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BIDDING FOR BRAINS:
INTELLECTUAL PROPERTY RIGHTS AND THE INTERNATIONAL MIGRATION OF KNOWLEDGE WORKERS

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ABSTRACT

We introduce international mobility of knowledge workers into a model of Nash equilibrium IPR policy choice among countries. We show that governments have incentives to use IPRs in a bidding war for global talent, resulting in Nash equilibrium IPRs that can be too high, rather than too low, from a global welfare perspective. These incentives become stronger as developing countries grow in size and wealth, thus allowing them to prevent the 'poaching' of their 'brains' by larger, wealthier markets.

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1. Introduction

The notion that it is privately (but not globally) optimal for developing countries to 'free ride' on technological innovations produced by the developed world is well known in the intellectual property rights literature (see for example Chin and Grossman 1990). Over the years, this literature has also identified a number of factors that might induce developing countries to protect intellectual property. These include the inappropriateness of Northern technology for the South (Diwan and Rodrik 1991), strategic reactions by Northern firms to the lack of Southern protection (Yang and Maskus 2001), dynamic effects on innovation in the South (Helpman 1993; Chen and Puttinanun 2005; Schneider 2005), the prospects of increased foreign direct investment or licensing (Markusen 2001, Maskus 2005), and of expanded international trade (Maskus and Penubarti 1995, Fink and Primo Baga 2005).

An equally well known idea—in a different literature—is the notion that an outflow of skilled labor, or 'brain drain', hurts developing countries, due to diminished opportunities for within-country trade and fiscal externalities (e.g. Berry and Soligo 1969; Bhagwati and Hamada 1974). Countervailing factors that might create benefits from brain drain include increased incentives to acquire education in the sending country arising from an 'emigration lottery' (Mountford 1997) and added discipline on the sending country's tax authorities (Bucovetsky 2003).

Perhaps surprisingly, the two literatures described above (on IPR policy in developing countries and the brain drain respectively) have remained largely isolated from each other.[1] This omission is particularly noteworthy in light of two key stylized facts. First, immigrants—including those from developing countries—account for a large fraction of U.S. innovative activity. For example, nearly one in five scientists and engineers in the United States is an immigrant (Zakaria 2005), while foreign students comprised 51 percent of U.S. science and engineering Ph.D. recipients in 2003 (Bound, Turner and Walsh (2009). These counts probably understate immigrants' contribution to U.S. innovation, since immigrant college graduates patent at twice the U.S. native rate (Hunt and Gauthier-Loiselle 2009); immigrant graduate students also contribute disproportionately to U.S. innovation (Chellaraj, Maskus and Mattoo 2008).[2] Second, internationally mobile scientists can also represent a large share of sending countries' innovative talent. According to Docquier and Rapaport (2009), these flows are particularly high for countries that are both poor and relatively small, such as Guyana,

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[1] Mondal and Gupta (2008) introduce international labor mobility into Helpman's (1993) model, but treat IPR policy as exogenous and consider only the limiting case of perfect international labor mobility. Oettl and Agrawal (2008) empirically study the patent flows that *result* from international labor mobility. To our knowledge, no existing papers model the choice of IPR policy in the presence of internationally mobile innovative talent.

[2] At the extreme top tail of the innovation distribution, Weinberg (2008) documents the flow of 'star' scientists out of developing nations, reporting a steep recent rise (to 14% for the 1990s) in the share of Nobel Prizes in Chemistry, Medicine and Physics awarded to researchers born in developing countries. *None* of this prize-winning work was done in a developing country.

Haiti, and Kenya: In 2000, 89, 84, and 47 percent of these countries' university-educated natives were living in developed (OECD) countries.

The goal of this paper is to study the interactions between IPR policy and brain drain. We do so by considering an IPR policy game between countries in a context where workers who produce intellectual property are internationally mobile (at a cost), and where innovations display some country-specificity in their usefulness or appeal. We offer two main contributions. The first is to identify some hitherto unrecognized factors affecting any country's (privately) optimal IPR policy, and the consequences of these factors for global efficiency. One such factor is what we term the "*bidding for brains*" effect. Unless innovations are truly universal, governments have an incentive to manipulate local policy to attract footloose innovators. In sharp contrast to the well known "free riding" effect, "*bidding for brains*" induces countries to *overprotect* intellectual property, as an outcome of a global bidding war for innovative talent.

We also identify an "*expatriate brains*" effect. When part (or all) of a country's intellectual workforce has departed to another country, the brain-sending country's incentives to protect intellectual property may be weakened, because the marginal innovations produced by those innovators are less relevant to the Source country when produced abroad. Thus, the 'South's' incentives to set low IPRs may both be intensified and, in part *explained by* the fact that many of the South's brains live in the North.

A final contribution of our paper is to identify conditions in which each of the two above effects is likely to be important. We show that the *expatriate brains* effect tends to dominate when developing countries are small or poor: such countries have no hope of contesting the outflow of their brains via strong protection of intellectual property and instead, as predicted by the traditional IPR literature, are likely to choose zero protection in a Nash policy equilibrium. The *bidding-war* effect is more likely to dominate as developing countries grow in prosperity and innovative capacity to a point where their IP laws are capable of having a quantitatively significant effect on the outflows of their brains. In fact, as the South grows, we show that its Nash equilibrium IPR policy can rise from zero to levels similar to North's, and that at this equilibrium, both countries overprotect intellectual property relative to globally efficient levels. We therefore speculate that continued development in countries like China and India might one day replace the debate over intellectual 'free-riding' by those countries with one about excessive IPR protection in a global bidding war for the world's top scientists, engineers and artists.[3]

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[3] We recognize, of course, that IPRs are only one of many factors affecting the location choices of scientists, engineers and artists, and that IPR policy is affected by many factors (such as the hope for additional foreign investment) other than the desire to attract scientists to one's country (or to prevent their departure). Our goal, instead, is to point out interactions between IPR policy and the international migration of knowledge workers that have not, to our knowledge, been noted before, and that may have the potential to be quantitatively significant, especially as developing countries grow in market size and innovative capacity.

2. Related Literature

As noted, our paper contributes to two literatures, one of which examines the determination and optimality of IPR policy in a group of nations. In an early contribution to this literature, Chin and Grossman (1990) showed that low, or zero IPRs might be in the interests of developing countries, since the benefits of consuming Northern innovations at low cost override the gains to local innovators from stronger IPRs. One cost to this 'free-riding' strategy, however, is the fact that relying solely on innovations produced by the North may generate innovations that are particularly inappropriate for the South (Diwan and Rodrik 1991).

