involves paying a set of administrative fees for that market, C_{ni}. These costs include application fees as well as translation fees if the patent must be filed in a language different from that of the inventor. If the incremental increase in the flow of rents is greater than the cost of patenting, then a patent will be sought. The fraction of innovations that satisfy this condition is given by f_{ni}, which also depends on the growth rate (g), the rate of interest (r), an index of the number of markets (J) and the steady-state rate of obsolescence (o_n) (see equation (3a)). The functional form of f_{ni} is an implication of the assumption that the quality of an innovation is modelled as a draw from an exponential distribution.

However, not all countries offer patent protection in all industries. Consequently, it is possible that a valuable innovation appears in a market, yet a patent will not be granted. In this case, only a fraction, s_{ni}, of the innovations will apply to industries that are covered by patent protection (equation (3c)). Whether or not an industry is covered by patent protection is captured by the dummy variable, D, which takes on a value of zero if protection is offered in that sector. Therefore, inventions that are sufficiently valuable and apply to a sector that offers patent protection are the ones that are ultimately patented.

4. Empirical implementation

To explore the implications of the model, the equilibrium predictions are utilized. In particular, the implications of the theoretical model are captured in two equations, the bilateral patenting equation (equation (1)) and the labour productivity equation (equation (2)). To estimate the bilateral patenting equation, begin by assuming that it is subject to an error, u_{ni}, which is taken to be independently and identically distributed with a variance of $\sigma_u{}^2$. This implies the following empirical relationship:

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

Following Eaton and Kortum (1996), it is assumed that a fraction of inventions, η, that are not worth patenting are patented by mistake. The bi-lateral patenting equation then becomes

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[9] For other approaches to analysing the decision to patent, see Pakes (1986), Lerner (1995), and Lanjouw and Schankerman (2001).

[10] Imitation is assumed not to be instantaneous without a patent.

$$P_{ni} = \alpha_i \varepsilon_{ni}[f_{ni} + (1 - \mathrm{f_{ni}})\eta]\mathrm{s_{ni}}\mathrm{e}^{\mathrm{u_{ni}}}. \tag{4}$$

Consider, next, the relationship between labour productivity and the technology index, whose equilibrium relationship is given by equation (2). In order to gain a measure of the technology index, the dynamic system must be solved. This evolution is a function of innovative behaviour (equation (1)), the structure of international diffusion of ideas and the exogenous growth rate, g. The solution to this dynamic system is described by an eigenvector, yielding the implicit value of the technology index for each country.[11] However, since the eigenvector is defined only up to a scalar multiple, the model has implications only for relative productivity levels. Hence, the following relative productivity equation is estimated:

$$\frac{Y_n}{Y_N} = \frac{\Gamma_n A_n}{\Gamma_N A_N} e^{v_n - v_N}, \tag{5}$$

where each country's productivity is measured relative to that of country N, a role that is allocated to the United States. It is assumed that the error, v_n, is independently and identically distributed with a variance of σ_v^2.

4.1. Estimation

The model embodied by equations (4) and (5) can be summarized as

$$Z = H(X, \vartheta), \tag{6}$$

where Z is a vector of endogenous variables (bilateral patenting and labour productivity), X is a vector of exogenous variables (DH_{ni}, KM_{ni}, $KM^2{}_{ni}$, HK_n, IM_{ni}, $D^j{}_i$, $D^j{}_n$, r_i, C_{ni}, Y_n, IP_n), and ϑ is a vector of parameters (ε_{dom}, ε_{km}, ε_{km2}, $\varepsilon_{\mathrm{hk}}$, $\varepsilon_{\mathrm{imp}}$, s^j, a_i, β, ϕ, ω, θ, ι_{ni}^{not}, ι_{ni}^{pat}, γ, η, J).[12] The relationships summarized by (6) represent a non-linear model.

Table 1 summarizes some of the key variables relating to patenting behaviour. In relation to previous work, the main innovation in this dataset is the construction of the patent index. Previous work has used measures that are based on laws that are on the books, with a natural criticism that this neglects enforcement issues. To take into account the variation in patent standards due to enforcement considerations, the measure of laws on the books (derived from Ginarte and Park 1997) is multiplied by an index of legal efficiency (EMF foundation 1989).

The model of patenting set out in section 3 suggests that important determinants of patenting behaviour are factors that affect the probability that an idea diffuses (distance, human capital, trade), the market size, the cost of patenting and the strength of patent protection. To get a sense of the whether these factors are correlated with bilateral patenting behaviour, table 2 presents OLS results for

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[11] See the appendix for the steps involved in solving the dynamic system.

[12] The definitions of all variables can be found in the appendix.

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

	Domestic patents[a]	Foreign patents[b]	Patents abroad[c]	*IP* Index[f]	Pharmaceuticals excluded[d]	Food excluded[d]	Chemicals excluded[d]	Imports excluded[e]
United States	75,633	69,097	177,529	2.85	0	0	0	0
Japan	63,053	35,219	96,952	3.03	0	0	0	0
Germany	31,981	51,140	117,131	2.86	0	0	0	0
United Kingdom	20,903	58,448	47,353	1.58	0	0	0	0
France	12,438	52,343	47,822	3.24	0	0	0	0
Australia	6,573	15,399	10,567	2.24	0	0	0	0
Korea	5,699	11,618	897	2.38	1	1	1	0
South Africa	4,829	4,870	1,323	1.27	0	0	0	1
Israel	4,829	2,835	2,223	2.27	0	0	0	1
Sweden	3,413	34,076	16,872	2.61	0	0	0	0
Switzerland	3,251	33,151	25,483	3.25	0	0	0	1
Canada	2,773	28,295	8,780	2.60	0	0	0	1
Brazil	2,343	9,803	508	0.18	1	1	1	1
Italy	2,290	41,900	22,454	1.59	0	0	0	0
Austria	2,228	29,626	6,578	2.45	0	0	0	1
Netherlands	2,162	37,667	18,879	4.03	0	0	0	1
Finland	2,039	7,191	6,160	3.58	1	1	0	1
Spain	1,817	23,963	2,526	1.02	1	0	1	0
Denmark	1,332	9,693	5,923	3.22	0	1	0	1
India	1,034	2,737	134	1.15	1	1	1	1
Norway	929	8,400	2,600	3.41	1	1	0	1
New Zealand	804	3,607	711	1.98	0	0	0	1
Mexico	733	4,459	177	0.40	1	1	1	1
Ireland	728	3,157	921	0.68	0	0	0	1
Belgium	637	32,377	5,663	2.71	0	0	0	1
Greece	375	13,118	223	1.23	1	0	0	1
Portugal	55	2,407	156	1.47	1	1	1	1