Another cost of low Southern IPRs is the possibility that zero protection stunts the development of innovative activity in the South, although Helpman (1993) has argued that zero Southern IPR may be optimal even in a fully dynamic model with endogenous Southern innovative capacity. Since then, Lai (1998) has shown that Helpman's result may depend on the way in which production is transferred to the South. In particular, if production is transferred via foreign direct investment rather than imitation, the South can benefit from raising its IPRs. In a similar vein, Glass and Wu (2007) show that whether strong IPRs raise Southern innovation depends also on whether innovation takes the form of improving existing products or developing new ones. Finally, Lai and Qiu (2003) show that developing countries can gain from raising their IPR protection if this is accompanied by trade concessions on other fronts by the North.

Two recent IPR papers that are closely related to ours are Grossman and Lai (2004) and Boldrin and Levine (2005), henceforth GL and BL.[4] A key question in these papers is the role of 'scale effects', which cause the optimal level of IPR protection under autarky to vary with the size of the economy. In particular, if —as BL argue empirically— optimal IPR falls (under autarky) with market size, the North's Nash equilibrium IPR protection can exceed the globally optimal level. Because our main focus is on the interactions between IPR policy and international flows of brains, our paper abstracts from scale effects.[5] Aside from this, our main departure from BL and GL's approach (other than to simplify various aspects to focus on essentials) is to introduce international mobility of the workers who produce 'ideas'. As already noted, this can also lead to overprotection of intellectual property in Nash equilibrium, this time by both the North *and* the South.

The earliest economics papers on brain drain (e.g. Berry and Soligo 1969), and indeed on international factor mobility in general (e.g. Jones, Coelho and Easton 1986), focused on induced changes in domestic factor prices and producer surplus.[6] Although

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[4] More recent versions of BL (e.g. 2009), no longer contain Section 7, which considers the international IPR game. These results are, however, briefly described in Grossman and Lai (2006).

[5] Specifically, in BL's language and our notation, we assume that $\Psi' = 0$ where Ψ is essentially the elasticity of 'idea supply' with respect to market size. Unlike the market size effect, the direction of the new effects identified in our paper do not hinge on the sign of Ψ'.

[6] For recent reviews of the brain drain literature, see Commander *et al.* (2004), and Docquier and Rapaport (2009).

there are exceptions[7], in most of these models factor outflows reduce the welfare of remaining residents because they reduce their opportunities to trade with differently-endowed agents. Considerations that increase the damage from brain drain include fiscal externalities stemming from the interaction of publicly-subsidized education and progressive taxation (Bhagwati and Hamada 1974). Also, in an endogenous growth framework, some authors have argued that an outflow of skilled workers will reduce a country's growth rate (Miyagiwa 1991, Wong and Yip 1999).[8]

At the same time, however, the brain drain literature has identified a number of potential benefits from skilled emigration. For example, Bhagwati and Rodriguez (1975) have proposed that emigration provides a social "safety valve" for unemployed skilled workers in less developed countries. Other potential benefits are remittances to the home country (e.g. Ozden and Schiff 2006), and the return migration of brains who have acquired new skills abroad. More recently, the "emigration lottery" argument (Stark, Helmenstein and Prskawetz (1997, 1998); Mountford 1997) has raised the possibility that foreign employment opportunities can raise the incentives to acquire education in less-developed sending countries. If enough of the newly-skilled workers stay, 'opening the exits' might ultimately raise a country's stock of human capital and growth rate (Beine, Docquier and Rapaport 2008).[9] Finally, the networks created by skilled migrants may increase beneficial exchanges of goods, factors and ideas between the home and host countries (Lopez and Schiff 1998; Kanbur and Rapaport 2005; Oettl and Agrawal 2008).

The closest paper to the current one in the "brain drain" literature is our own (Kuhn and McAusland 2009). Unlike most of the brain drain literature, that paper explicitly models 'brains' as mobile producers of patentable/copyrightable ideas, whose relevance to consumers depends on the country in which those ideas were invented. That paper's main goal is to establish conditions under which brain drain might benefit a small Source country. IPR policy is taken as exogenous, and Nash policy interactions between countries are not modeled.[10] Thus, the current paper can be viewed either as endogenizing IPRs in our own previous model of brain drain, or as introducing international mobility of brains into BL or GL's model of IPR determination.

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[7] For example, the two-good, two-factor small open economy model in which factor rewards are independent of factor endowments, and the case of large countries whose terms of trade are advantageously affected by a factor outflow.

[8] Introducing a skilled worker outflow into more traditional growth models (where growth occurs purely via either human or physical capital accumulation) has less dramatic negative long run effects (see, e.g. Rodriguez 1975).

[9] Even more recently, Bucovetsky (2003) and Haupt and Janeba (2004) have argued that the possibility of skilled emigration may impose useful discipline on the tax authorities in skilled-worker "sending" countries.

[10] Other differences of the current paper from Kuhn-McAusland (2009) include a heterogeneous population of potential migrants (KM consider only the effects or relocating a single 'designer'), the fact that we include Source's designers (both resident and expatriate) in Source's welfare function, and a greater emphasis here on cases where translation costs are high (i.e. τ is low). Low τ seems more appropriate for developing countries (which are our main interest here).

3. Model

We consider a world with two countries, *Source* and *Recipient*; values for Recipient are denoted with asterisks. Let N, N^* denote the number of consumers in each country. Each country is endowed with a stock of *designers* D and D^*; designers create unique goods of endogenous quality but do not consume goods themselves.[11]

Consumers are willing to pay more for goods the higher their quality, ρ, and relevance, r. Specifically, we assume per capita inverse demand for a good is given by $r\rho p(q)$ where $p(q)$ is a decreasing function of quantity consumed per capita, q. Let $\varepsilon \equiv -\frac{1}{dp(q)/dq}\frac{p(q)}{q}$ denote the elasticity of base demand; we assume ε is decreasing in q, thus ensuring each designer's profit maximization problem has an interior solution.

We can interpret ρ as measuring intrinsic quality of a good; for example, ρ may index the quality of graphics in a computer game, the speed with which a cold medicine suppresses symptoms, or the number of laugh-out-loud moments in a movie. Relevance measures the value of these attributes to consumers. While there may be some innovations with close to universal relevance—e.g. instrumental music and some basic scientific discoveries—, for many goods consumers will exhibit *home bias*: powerful software for preparing US tax returns will have limited value to non-US consumers, while jokes catering to moviegoers in one country may be less potent for audiences abroad.[12] We assume home bias takes the form of an iceberg "translation" cost $1-\tau$, where τ measures the fraction of a good's value that survives translation to a foreign market. Thus $r = 1$ if a good is consumed in the same country as it is developed and equals τ otherwise. For the majority of this paper we treat τ as a parameter outside the control of designers and governments.