a Patent applications by residents of each country for 1988 in 000s, from WIPO (1990) and unpublished data

b Applications from residents of other 26 countries

c Applications by residents of a given country for patent protection in one of the other 26 countries

d Dummy variable assigned a value of one if the sector is excluded from patent protection in a given country, WIPO (1988)

e Dummy variable 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 zero to five, which summarizes the national enforcement institutions associated with patent protection; adapted from Ginarte and Park (1997) and EMF foundation (1989)

the bi-lateral patenting behaviour between 27 countries (i.e., 729 bilateral relationships).[13] While offering only descriptive evidence, a model based on the variables suggested by the above theory appears to capture important elements in the patenting decision, with all variables estimated to have the correct signs and be significant. However, these OLS estimates do not utilize the functional forms suggested by equation (3), and they do not capture a number of equilibrium

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[13] For a description of the variables and sources, see the appendix.

TABLE 2
OLS estimates of patenting determinants

Variable	Estimate	Std error
Distance	−0.31	0.025
Distance squared	0.01	0.001
Human capital	0.06	0.02
Application cost	−0.0002	0.00003
ln(GDP)	0.62	0.03
IPR	0.065	0.028
Scope	−0.61	0.12
ln (researchers)	0.84	0.04
ln (Imports)	0.12	0.02

properties of the model (e.g., the role of the growth rate, the steady-state rate of obsolescence or the imitation rates).

To facilitate estimation of the full model, a number of parameters have been predetermined. In particular, the estimated model cannot identify all the imitation rates implied by the theoretical model. To overcome this issue, the domestic and foreign imitation rates of non-patented technology $\left(\iota^{not}_{dom}, \iota^{not}_{for}\right)$ are set to predetermined values. 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 U.S. firms to non-U.S. 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. In addition, the model is solved to attain a steady-state growth rate of 2.45%, which is the average for the 27 countries in the sample over the period 1985–90, and J is calibrated so that the model achieves this growth rate exactly. Furthermore, such a growth rate implies that ϕ is equal to 0.31.[14] The real interest rate is set at 7%.

In order to estimate the remaining parameters, logarithms are taken of equation (6), which yields, after isolating the additive error structure, the following system: $z = h(X, \vartheta) + \psi$. ψ is a vector of errors that are assumed to satisfy $E[\psi \mid x] = 0$, with an assumed covariance matrix of

$$\Omega = \begin{bmatrix} \sigma_u^2 I_N^2 & 0 \\ 0 & \sigma_v^2 \Omega_v \end{bmatrix},$$

where I_k is a $k \times k$ identity matrix, and $\Omega_v = [I_{N-1} + e_{N-1} e'_{N-1}]$, where e_{N-1} is an $N - 1$ vector of ones. An estimate of the parameter vector, $\hat{\vartheta}$, is obtained through non-linear least squares.[15] In particular, $\hat{\vartheta}$ is chosen to minimize,

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[14] The steady state implies the following condition holds: $\phi = g_L/g$, where g_L is the growth rate of the labour force and g is the growth rate of income.

[15] For a discussion of non-linear least squares, including issues associated with identification, see Greene (2001).

$[z - h(X, \hat{\vartheta})]'\Omega^{-1}[z - h(X, \hat{\vartheta})]$. Note that the assumed covariance matrix corrects for the correlation in the errors induced by the use of relative productivities.[16]

4.2. Results

Table 3 reports the results from the non-linear least squares procedure. Overall, the parameters are precisely estimated, with all but the estimates of s^{ph} significant at conventional levels. While the specification differs from that used in McCalman (2001), it is still sufficiently close that the estimates can be meaningful compared. The main differences in the specification relate to that inclusion of an innovation production function (in order to facilitate the long-run analysis) and the allowance of more complex pricing behaviour. This new specification has an asymmetric impact on the fit of the model, with a better fit achieved for bilateral patenting behaviour but an inferior fit for the relative productivity equation. Nevertheless, the estimated parameters that are comparable (ε_{dom}, ε_{km}, ε_{km2}, $\varepsilon_{\mathrm{hk}}$, $\varepsilon_{\mathrm{imp}}$, s^{j}, ω, θ, γ, η) are similar under the two specifications. The most notable difference is the estimate of ε_{imp}, with the current specification generating a much greater role for trade in the international diffusion of ideas.

The central new parameter estimated is β. In a traditional production function framework, this parameter would describe the nature of decreasing returns to scale, with an estimate of less than one indicating decreasing returns. In an endogenous growth set-up, knowledge spillovers offset the decreasing returns and provide an ongoing incentive to invest in R&D. In a model of semi-endogenous growth (as employed in the current paper), knowledge spillovers are not sufficient to offset the decline in the productivity of R&D to provide an ongoing incentive to conduct research. Instead, the growth of the market (through population growth) provides this incentive. An estimate of 0.27 suggests that decreasing returns set in relatively quickly. In addition, heterogeneity in research productivity (a_i), provides scope for differences in the amount of research undertaken around the world.