We assume each designer develops a prototype for a distinct good, replicas of which can be produced at zero cost. Define $\pi = max_q\, p(q)q$ as the maximum per capita *base* profits available in the Source market when a designer has monopoly power in Source; define π^* similarly. As reproduction is costless, each designer will choose per capita deliveries such that $\varepsilon=1$ in each market. Given the separability of relevance, quality and quantity in consumers' demand functions, we can treat π as a parameter when examining designers' investment and location problems.

We follow Grossman and Lai (2004) in assuming that government enforces a designer's monopoly power in a probabilistic fashion. Specifically, let ω and ω^* measure the probability that an individual designer will have full monopoly power over sales of her good in the Source and Recipient countries respectively. If her monopoly rights are not enforced in a country, a designer faces competition from local competitive pirates; as

[11] If instead designers also consumed goods, then their migration would shift the composition of global demand. This demand shift would make the receiving market even more profitable, attracting additional migrants from the sending country.
[12] At the extreme end of the home bias spectrum, one can even imagine innovations (such as developing certain kinds of weapons) that are of negative value to consumers in one country when invented in another.

marginal reproduction costs are zero, the designer earns zero revenues from sales of her good in, for example, Source with probability $1-\omega$. We interpret ω as an index of the strictness of Intellectual Property Rights (IPRs) in the Source country.

We assume goods are traded freely between countries and rule out the possibility of *gray* or *parallel* imports[13]. Using the definitions, we can rewrite the designer's total *expected* revenues from her global market when residing in Source as $N\omega\rho\pi+\tau N^*\omega^*\rho\pi^*$.[14] To simplify matters, we assume $\pi=\pi^*$, i.e. any differences between Source and Recipient in the number or incomes of consumers are captured by differences in N and N^*. Define $M\equiv [N\omega +\tau N^*\omega^*]\pi$. Using similar logic and definitions, when a designer resides in Recipient, her expected revenues from supplying quality ρ^* is given by $M^*\rho^*$ where $M^*\equiv[\tau N\omega+N^*\omega^*]\pi$. We can interpret M and M^* as the effective expected market sizes facing a designer according to where she resides. We will be frugal and regularly omit the qualifier that revenues (and hence profits and welfare) are all *expected* values, although this will be implicit in the analysis.

It is worth noting that, for the analysis from here forward, we could just as easily think of N, N^* as measuring market wealth, where $N=nb(I)$, $N^*=n^*b(I^*)$, in which n and n^* are population counts while $b(\cdot)$ is an increasing function of (exogenous) per capita income I, I^*.[15] Accordingly, we will often refer to differences between N and N^* as arising from differences in country size *or* wealth.

3.1 Investment

Improving product quality is costly. It may require spending additional hours in the laboratory, acquiring additional human capital, or hiring complementary inputs. We will refer to all such actions as *investments*. Let $c(\rho)$ measure the total cost of producing a prototype of quality ρ. To make things simple we assume

$$c(\rho)= \frac{\Psi}{1+\Psi}\rho^{\frac{1+\Psi}{\Psi}}$$

where $\Psi\in(0,1]$.[16]

The designer chooses her quality/investment level before she knows whether her intellectual property rights will be enforced in any given market; her optimal investment

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[13] That is, we assume consumers and third parties are prohibited from purchasing goods in one market for consumption or resale in another market.

[14] Consistent with the principle of National Treatment, we implicitly assume goods face the same probability of property rights infringement, regardless of whether they are designed locally or abroad. Moreover, only a product's designer may take out a patent on that product, regardless of where the product was designed/produced.

[15] For example, if per capita inverse demand is $b(I)\rho tp(q)$, then $M=b(I)n\omega+\tau b(I^*)n^*\omega^*$.

[16] See Section 6 for a discussion of available evidence concerning Ψ. In addition to these empirical considerations, our focus on the $\Psi\leq 1$ case is also motivated by our interest in the showing the potential for one country's IPRs to *harm* others, in contrast to most existing research. (Kuhn and McAusland 2009 show that (for fixed IPRs) $\Psi>1$ is a necessary condition for brain drain to *benefit* the Source country.)

therefore depends on the size of her expected global market. When the designer lives in Source she chooses ρ to

$$\max_{\rho}\ \rho M - c(\rho).$$

The cost function's convexity ensures the second order conditions for an interior maximum hold; rearranging the first order condition $M= c'(\rho)$ yields

$$\rho(M)=M^{\Psi}. \qquad (1)$$

Similarly, when a designer resides in Recipient, she will provide quality $\rho^*=M^{*\Psi}$. Not surprisingly, quality is increasing in effective market size. Define $P(M)$ and $P(M^*)$, respectively, as expected profits earned by a designer residing in Source or Recipient; using (1) in the profit function yields

$$P(M) \equiv \frac{M^{1+\Psi}}{1+\Psi} \text{ and } P(M^*) \equiv \frac{M^{*1+\Psi}}{1+\Psi}.$$

3.2 Migration

Migrating is costly. Index each Source-born designer by her relocation cost z—the monetary-equivalent of physical and psychological costs of leaving one's native land and setting up shop abroad. We assume $z \sim [0, \bar{z}]$ and define $f(z)$ and $F(z)$ as the probability and cumulative density functions for z with $F(\bar{z})=1$. Similarly, let $-z^*$ measure the cost to Recipient-born designer of type z^* of relocating to Source, where $z^* \sim [-\bar{z}, 0]$ with symmetric functions f^* and F^* for z^*. We assume the distributions exhibit no mass points.[17]

Define $g(M,M^*) \equiv P(M^*)-P(M)$ as the gap between profits available in Recipient and Source; we will regularly suppress the arguments of g. Assuming indifferent designers stay home, we can define $\tilde{z}$ as the lowest *type* designer who chooses to reside in Source:

$$\tilde{z} = \begin{cases} \min\{g, \bar{z}\} \text{ if } g > 0 \\ \max\{g, -\bar{z}\} \text{ if } g < 0 \end{cases} \qquad (2)$$

Designers with type greater than or equal to $\tilde{z}$ will choose to reside in Source.

Provided the gap between profits is not too large, Source and Recipient IPRs impact migration as follows:[18]

[17] We also examined a version of the model in which designers differ in their investment costs but face a common relocation cost. Not surprisingly, this alternate model predicts the most talented designers are the first to migrate while the least talented stay home. Although the mathematics are more complicated, in that model governments face the same qualitative incentives as identified in section 4.