In isolation, most the parameters are difficult to interpret, making it hard to assess the value of the model. One gauge of the fit, and therefore the value of the model, can be gained through simulation exercises that allow the performance of the model to be benchmarked against previous findings in the literature on patent values.

5. The pre-TRIPs system

In order to calculate the value of a country's patent portfolio, the structural model will be exploited. In particular, section 3 describes the patenting decision

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[16] For further details on the properties of the estimator, see the appendix.

TABLE 3
Non-linear least squares coefficients and standard errors

	Symbol	Estimate	Std error		
Enforcement parameter	γ	0.51	0.14		
Pharmaceutical coverage	S^{ph}	0.11	0.12		
Food coverage	S^{fd}	0.51	0.06		
Chemical coverage	S^{ch}	0.18	0.12	$u'u$	447.14
Working Requirement	S^{wr}	0.33	0.05	$v'\Omega_v^{-1}v$	4.10
Step-size parameter	θ	1.85	0.16		
Catch-up parameter	ω	0.89	0.21		
Mistaken patents	η	0.05	0.007		
Research elasticity	β	0.27	0.03		
Diffusion coefficients				Number of observations	755
Imports	ε_{imp}	0.47	0.03		
Human capital	ε_{hk}	2.77	0.50		
Home bias	ε_{dom}	−0.41	0.18		
Distance	ε_{km}	−0.06	0.02	$\sigma^2{}_u/\sigma^2{}_v$	3.83
Distance squared	ε_{km2}	0.001	0.0001		
Research productivity					
Australia	a_{al}	307.8	67.6		
Austria	a_{as}	595.3	130.5		
Belgium	a_{be}	236.5	49.4		
Brazil	a_{br}	10.9	3.1		
Canada	a_{ca}	81.3	16.9		
Denmark	a_{dn}	542.2	122.2		
Finland	a_{fi}	565.2	119.0		
France	a_{fr}	279.8	53.6		
Germany	a_{ge}	239.9	43.1		
Greece	a_{gr}	52.4	14.6		
India	a_{in}	0.4	0.1		
Ireland	a_{ir}	92.0	21.2		
Israel	a_{il}	427.6	94.3		
Italy	a_{it}	172.1	35.6		
Japan	a_{jp}	72.8	13.6		
Korea	a_{kr}	2.7	0.6		
Mexico	a_{mx}	2.9	0.8		
Netherlands	a_{ne}	491.2	101.3		
New Zealand	a_{nz}	190.7	48.9		
Norway	a_{nr}	254.9	54.6		
Portugal	α_{pr}	22.4	6.5		
South Africa	a_{za}	53.9	13.2		
Spain	a_{sp}	68.6	16.4		
Sweden	a_{sw}	607.8	121.5		
Switzerland	a_{swi}	1297	242.5		
United Kingdom	a_{uk}	163.9	49.5		
United States	a_{us}	81.3	12.4		

as the outcome of a cost-benefit decision on the part of an innovator. Hence, using the parameter estimates contained in table 3 it is possible to impute the mean value of a patent originating in country *i* and employed in country *n*. Calculation of this quantity involves a comparison of the present value of rents

TABLE 4
Patent values for Pre-TRIPs Regime ($US millions 1988)

	Present value of patent rents[a]	*PV of patent rents* R&D expenditure[b]	Share of patent rents from abroad[c]
United States	12,383	0.13	0.22
Japan	3,007	0.08	0.24
Germany	2,628	0.13	0.58
France	1,831	0.16	0.41
United Kingdom	1,109	0.09	0.66
Italy	586	0.10	0.49
Switzerland	498	0.17	0.86
Netherlands	385	0.14	0.8
Australia	283	0.21	0.79
Sweden	249	0.09	0.84
Canada	212	0.06	0.64
Austria	118	0.12	0.72
Belgium	112	0.07	0.91
Finland	101	0.13	0.77
Denmark	80	0.13	0.86
Spain	55	0.03	0.63
Israel	47	n.d.	0.95
Norway	36	0.05	0.8
South Africa	33	n.d.	0.93
Ireland	20	0.14	1.00
New Zealand	13	0.11	0.98
Brazil	9	n.d.	0.9
Korea	7	n.d.	0.93
India	4	n.d.	0.35
Mexico	3	0.01	0.94
Greece	3	0.04	0.93
Portugal	2	0.02	0.93

a Expected present value of rents from the lower imitation rate associated with a patent
b The R&D variable is expenditure by business enterprises for 1988; taken from table 22 OECD (1995).
c Share of the value of patent rights held by residents of a country that come from patents held in the other 26 countries

appropriated both with and without patent protection (see section A.4 in the appendix for details).

At the bilateral level, the private value of patent protection is calculated by multiplying the mean present value of patent rights by the number of patent applications. Column one of table 4 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 U.S. residents. The aggregate value of U.S. 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 the large number of patents held by U.S. residents both abroad and at home. The domestic patents are especially influential in this calculation, since the United States is the most valuable market in which to hold patent rights.

Columns 2 and 3 of table 4 help to put these numbers into perspective and provide a check on their plausibility. Column 2 provides a general measure of the importance of patent protection by comparing the present value of patent rights with 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 that 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 second column for France, Germany, and the United Kingdom (see Lanjouw 1993; Schankerman 1991; Pakes 1986; Schankerman and Pakes 1986). These ratios are also consistent with survey evidence for the United States, 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 model produces an estimate that gets close to this figure, with the estimated return for the United States being 13%.

As a final check on the calculated size and distribution of the value of patent rights under the pre-TRIPs system, the third column of table 4 provides a breakdown between the rents appropriated from the domestic and foreign markets. The breakdown for the United States is particularly encouraging, given that Mansfield, Romeo, and Wagner (1979) find that less than one-third of the returns to U.S. R&D projects are expected to come from abroad. Taken together, the evidence presented in table 4 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.