[18] The full expressions for $d\tilde{z}/d\omega$ and $d\tilde{z}/d\omega^*$ are provided in Appendix 1.

$$\frac{d\tilde{z}}{d\omega} = \frac{dg}{d\omega} = N\pi[\rho^* \tau - \rho]$$
$$\frac{d\tilde{z}}{d\omega^*} = \frac{dg}{d\omega^*} = N^* \pi[\rho^* - \tau\rho].$$

4. Policy Game

We assume the governments of Source and Recipient each set domestic policy so as to maximize the expected welfare, *E(W)* and *E(W*)*, of local consumers from the consumption of goods produced worldwide, plus profits (net of moving costs) of *native born* designers. Although some readers may wonder whether governments weight the welfare of emigrants the same as natives who stay home, we believe this is a sensible approach as policy is set *prior* to emigration decisions in our model.[19] Following the same principle, we assume host country governments put no weight on the welfare of potential immigrants when setting IPRs.

We assume each government sets domestic IPRs taking the policy of its neighbor as fixed. In the interest of brevity, we only write out only the portion of the first order conditions and the like corresponding to $\tilde{z} \geq 0$.[20] Source, for example, solves $\max_\omega E(W)$ where

$$E(W) = N\left[\omega\varphi + [1-\omega]\mu\right]\left[\rho D[1-F(\tilde{z})] + \tau\rho^*\left[DF(\tilde{z}) + D^*\right]\right] + D\left[1-F(\tilde{z})\right]P(M) + F(\tilde{z})DP(M^*) - D\int_0^{\tilde{z}} f(z)zdz \qquad (3)$$

and $\tilde{z}$ is as defined by (2), subject to the constraint $\omega \in [0,1]$ and taking ω^* as given.

In equation (3), φ and μ are base consumer surplus per capita for goods sold by a monopolist and competitive firms, respectively; we assume base consumer surplus is identical across countries: $\varphi^*=\varphi$ and $\mu^*=\mu$. Under reasonable assumptions concerning the implicit demand function $p(q)$, μ is greater than $\pi+\varphi$. In what follows, $\mu-(\varphi+\pi)>0$ will represent the per capita (base) deadweight loss from monopoly power.

Assuming an interior solution, Source's "non-cooperative" best response $\omega(\omega^*)$ solves the following first order condition:

[19] Excluding emigrants from Source's welfare function (and including them in Recipient's) would also significantly complicate the model, because it could lead to possible dynamic inconsistencies in both countries' IPR policies. For example, designers will anticipate that, after migration takes place, the talent-sending country will disown its emigrant talent (and the profits they earn) and weaken local IPRs accordingly.

[20] An unabbreviated statement of Source's best response would of course allow for *in*-migration from Recipient in cases where ω^* is sufficiently small. The numerical simulations presented in Section 6 and 7 allow for migration in either direction.

$$\frac{dE(W)}{d\omega} = \underbrace{N\left[(\pi+\varphi-\mu)\,D\left[\rho\left(1-F(\tilde{z})\right)+\tau\rho^{*}F(\tilde{z})\right]+D^{*}\tau\rho^{*}(\varphi-\mu)\right]}_{\substack{\text{Allocative Inefficiency}\\(-)}}$$

$$+\,N\left[\varphi\omega+(1-\omega)\mu\right]\left[\underbrace{D\left(1-F(\tilde{z})\right)\frac{d\rho}{d\omega}+\tau\left(DF(\tilde{z})+D^{*}\right)\frac{d\rho^{*}}{d\omega}}_{\substack{\text{Induced innovation}\\(+)}}+\underbrace{D\left[\tau\rho^{*}-\rho\right]\frac{dF(\tilde{z})}{d\omega}}_{\substack{\text{Brain retention}\\(+)}}\right] \quad (4)$$

when set equal to zero.

Source's government balances a variety of competing concerns when setting domestic IPRs. Some of these concerns are well known from the literature on IPRs. For example, strict IPRs give designers monopoly power, reducing allocative efficiency. Conversely, strict IPRs allow designers to reap the benefits from investments in innovation; in our model induced innovation ultimately raises the quality of goods produced.

Finally, and unique to our analysis, strengthening Source IPRs stems the outflow of designing talent: the *brain retention* effect of strong IPRs. As identified in Kuhn and McAusland (2009), when $\tau<1$, brain drain leads to *relevance diversion*: goods that would have been 100% relevant to Source consumers (had their respective designers remained Source residents) only have relevance $\tau<1$ if the designer emigrates. Raising ω makes Source a more attractive base of operations, encouraging the marginal emigrant to stay home, thereby preventing relevance loss of $1-\tau$ on that designer's products.[21]

Recipient balances similar concerns when setting local IPRs. Recipient's government chooses ω^* to maximize

$$E(W^*) = N^{*}\cdot\left(\omega^{*}\varphi+\left[1-\omega^{*}\right]\mu\right)\cdot\left(\tau\rho D[1-F(\tilde{z})]+\rho^{*}[DF(\tilde{z})+D^{*}]\right)+D^{*}P(M^{*}),$$

subject to the constraint $\omega^*\in[0,1]$. Assuming an interior solution, Recipient's best response, $\omega^*(\omega)$ solves

$$\frac{dE(W^*)}{d\omega^*} = N^{*}\left\{(\varphi-\mu)\left[\tau\,\rho D\left(1-F(\tilde{z})\right)+\rho^{*}\left(DF(\tilde{z})+D^{*}\right)\right]+\pi\rho^{*}D^{*}\right\}$$

$$+N^{*}\left[\varphi\omega^{*}+(1-\omega^{*})\mu\right]\left[\rho\tau^{2}D\left(1-F(\tilde{z})\right)\frac{\Psi}{M}N^{*}\pi^{*}+\rho^{*}N^{*}\pi\left(DF(\tilde{z})+D^{*}\right)\frac{\Psi}{M^{*}}+D\frac{dF(\tilde{z})}{d\omega^{*}}\left(\rho^{*}-\tau\rho\right)\right], \quad (5)$$

when set equal to zero.

Above we assume interior solutions. However a corner solution to one country's IPR choice is quite possible. If, for example, Recipient is sufficiently large, then so long

[21] Designer relocation to a larger market also raises the quality of goods produced, so quality-adjusted relevance declines only by $\rho-\rho^*\tau$, which Kuhn and McAusland (2009) show to be positive whenever $\Psi\leq 1$.

as Recipient offers some IP protection, Source might prefer to free ride (setting ω=0) rather than protect intellectual property domestically.[22]

Define ω_e^{NC} and ω_e^{*NC} as the IPRs that jointly solve the system formed by equations (4) and (5) under the following complementary slackness conditions: $[1-\omega]dE(W)/d\omega \le 0 \le \omega$, $\omega dE(W)/d\omega \ge 0 \le 1-\omega$, $[1-\omega^*]dE(W^*)/d\omega^* \le 0 \le \omega^*$, $\omega^* dE(W^*)/d\omega^* \ge 0 \le 1-\omega^*$. ω_e^{NC} and ω_e^{*NC} are the equilibrium strategies played in a non-cooperative policy game between Source and Recipient.