6. Evaluating the TRIPs agreement

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 a number of counterfactual exercises relating to the TRIPs agreement. A useful way to approach the analysis is to divide it into issues that arise in the short run and those that arise in the long run. Short-run analysis is conducted holding research effort, and therefore the level of technology, constant. During the short run the redistributional consequences are most pronounced, and therefore the framework can be used to characterize the transfers of income between countries implied by the TRIPs agreement. These short-run implications provide insight into the factors that determine the relative negotiating positions of the various countries during the Uruguay round. While the short-run implications are insightful, the ultimate merit of the TRIPs agreement must lie in its ability to raise income levels, thus providing a payoff to any short-run costs a country might incur from the reform of patent protection. Assessment of the ability of the TRIPs agreement to raise the income levels of all countries, after accounting for net transfers between countries, requires an analysis that allows research effort to respond to changes in incentives. Such an analysis will be considered to relate to the long run.

To translate the text of the TRIPs agreement into implications characterized by numerical quantities, the data used to describe patent protection in the empirical model will be recalculated. In particular, the TRIPs agreement can be simulated by adjusting the data on both the enforcement institutions that are available, as well as the industrial sectors that are eligible for patent protection. Compliance with the TRIPs agreement requires all countries to adopt the same broad sectoral coverage of protection (see Articles 27 (2) and (3)). This requires that coverage be extended to the pharmaceuticals, food, and chemical industries. The TRIPs agreement also allows a patentholder to service a market through imports without fear of revocation of patent rights (see Article 27 (1). Setting the sectoral coverage dummies (D^{ph}, D^{fd}, D^{ch}, and D^{wr}) to zero can approximate the implication of these changes. The TRIPs agreement also requires that a basic enforcement infrastructure be erected to allow patentholders to defend their intellectual property.[17] Setting the data on the availability of enforcement institutions to five can approximate this change.[18]

6.1. Short-run analysis

The central assumption underlying the short-run analysis[19] is that research effort has not had an opportunity to respond to the changed incentives due to the TRIPs reforms. Therefore, all the implications for the short run are deduced from the implied changes in the value of a patent. Since standards of patent protection are higher in all countries after the TRIPs agreement, the value of an innovators current portfolio of patents must increase. The mechanism that generates this result is clear: an increase in patent strength lowers the probability of imitation and therefore increases the expected tenure as technology leader.

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17 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.

18 Note that setting the index to five requires that all countries have the same laws on the books. However, variation in the quality of these institutions is still likely to persist. This is accounted for by multiplying 5 (the availability of institutions under TRIPs) by the effectiveness measure for each country.

19 The results for the short-run analysis are similar to those of McCalman (2001). For more discussion of the short run see McCalman (2001).

TABLE 5
Short-run estimates of TRIPs

	TRIPs net transfer[a] (in $US millions)	Std error[b]
United States	1,277	242
Germany	496	119
France	292	66
Italy	116	25
Switzerland	101	28
Netherlands	58	24
Sweden	57	16
Japan	52	132
Belgium	12	9
Israel	7	3
Ireland	5	1
Denmark	3	8
New Zealand	1	1
Australia	−4	21
Portugal	−13	5
Korea	−19	8
South Africa	−23	6
Finland	−33	14
Greece	−33	6
Austria	−36	12
Norway	−37	13
United Kingdom	−126	137
Mexico	−126	19
Spain	−144	44
Canada	−317	72
Brazil	−438	55
India	−1129	112

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, owing to the higher patent standards required by the TRIPs agreement.

b Derived using the delta method

Table 5 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. McCalman (2001) performs the same exercise, the main difference being the specification utilized in this paper. Despite the difference in specification, the results are very similar. In particular, a minority of countries in the sample stand to benefit from the TRIPs agreement, with the largest benefits accruing to the United States, Germany, France, Italy, and Switzerland. The United States stands out as the major beneficiary, gaining almost three times as much as the second largest beneficiary. The remaining countries experience a net loss from raising their standards of patent protection, with India experiencing the most pronounced loss of $1.1 billion. Somewhat surprisingly, Canada is one of the largest losers in the short run.

However, this is consistent with Canada's alignment with developing countries in the negotiation of the TRIPs agreement (Cottier 1991). The potential for this transfer lies in Canada's proximity, size, and shared language with the United States, factors that combine to make Canada the largest trading partner for the United States. However, Canada ranks only fifth in terms of destination for U.S.-owned patents. In addition, in 1988 U.S. inventors sought only 14,687 patents in Canada, while seeking over 75,000 domestically. In contrast, Canada seeks more patents in the United States 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 U.S. 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. This short-run analysis confirms the relatively bleak picture for the majority of countries from McCalman (2001), one in which the TRIPs agreement serves as a mechanism for foreign owners of technology to increase their ability to appropriate rents.

6.2. Long-run analysis

However, these short-run estimates assume that research effort is constant and therefore do not include the response of innovators to the new set of incentives implied by the TRIPs agreement. To incorporate the impact of the TRIPs standards, a new steady state needs to be derived. Note that this will differ from the pre-TRIPs steady state in terms of the level of income along a steady-state growth path, but the steady-state growth rate will be the same under the two scenarios. This is an implication of the semi-endogenous growth specification that has been utilized. The steady-state growth rate is exogenous in this setting, with any change in the incentive to conduct R&D reflected in the level of technology and therefore the level of income.

The new steady-state path of income is determined by the division of labour between R&D and production.[20] Since the TRIPs agreement allows for both a reduction in the hazard of imitation and a greater number of sectors to be eligible for protection, this leads to an increase in the expected value of an innovation. This raises the incentive to conduct R&D and raises the rate at which ideas are produced in the long run. A higher level of technology directly increases the steady income path. However, there are also mechanisms that mitigate the increase in the expected value of an innovation. One mechanism follows naturally from the increased rate of innovation, namely, a higher steady-state rate of obsolescence. As more ideas are

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[20] See the appendix for additional detail.

produced, the greater is the hazard that any given frontier technology will be surpassed. A second mechanism follows from a higher technology level that increases the marginal product of labour, which increases the equilibrium wage and hence the opportunity cost of research. Although both these mechanisms temper the increase in the expected value of an innovation, more resources are devoted to R&D in equilibrium.

Since all countries devote more resources to R&D, and all countries depend on technology from other countries, this raises the level of technology in any given country. However, countries vary in terms of the productivity of R&D, resources available to devote to R&D, the rate at which ideas diffuse from other countries, the impact that any given invention has on a country, as well as the equilibrium rate of obsolescence. Therefore, while a greater incentive to conduct R&D leads each country to utilize a superior set of technologies, the differences in the ability to respond to these incentives or absorb technology from abroad suggests that the implications of multilateral reform are unlikely to be uniform across countries in the long run. In particular, for those countries that suffered in the short run from implementing the TRIPs agreement, the key question is whether these long-run gains are large enough to offset the negative transfers of income due to patent reform.

Table 6 provides estimates of the long-run implications of the TRIPs agreement, by comparing the income paths for the pre and post TRIPS standards. Note that the comparison is between steady-state income paths and does not represent a complete cost-benefit analysis of the TRIPs agreement. Such an assessment would require analysis of the transition paths in order to determine whether the short-run costs are worth the potential higher income levels in the long run. The analysis presented here just reports whether or not the steady-state income paths involve higher levels of income. With this caveat in mind, the counterfactual simulation summarized in table 6 reveals that all countries stand to gain from the TRIPs agreement in the long run. That is, the increase in income associated with the TRIPs agreement is more than sufficient to offset the negative transfers of income that a country may experience, resulting in all countries having higher steady-state income paths. In this context the Canadian counterfactual is particularly interesting. Recall that Canada was predicted to be one of the largest losers in the short-run, a prediction that seems plausible given its proximity and extent of integration in terms of trade with the United States. However, the increased innovation induced by the TRIPs agreement implies that the very same factors that generated a short-run loss for Canada are responsible for the long-run increase in income levels. Ultimately, Canada, like the other countries considered, is predicted to benefit in the long run.

Despite this positive conclusion, the benefits of the TRIPs agreement are not evenly distributed. The largest proportional gains accrue to Switzerland with an income level estimated to be 2.4% higher in steady-state. This gain consists of both a benefit from innovation induced by the TRIPs agreement but also an ability to appropriate net rents from abroad. In contrast, the TRIPs agreement delivers the smallest gains to India which experiences only

TABLE 6
Long-run estimates of TRIPs

	Income[a]	Bootstrapped 95% confidence	interval
Switzerland	2.45	3.15	1.76
United Kingdom	1.87	2.50	1.24
Sweden	1.72	2.05	1.38
Netherlands	1.61	2.00	1.22
Germany	1.59	2.01	1.18
Austria	1.57	1.94	1.21
United States	1.54	1.94	1.15
Australia	1.51	1.90	1.12
France	1.42	1.89	0.96
Italy	1.36	1.68	1.04
Japan	1.35	1.69	1.01
Denmark	1.31	1.68	0.94
Israel	1.16	1.47	0.85
Finland	1.14	1.56	0.72
Belgium	1.12	1.44	0.80
Spain	1.10	1.47	0.73
New Zealand	1.02	1.38	0.67
Canada	1.02	1.40	0.64
South Africa	0.99	1.39	0.59
Norway	0.97	1.35	0.59
Ireland	0.88	1.25	0.50
Korea	0.84	1.23	0.46
Brazil	0.83	1.27	0.40
Mexico	0.80	1.30	0.31
Greece	0.75	1.15	0.35
Portugal	0.63	1.04	0.22
India	0.08	0.75	−0.59

a The percentage change in the steady-state path of income

a gain of 0.08% in the level of steady-state income, with the magnitude of this gain limited by the net transfers paid by India. Despite the uneven distribution of benefits this analysis nevertheless suggests that all countries are likely to benefit from the TRIPs in the long run, with the key to the successful implementation of this agreement being how the short run negative implications (as indicated by table 5) are handled.

However, it should be kept in mind that this relatively optimistic conclusion is based on only one set of parameter estimates. Since these underlying estimates are associated with standard errors, it is of interest to examine the robustness of the long run results in the relation to this variability. The second and third columns of table 6 report the 95% confidence intervals associated with the long run outcome of the TRIPs agreement.[21] These confidence intervals generate an

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[21] These confidence intervals represent the outcome of a parametric bootstrap algorithm. For an overview of the bootstrap procedure see Greene (2001).

important result. Specifically, the lower bound of the confidence interval is -0.59 for India, which suggests that even in the long run India may lose from the TRIPs agreement. This negative outcome is the result of a tension between two competing forces. As revealed in the short-run analysis, a technology-importing country like India will make increased payments to technology owners, owing to the TRIPs agreement, regardless of whether or not any additional technology is induced by TRIPs. This negative distributional consequence of TRIPs is offset in the long run by the increased level of technology, generating higher income levels. However, in the case of India this trade off does not pay (under the perturbed parameter values). This result qualifies the conclusion above that all countries gain from the TRIPs in the long run, as now no matter how the short run issues are handled, India has no incentive to abide by the terms of the TRIPs agreement. Aside, from the case of India, all other countries continue to benefit from the TRIPs agreement in the long run, with the distribution of benefits favouring the developed countries.