5. Bidding for Brains

As Grossman and Lai (2004) identify, when choosing policy stringency, each country ignores the benefits that domestic IP protections confer on foreigners: strict domestic IPRs raise the expected profits of foreign born producers, and spur innovation which benefits overseas consumers. Each country's failure to internalize these external benefits of strict domestic IPRs suggests that, from a global welfare perspective, IPRs in the Nash equilibrium may be too weak. The benefit-internalization failure is most apparent in our model when translation costs are small. In what follows, define $E(W^G) \equiv E(W)+E(W^*)$ as expected Utilitarian Global welfare; define $\omega^G(\omega^*)$ as the global welfare maximizing Source IPRs when Recipient IPRs are ω^*, with a similar definition for $\omega^{*G}(\omega)$. Define ω_e^G and ω_e^{*G} as the IPRs that jointly maximize $E(W^G)$ subject to the constraints $\omega^G \in [0,1]$, $\omega^{*G} \in [0,1]$.

Proposition 1: When translation costs are sufficiently small (i.e. τ sufficiently large)

(a) each country's non-cooperative best response is to set weaker IPRs than would a global welfare maximizer: $\omega^{NC}(\omega^*) \le \omega^G(\omega^*)$ and $\omega^{*NC}(\omega) \le \omega^{*G}(\omega)$;

(b) if countries are symmetric then non-cooperative equilibrium policies ω_e^{NC} and ω_e^{*NC} are (weakly) lower than joint welfare maximizing policies ω_e^G and ω_e^{*G}.

Proof: *See Appendix 1.*

When τ is large, designers have little incentive to emigrate. Even if some do relocate from Source to Recipient, the resulting relevance diversion is small because little is lost in translation. Accordingly, when the fraction of a good's value that survives

[22] For example, when $\bar{z}$ is finite, then whenever $\omega^*>0$ and N^* is sufficiently large then $g>\bar{z}$ and $F(\tilde{z})=1$ for all values of ω, rendering $\frac{dF(\tilde{z})}{d\omega}=0$. Rewriting (4) gives

$$\frac{dE(W)}{d\omega} = N\rho^*\tau\left[(\varphi+\pi-\mu)D+(\varphi-\mu)D^*+[\varphi\omega+(1-\omega)\mu]\,[D+D^*]\,\Psi\frac{N\pi\tau}{M^*}\right].$$ As

$(\varphi+\pi-\mu)D+(\varphi-\mu)D^*$ is negative, then $[\varphi\omega+(1-\omega)\mu]\,[D+D^*]\,\Psi\frac{N\pi\tau}{M^*}$ sufficiently small—or, alternately stated, $\omega^*>0$ and N^* sufficiently large—is a sufficient condition for $dE(W)/d\omega<0$ for all $\omega \in [0,1]$.

translation to a foreign market, τ, is high, each country's Brain Gain/Retention motive is small, freeing governments to set IPRs so as to balance traditional concerns over allocative inefficiency and induced innovation, ignoring benefits to overseas consumers and foreign-born producers. Consequently, when translation costs are low, countries err on the side of under-protecting intellectual property relative to what would maximize global welfare.

If translation costs are instead non-negligible, the power of weak IPRs to repel footloose talent is more pronounced: when innovations are, to some extent, region specific, designers will find it important to produce them in the market most likely to let them collect the fruits of their labor. Recognizing this, each government has an incentive to tighten domestic IPRs in a bid to attract footloose talent—the *bidding for brains* effect. Because each government ignores one of the costs—the relevance diversion suffered by consumers abroad—of this *bidding*, it follows that non-cooperative IPRs may be too *strong* when viewed from a global welfare perspective.

The strength of the *bidding for brains* effect relative to traditional concerns regarding free riding depends largely on τ. As per Proposition 1, if τ is large then the amount of relevance lost when a designer emigrates is small and free-riding concerns dominate. However, if translation costs are instead large, then free-riding is relatively unimportant since products developed for one market offer little value to consumers abroad; likewise, IPRs abroad offer little inducement to inventors at home. Relevance diversion, on the other hand, will be significant, heightening incentives to poach foreign talent via overly strict IPRs. This bidding effect induces the talent-sending country to over-protect intellectual property, as per the following proposition.

Proposition 2: When translation costs are sufficiently high (i.e. τ sufficiently small), Source's non-cooperative best response to Recipient's IPRs is too strict when viewed from a global welfare perspective; *i.e.* $\omega^{NC}(\omega^*) \geq \omega^{G}(\omega^*)$ with inequality whenever $\omega^{G}(\omega^*)<1$ and $\omega^{NC}(\omega^*)>0$.

Proof: *See Appendix 1.*

If Recipient and Source are sufficiently similar in size, they end up in a bidding war characterized by sub-optimally strict IPRs.

Proposition 3: When translation costs are sufficiently high (i.e. when τ is sufficiently low) and the countries are symmetric then both Source and Recipient set non-cooperative IPRs that are too strict from a global welfare perspective provided $\omega_e^{G}<1$, $\omega_e^{NC}>0$.

Proof: *See Appendix 1.*

If countries are instead asymmetric, there is a final distortion that must be considered. As noted above, as translation costs rise, the link between ω^* and profits and consumer surplus abroad weakens, suggesting that traditional concerns over free riding become less important. However when talent is mobile, there will be one group of

Source-borns who benefit from strong Recipient IPRs even when τ is small: immigrant talent. As Proposition 4 lays out, if Source's market is sufficiently small, the brain drain costs of beggar-thy-neighbor IPRs will also be small and the revenue-internalization failure will dominate, rendering Recipient's non-cooperative IPRs too weak from a global welfare perspective.

Proposition 4: When Source is sufficiently small, Recipient's policy is too weak from a global welfare perspective.

Proof: *See Appendix 1.*

Combined, Propositions 2 and 4 suggest that, when countries are unequal in size and translation costs are sufficiently high, it could well be the case that non-cooperative IPRs are too strict in the small country and too weak in the large country when viewed from a global welfare perspective. In this sense—Source's IPRs are *certainly* too strict when τ is low enough while Recipient's IPRs may be too high or low depending on relative market size—we can say that, perhaps surprisingly, Source's incentives to raise IPRs are qualitatively *stronger* than Recipient's.