While variation in the estimated parameters changes the magnitude and potentially the sign of the long-run outcome, the model also relies on specific assumptions about the rate of imitation of non-patented innovations. In particular, the model assumes that the foreign hazard of imitation of non-patented ideas is 0.25. This quantity is central to determining the value of seeking patent protection in a foreign country and therefore is a major determinant of the foreign transfers under the TRIPs reforms. The implications of varying this assumption are contained in table 7. The first column examines the implications of a foreign hazard of imitation that is half of what was used in the baseline case (i.e., $\iota_{for}^{not} = 0.125$ rather than $\iota_{for}^{not} = 0.25$). Lowering the hazard of imitation on non-patented innovations also lowers the value of a patent and hence dilutes the impact of patent reform. This is evident from column 1, where the percentage change in the steady income path is uniformly lower than the case depicted in table 7, reflecting a smaller inducement to invest in R&D associated with any given level of patent protection. In contrast, the second column of table 7 covers the case where the foreign hazard of imitation is double the baseline case (i.e., $\iota_{for}^{not} = 0.5$). This now represents an environment where a patent is more valuable. Consequently, the TRIPs agreement has a more pronounced effect of the level of innovation and the level of income, leading to enhanced long-run outcomes for all countries. Therefore, although varying the assumption relating to the foreign hazard of imitation does affect the magnitude of the impact of the TRIPs agreement, the qualitative message remains the same, with all countries benefiting from the TRIPs agreement in the long run, although the benefits remain skewed towards developed countries.

Variation of both the estimated and the pre-determined parameters demonstrates the robustness of the qualitative results of the model, the central conclusion being that the long-run benefits of the TRIPs agreement are unlikely to be evenly distributed between countries. Since developing countries,

TABLE 7
Long-run estimates of TRIPs: Sensitivity analysis

	$\iota_{for}^{not} = 0.125$	$\iota_{for}^{not} = 0.5$
Switzerland	1.68	3.45
United Kingdom	1.31	2.73
Sweden	1.19	2.48
Netherlands	1.12	2.33
Germany	1.10	2.28
Austria	1.10	2.26
United States	1.12	2.14
Australia	1.08	2.14
France	0.99	1.98
Italy	0.96	1.93
Japan	0.98	1.92
Denmark	0.96	1.96
Israel	0.87	1.69
Finland	0.82	1.76
Belgium	0.80	1.64
Spain	0.78	1.66
New Zealand	0.80	1.44
Canada	0.81	1.52
South Africa	0.74	1.50
Norway	0.74	1.48
Ireland	0.82	1.35
Korea	0.67	1.23
Brazil	0.61	1.33
Mexico	0.62	1.25
Greece	0.56	1.18
Portugal	0.51	1.10
India	0.04	0.52

and India in particular, are predicted to experience short-run losses and negligible long-run gains, this suggests that a policy to hold all countries to a global standard of patent protection may not be stable. To some extent, these issues have been anticipated in the TRIPs agreement in the form of transition periods for developing and least developed countries. However, this paper casts doubt on whether transition periods are sufficient, with even the possibility of long-run gains in doubt under certain plausible parameter values. This raises the possibility that differential standards may continue to persist between developed and developing countries. A natural question in this context is whether gains can still be realized if only a subset of countries adopts the TRIPs standard.

6.3. Unilateral reform

The existence of a group of countries that gain in both the short and the long run raises the issue of whether a multilateral agreement like TRIPs was necessary for patent reform. One way to address this question is to consider what would happen if a country adopted the TRIPs standards on a unilateral

TABLE 8
Unilateral policy reform

	Income[a]		Income[a]
United States	0.74	France	0
United Kingdom	0.61	Norway	−0.05
Switzerland	0.37	Brazil	−0.05
Japan	0.29	Mexico	−0.09
Germany	0.28	Belgium	−0.1
Finland	0.18	Canada	−0.17
Denmark	0.14	Portugal	−0.19
Netherlands	0.09	Israel	−0.21
Australia	0.09	New Zealand	−0.22
Sweden	0.05	South Africa	−0.24
Korea	0.02	India	−0.31
Spain	0.01	Greece	−0.33
Austria	0.01	Ireland	−0.38
Italy	0		

a The percentage change in the steady-state path of income

basis. Clearly, such a country would experience a net transfer abroad, since unilateral reform is not reciprocated. Nevertheless, incentives to increase research effort will increase, giving rise to some prospect for gain. Table 8 provides a breakdown of the implications of unilateral policy reform. The way to interpret this table is to note that each row represents a different simulation, with the results of each simulation reported only for the reforming country (i.e., the first row describes the impact on the United States if it were the only country to adopt the standards set out in the TRIPs agreement, while the second row describes the impact on the United Kingdom if it were the only country to adopt the TRIPs reforms, and so on). Just fewer than half the countries in the sample are revealed to have an incentive to reform patent policy unilaterally, and all of these countries are developed countries. Of these countries, the United States has the strongest incentive to undertake unilateral reform, with the prospect of a gain equal to half of that available if all countries adopted the TRIPs standards. In this sense table 8 also offers a way of decomposing the sources of the gains to countries from the TRIPs agreement, revealing that no other country gains more than a third of the benefits available under the TRIPs agreement if it acts unilaterally. This underscores the benefits that coordinated policy reform can produce, but it also indicates that a sizable share of the benefits of the TRIPs agreement would still be realized if only a subset of countries adopted its standards.

7. Conclusion

This paper has employed a multi-country growth model to offer an assessment of the TRIPs agreement for 27 countries. This analysis provides a contrasting assessment for the short- and long-run impact of the TRIPs agreement. In the short run all countries experience an increase in the value of their global patent portfolios; however, owing to asymmetries in the reforms required, some countries gain to a disproportionate extent from policy changes undertaken in other countries. Therefore, the net benefits of the TRIPs agreement in the short run are negative for the majority of countries, with developing countries being particularly disadvantaged. The long-run analysis, on the other hand, reveals that the greater incentives to innovate associated with TRIPs may be sufficient to offset any negative short-run effects. However, these benefits are not uniformly distributed among all countries, with the developing countries experiencing the smallest gains. This ranking and the possibility that some countries may not gain even in the long run suggest that developing countries are likely to continue to question the value of the TRIPs agreement and how it influences the allocation of the benefits from new technology.