6. Examples

To explore additional properties of our model when countries differ in size and innovative capacity, we consider a case where consumers' inverse demand function, $p(q)$, is linear, and we normalize consumer surplus when a good is competitively supplied (i.e. when the price is zero), to $\mu=1$. It immediately follows that profits when the good is monopolistically supplied, π, equal .5 and that consumer surplus under monopoly, φ, is .25.

We then think of our two countries as the United States and China and solve for Nash equilibria under what seem to be reasonable parameter values. Since N (and N^*) represent the size of the market for consumer goods in our model, we use GDP to approximate these magnitudes. Normalizing $N^*=1$, and using IMF GDP statistics for 2008 yields an N for China of ($4.4/14.3 billion), or about .3. D^*/N^* represents the share of the U.S. population who are "designers"; we estimate this by the share of U.S. research and development expenditures to GDP; according to Boldrin and Levine (2009, p. 868) this was about 3 percent in 2002, thus $D^*=.03$. To estimate the share of the South's population engaged in R&D, we note that, between 1975 and 1999, only 8 percent of U.S. patents were attributed to inventors *not* living in the U.S., European Union or Japan (Griffith, Lee and Van Reenen 2007, Table 2). Optimistically assigning one quarter of those patents to China yields a D of (.08/4).03 = .0006.[23]

[23] While it is clear that China accounts for fewer than one quarter of US patents by inventors outside the US, EU and Japan, it is also clear that not all innovations result in US patents, in part because (as suggested by our model) not all innovations are relevant to US consumers. Further it seems likely that the share of innovations that do not result in US patents is higher in less-developed countries, including China. Overall, we view our estimate of Chinese innovation at .08/4 = two percent of US innovation as a reasonable estimate of relative magnitudes.

Boldrin and Levine make numerous attempts to estimate the elasticity of inventive activity with respect to the reward to innovation, Ψ. For the largest market size considered, (which is most applicable to our model, since our marginal inventor is indifferent between moving to the U.S. and not), Figure 2 in their paper estimates Ψ to be about .2.[24] As a point of reference for our results in the presence of brain drain, it is worth noting that in our model $\Psi = .2$ leads to a privately optimal IPR level, ω, of .5 under autarky for any country, regardless of size and regardless of the ratio of designers to consumers (D/N).[25]

Empirical evidence on the magnitude of τ, the relevance of Northern innovations to Southern consumers (and vice versa) is scarce. For a number of reasons, including ecological specificities (see for example Kremer and Zwane 2005)[26] and lack of LDC research infrastructure and tacit knowledge required to understand and *implement* Northern innovations (Evenson and Binswanger 1978), we would expect the transferability of Northern innovations to the South to be much less than the value of 2/3 estimated by Eaton and Kortum (1999) among the five most developed nations. Acemoglu and Zilibotti (2001) report a case study where the same innovation was only one quarter as productive in an Indian as a U.S. plant. Using data on manufacturing industries, they estimate that output per worker would rise by a factor of 1.5 for LDCs as a whole, and by a factor of 3.2 for the poorest LDCs, if new technologies were designed for Southern rather than Northern *skill mixes* alone (leaving aside all other sources of inappropriateness).[27] Taking all of the above considerations into account, we use $\tau = .25$ as our baseline parameter.[28]

Finally, we model the density of moving costs, $f(z)$, as uniform on the interval $[0, 1/a]$. We choose $a=5$ so that, in the equilibrium of the base case of our model, a substantial fraction of Source's brains (just under half) live in the North. Since we do not endogenize skill formation in our model, it seems reasonable to think of designers here as persons who are *currently capable* of producing patentable inventions; by this measure the share of South's brains living in the North will be much higher than the emigration rates of highly-educated workers reported for most countries in Docquier and Rapaport (2009).

Source and Recipient's reactions functions under the above assumptions are shown by the thick lines in Figure 1.

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[24] Elsewhere in their paper they estimate both larger and smaller values of Ψ in a variety of contexts. In their model, the only variation in innovative activity is on the extensive margin (number of inventors), whereas (at least absent immigration) we model the intensive margin only. Nevertheless, Ψ measures the response of interest in both cases.

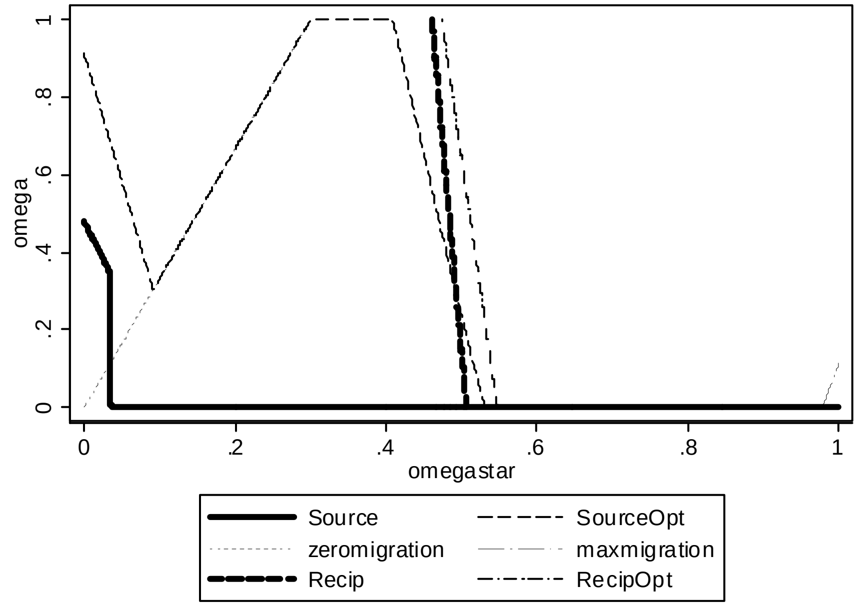
[25] Globally optimal IPRs are also .5 for all countries when countries are symmetric.

[26] Sachs (2003) importantly points out that ecological specificities extend beyond agriculture, into areas including health, construction and building materials, energy sources and uses, and infrastructure design.

[27] Statistics are taken from row 2 of Acemoglu and Ziliibotti (2001) Table IV; specifically, 41/27 = 1.5 and 16/5 = 3.2

[28] Appendix 2 and footnote 28 consider some cases with alternative values.

Figure 1: Reaction Functions: *N=.3, D=.0006*

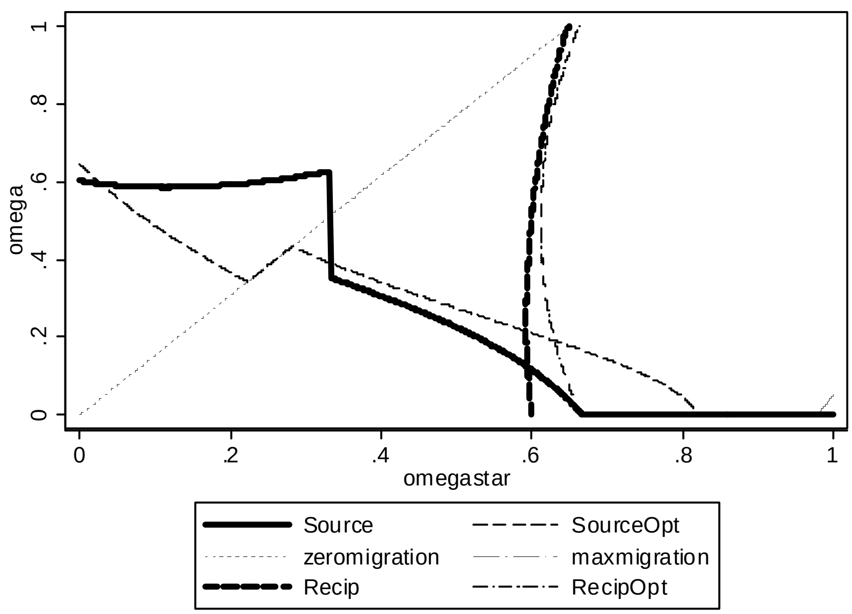


The set of all possible Source and Recipient IPRs forming the space in Figure 1 is divided into three regions: To the northwest of the "zero migration" line, brain migration is *into* Source from Recipient. This occurs despite Source's smaller market size because Source protects intellectual property much more than Recipient. To the southeast of the "maxmigration" line (in the very bottom corner of the Figure), 100 percent of Source's designers have left; in between these boundaries there is positive (but not complete) brain drain from Source into Recipient.

Source's reaction function jumps downward at the "zero migration" boundary, because the countries' different population sizes create a discrete jump in the marginal number of brains that are attracted (or retained) by raising ω. Beyond that, because of its small size, in this example Source finds it optimal not to protect intellectual property, but to free ride on Recipient's inventions (even with $\tau = .25$ the U.S.'s much larger R&D sector makes 'free riding' very appealing). Recipient's privately optimal IPRs (at around .5) are relatively independent of Source's IPRs, due to Source's small market size. At the Nash equilibrium ($\omega=0,\ \omega^*=.51$) Recipient underprotects intellectual property relative to the global optimum ($\omega=0,\ \omega^*=.55$). (The *RecipOpt* curve shows the level of Recipient's IPR, ω^*, that maximizes *global* welfare for every fixed ω and vice versa for *SourceOpt*). Even though Recipient has an incentive to overprotect IP to 'beggar Source's brains" (the *bidding-for-brains* effect), this effect is outweighed in the current example by the fact, already noted, that Recipient ignores benefits of IPRs that accrue to Source's brains living in Recipient (i.e. the *expatriate brains* effect).

Figures 2 through 4 show what happens in our model as China's market size and innovative capacity (*D* and *N*) grow relative to to the U.S., holding the other parameters of our model constant. In Figure 2, China has eliminated half the China-U.S. gap in both market size and innovative capacity, so *N=.65* and *D=.015*. Now, Nash equilibrium protection is positive in both countries, but protection remains below the global optimum. In Figure 3, about two thirds of the market-size gap is gone, and Source protection rises dramatically (to about .5) in equilibrium. Both countries now *overprotect* intellectual property relative to the global optimum. Finally, Figure 4 shows the limiting, symmetric case where the two countries are identical. As we have demonstrated analytically, equilibrium migration is zero in this case, with both countries now selecting much higher levels of IPR than the global optimum (.79 versus .50), in an attempt to outbid each other for the world's footloose innovative talent.[29]

Figure 2: Reaction Functions: *N=.65, D=.015*



[29] An important caveat to the over-protection result is that it will not necessarily hold if τ, the relevance of Northern innovations to the South, rises sufficiently rapidly as the South expands in market size and innovative talent. For example, if τ is a decreasing function of the gap between Northern and Southern per capita incomes, then income growth in the South could reduce the extent to which migration generates a relevance loss in the first place. In this case, a "race" between increasing cultural/technological proximity and increasing market size will determine whether Southern IPR protection rises or falls as South grows. However, we point out that, at least for countries with vastly different population sizes like China and the United States, total market size, *N*, is likely to catch up to *N** long before per capita incomes equalize.

Figure 3: Reaction Functions: *N=.8, D=.020*

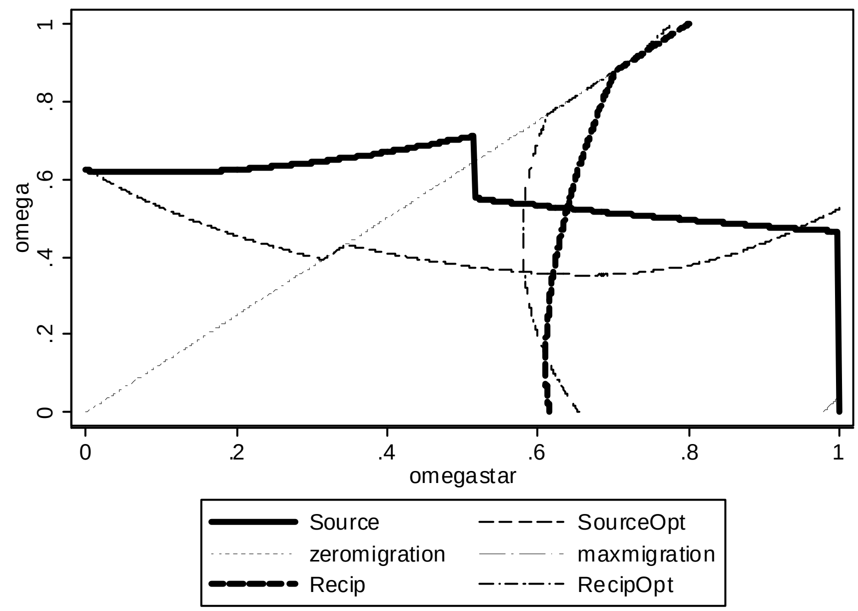
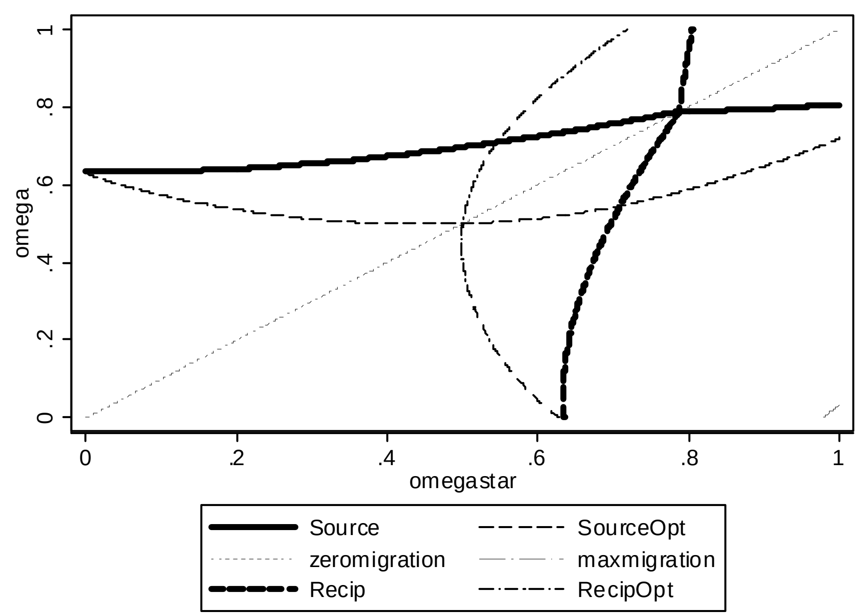