Appendix

A.1. Solving the dynamic system

Output is derived from the following Cobb-Douglas production function:

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

where Y is the quantity of output, $X(j)$ is the quantity of input j and $Z(j)$ is the quality of input j. J is an index of the range of inputs and is assumed to be fixed. A measure of the level of technology in country n is

$$\ln\ A = J^{-1} \int_0^J \ln\ Z(j)dj.$$

Technological change occurs in a quality ladders fashion. 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,

$$\Pr[Q < q] = 1 - e^{-\theta_{ni} q}, \text{ where } \theta_{ni} = \theta\left(\frac{A_i}{A_n}\right)^{-\omega},$$

and the catch-up parameter, ω, is assumed to be strictly greater than zero.

To solve the model for relative technology levels, begin by defining: $\mu_n = A_n{}^{\omega}$, This implies

$$\frac{d\mu_n}{dt} = \frac{dA_n^{\omega}(t)}{dt} = \omega A_n^{\omega-1}\frac{dA_n}{dt} = \omega A_n^{\omega-1}\dot{A}_n = \dot{\mu}_n.$$

Eaton and Kortum (1996) show that in this framework growth can be decomposed such that

$$g_n = \frac{\dot{A}_n}{A_n} = \frac{1}{J\theta}\sum_{i=1}^{N}\varepsilon_{ni}\alpha_i\left(\frac{A_i}{A_n}\right)^{\omega}.$$

Furthermore, as described in Eaton and Kortum, the steady state requires that all countries grow at the same rate (i.e., $g_n = g$). From this growth equation it follows that $\dot{\mu}_n = \frac{\omega}{J\theta}\Sigma_{i=1}^{N}\varepsilon_{ni}\alpha_i\mu_i$. This defines a system of linear differential equations

$$\begin{bmatrix}\dot{\mu}_1\\ \\ \\ \dot{\mu}_n\end{bmatrix} = \frac{\omega}{J\theta}\begin{bmatrix}\varepsilon_{11}\alpha_1 \ldots\ldots\ldots \varepsilon_{1n}\alpha_n\\ \\ \\ \varepsilon_{n1}\alpha_1 \ldots\ldots\ldots \varepsilon_{nn}\alpha_n\end{bmatrix}\begin{bmatrix}\mu_1\\ \\ \\ \mu_n\end{bmatrix}$$

or $\dot{\mu} = (\omega/J\theta)\Delta\mu$. 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

$$\frac{A_i}{A_N} = \left(\frac{\mu_i}{\mu_N}\right)^{\frac{1}{\omega}}.$$

A_N is defined as the technology level of the United States.

A.2. Specification of non-linear system

Using this relative technology index generates a predicted value for relative labour productivity.

$$\frac{\hat{y}_n}{y_N} = \frac{\Gamma_n A_n}{\Gamma_N A_N},\ n = 1, \ldots\ldots\ldots, 26,$$

where

$$\Gamma_n = \frac{\sum_i^N K_{ni}((s_{ni}-1)(1-\eta)(e^{-(1+\theta_{ni})\bar{q}_{ni}} - e^{-\theta_{ni}\bar{q}_{ni}})) + 1}{\sum_i^N K_{ni}((s_{ni}\eta + (1-\eta) + (s_{ni}-1)(1-\eta)e^{-\theta_{ni}\bar{q}_{ni}(1+\theta_{ni}\bar{q}_{ni})})}$$

$$\text{and } K_{ni} = \frac{\varepsilon_{ni}\alpha_i}{J\left(\iota_{ni}^{pat} + o_n\right)\left(\iota_{ni}^{not} + o_n\right)}$$

The predicted bilateral patenting behaviour is

$$\hat{P}_{ni} = \alpha_i \varepsilon_{ni} s_{ni}[f_{ni} + (1 - f_{ni})\eta], \quad \text{i, n} = 1, \ldots\ldots\ldots\ldots\ldots, 27,$$

where

$$\alpha_i = \frac{a_i (r_i L_i)^{\beta}}{\bar{A}^{\phi}}$$

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

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

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

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

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

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

A.3. Estimation of non-linear system

In order to estimate the system, a non-linear least squares approach is adopted. The errors for each equation are given by

$$u_{ni} = \log\ (P_{ni}) - \log\ (\hat{P}_{ni}) \qquad n, i = 1, \ldots\ldots\ldots\ldots, 27 \tag{A1}$$

$$v_i = \log\ \left(\frac{y_n}{y_{us}}\right) - \log\ \left(\frac{\hat{y}_n}{y_{us}}\right) \qquad n = 1, \ldots\ldots\ldots\ldots\ldots, 26 \tag{A2}$$

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 non-linear least squares procedure. The first step imposes a value on the ratio of $\sigma^2{}_u/\sigma^2{}_v$; these estimates are consistent but not efficient. 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.

A.4. Calculation of patent values

The estimated parameters, given in table 3, enable the quantities of interest to be constructed. The key quantity for the short-run analysis is the value of patent rights. At the bilateral 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 (the derivation of these quantities is provided in McCalman 2001):

$$\begin{aligned}
&\int_{\bar{q}_{ni}}^{\infty} \left[V_{ni}^{pat}(Q) - V_{ni}^{not}(Q)\right] f(Q|Q > \bar{q}_{ni})dQ \\
&= \frac{\left(1 - \frac{\theta_{ni}}{1+\theta_{ni}} e^{-\bar{q}_{ni}}\right)\left(\iota_{ni}^{not} - \iota_{ni}^{pat}\right) Y_n}{J\left(r + \iota_{ni}^{pat} + O_n - g\right)\left(r + \iota_{ni}^{not} + O_n - g\right)} \\
&\equiv PV_{ni}^{prof}.
\end{aligned}$$

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

$$\begin{aligned}
&\int_{0}^{\bar{q}_{ni}} \left[V_{ni}^{pat}(Q) - V_{ni}^{not}(Q)\right] f(Q|Q \leq \bar{q}_{ni})dQ \\
&= \frac{\left(1 - \frac{\theta_{ni}}{1+\theta_{ni}} \left(\frac{1-e^{-(1+\theta_{ni}\bar{q}_{ni})}}{1-e^{-\theta_{ni}\bar{q}_{ni}}}\right)\right)\left(\iota_{ni}^{not} - \iota_{ni}^{pat}\right) Y_n}{J\left(r + \iota_{ni}^{pat} + O_n - g\right)\left(r + \iota_{ni}^{not} + O_n - g\right)} \\
&\equiv PV_{ni}^{mistake}.
\end{aligned}$$

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

$$\varepsilon_{ni}\alpha_i s_{ni}\left[f_{ni} PV_{ni}^{prof} + \eta(1 - f_{ni}) PV_{ni}^{mistake}\right] - P_{ni}C_{ni}.$$

Using this valuation as the starting point, all the quantities analysed in the short run can be obtained.

A.5. Solving for the steady-state income path

For the long-run analysis, the steady-state income paths are derived from the labour market-clearing conditions. The approach taken here is to solve the profit maximization problem of a research lab in order to find the derived demand for research labour. Solving the problem for country i yields the fraction of labour involved in R&D as

$$r_i = \left[\frac{a_i \beta E[V_i]}{\overline{A}^{\gamma} A_i e^{-E[U_i]}}\right]^{\frac{1}{1-\beta}}, \tag{A3}$$

where

$E[U_i]$ is the expected markup in country i

$E[V_i]$ is the expected value of an innovation produced in country i, which is given by

$$E[V_i] = \sum\nolimits_n^N \left\{ \begin{array}{r} s_{ni} Y_n \Theta^1_{ni}\left(\dfrac{1}{\phi^{pat}_{ni}} + \dfrac{1}{\phi^{not}_{ni}}\right) + Y_n \Theta^2_{ni}\left(\dfrac{\eta s_{ni}}{\phi^{pat}_{ni}} + \dfrac{(1-\eta s_{ni})}{\phi^{not}_{ni}}\right) \\ q - s_{ni} C_{ni}(\eta(1 - e^{-\theta_{ni}\bar{q}_{ni}}) + e^{-\theta_{ni}\bar{q}_{ni}}) \end{array} \right\}$$

where

$$\phi^k_{ni} = J(i^k_{ni} + o_n + r - g),\ k \in \{\text{pat, not}\},\ \Theta^1_{ni} = e^{-\theta_{ni}\bar{q}_{ni}} - \frac{\theta_{ni}}{1+\theta_{ni}} e^{-\theta(1+\theta_{ni})\bar{q}_{ni}}$$

$$\text{and } \Theta^2_{ni} = \frac{1}{1+\theta_{ni}} - \Theta^1_{ni}$$

Note, in particular, that the expected value of an innovation in country n is a function of income in country n, Y_n. The resulting fraction of labour devoted to R&D in country i is, therefore, a function of the income levels of all 27 countries. This income level can be determined from the production function, which can be written as

$$Y_i = \frac{A_i e^{-E_i[U_i]}}{E_i[e^{-U_i}]} L^P_i, \tag{A4}$$

where L^P_i denotes the quantity of labour devoted to production.

Using the estimated parameter values from table 3, (A3) and (A4) are solved simultaneously, using numerical techniques. This calculation is performed under both the pre- and the post- TRIPs standards of patent protection, with the difference between income paths given in table 6.

A.5. Data and notation

Symbol	Variable	Source
y_n	Log of real GDP per worker, averaged over 1986–8	Summers and Heston (1991)
p_{ni}	Log of bilateral patenting of inventions from country i in country n's market, 1988	WIPO (1990)
DH_{ni}	Home bias dummy variable. Equals 1 if $n = i$.	
KM_{ni}	Distance in kilometres between capital cities	

KM^2_{ni}	Squared distance in kilometres between capital cities	
HK_n	Human capital	Barro and Lee (1996)
IM_{ni}	Bilateral imports as a share of GNP	IMF
D^j	Dummy variable. Equals 1 if industry is excluded from patent protection or a domestic working requirement is imposed on a patent. $j =$ chemical (*ch*), pharmaceutical (*ph*), food (*fd*), working requirement (*wr*).	WIPO (1988), Baxter and Sinott (1989)
r_i	The fraction of the labor force involved in research	OECD (1995) and UNESCO (1998)
C_{ni}	Cost of applying for a patent, which includes official application fees, agent's fees and translation fees.	Helfgott (1993)
Y_n	GDP, 1988	World Bank
IP_n	Index of the strength of patent protection, accounting for both the laws on the books and the efficiency with which justice is applied.	Ginarte and Park (1997), EMF (1989)
A_n	Technology index for country n	
J	Index of range of inputs for the quality ladder model	
γ	Enforcement parameter	
s^{ph}	Pharmaceutical coverage parameter	
s^{fd}	Food coverage parameter	
s^{ch}	Chemical coverage parameter	
s^{wr}	Working requirement parameter	
θ	Step Size parameter	
ω	Catch-up parameter	
η	Mistaken Patents	
α_i	Number of innovations produced in country i	
a_i	Research productivity of country i	
β	Research elasticity	
ε_{ni}	Probability of diffusion from i to n	
ε_{imp}	Diffusion coefficient on imports	
ε_{hk}	Diffusion coefficient on human capital	
ε_{dom}	Diffusion coefficient on home bias	
ε_{km}	Diffusion coefficient on distance	
ε_{km2}	Diffusion coefficient on distance squared	
f_{ni}	Fraction of innovations worth patenting from i that arrive in n	
o_n	Rate of obsolescence in n	
V_i	Value of an innovation produced in i	
q	Step size of an innovation	
ι^l_k	Hazard of imitation, $k \in \{dom, for\}$, $l \in \{not, pat\}$	
g	Steady-state growth rate	

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