Figure 4: Reaction Functions, Symmetric Countries (*N=1, D=.03)*



7. Extensions

7.1 Can Brain Drain Explain LDCs' Non-Protection of IPRs?

Thus far, we have shown that introducing international mobility of scientists/designers might lead a developing country to overprotect IPRs—the "bidding for brains" effect. We have also shown that the bidding-for-brains effect is more likely to dominate the well known "free riding" effects when South's market size grows to a point where South can effectively contest the outflow of its brains by strengthening local IPRs. In this section we change our focus to the case where South is small, and show –perhaps surprisingly—that international mobility of scientists can, under certain conditions, also help explain why small, poor countries do *not* protect intellectual property. This countervailing tendency arises from what we call the *expatriate brains* effect.

To explore the possibility that out-migration causes weak IPRs, we begin by rearranging the expression for $dE(W)/d\omega$ in (4) to isolate terms containing $F(\tilde{z})$:

$$\frac{dE(W)}{d\omega} = ND\rho\left(\varphi+\pi-\mu\right) + ND^*\tau\rho^*\left(\varphi-\mu\right)$$
$$+N\left[\varphi\omega+(1-\omega)\mu\right]\left[\frac{D\rho}{M}+\frac{\tau^2 D^*\rho^*}{M^*}\right]\psi N\pi + N\left[\varphi\omega+(1-\omega)\mu\right]\left[D\left[\tau\rho^*-\rho\right]\frac{dF(\tilde{z})}{d\omega}\right]$$
$$+\underbrace{DF(\tilde{z})}_{\substack{number\\ of\\ emigrants}}\underbrace{\left[N\left[\varphi\omega+(1-\omega)\mu\right]\left[\frac{\tau^2\rho^*}{M^*}-\frac{\rho}{M}\right]\psi N\pi\right.}_{induced\ \ innovation\ \ (-)} + \underbrace{\left.N(\tau\rho^*-\rho)(\varphi+\pi-\mu)\right]}_{allocative\ \ inefficiency\ \ (+)}. \quad (9)$$

The final term in (9) measures a two-pronged *expatriate brains* effect of migration. The first prong is as follows. Marginally increasing ω raises expected base profits by $N\pi$ for locals but only by $\tau N\pi$ for expatriates, with implications for induced innovation: strict local IPRs buy less quality at the margin when talent operates abroad. This effect of expatriate brains argues in favor of *weaker* Source IPRs. The other prong concerns allocative inefficiency. When designers emigrate, the quality-adjusted relevance of their goods to the Source market declines. In turn, the deadweight loss from allowing monopoly power in the Source market shrinks, arguing in favor of stricter Source IPRs. Thus, whether the net *expatriate brains* effect leads to stricter or weaker policy depends on parameter values. For example, when $\Psi=1$, we find the final term in (9) is negative for all $\omega<1$ (and equal to zero when $\omega=1$) whenever $\tau<1$ provided $2\varphi+\pi > \mu$.[30]

In sum, in contrast to the 'bidding-for-brains' effect, which always raises a country's demand for IPRs, the 'expatriate brains' effect *may* shift the sending brain-sending country's IPR best response function inwards. This happens because Source's incentives to protect IPRs are weakened when a large share of its native designers reside

[30] We have no qualms about this restriction, since $2\varphi+\pi>\mu$ is also a necessary condition for each country to offer less than full IPRs in autarky when $\Psi=1$.

abroad, producing innovations that are less relevant to Source's consumers. A key distinction between the two effects is that the bidding-for-brains effect operates whenever a marginal, unilateral change in IPR policy would lead any brains to switch their location. This includes the symmetric-country Nash equilibrium in which net migration is zero. The expatriate brains effect, in contrast, does not require immigration flows to respond to IPRs; it does however require a significant share of Source's brains to be living abroad (for whatever reason). Thus, we expect to see the two effects in different situations. This is illustrated in Appendix 2, which reports simulations of our model in which shutting down the possibility of international migration *raises* South's Nash equilibrium IPRs from zero to a positive level, due to an expatriate brains effect.[31] As expected, this occurs in a situation where Source's market size is small, when τ is low, but when Source is relatively well endowed with innovative talent (this is needed to give Source an incentive to protect intellectual property in the absence of international migration).

7.2 Endogenous Relevance

Our baseline model assumes that the relevance of Source-produced goods to Recipient consumers is fixed at τ. This ignores the growing phenomenon of designers developing products specifically for overseas markets.[32] We analyze this possibility by introducing an intermediate stage into the game. Suppose that, after having chosen her quality level, ρ, a Source-based designer can make an investment that increases the relevance of her product to the overseas market. Critically, we assume it is cheaper for a designer to provide goods of a given relevance to a market if she lives in that market. Specifically, we assume a Source-residing designer achieves relevance $r \in [\tau, 1]$ in the Recipient market at cost $d(r) \geq 0$, where $d(\tau)=0$. We assume increased relevance to the Recipient market simultaneously reduces relevance in Source, so that a Source-residing designer's effective market size is $M(r)=\pi N\omega[1+\tau-r]+\pi r N^*\omega^*$.[33] The designer's associated optimization problem—taking ω, ω^*, residency, and ρ as given—is

$$\max_r \ \rho\pi\left[N\varpi[1+\tau-r]+rN^*\varpi^*\right]-c(\rho)-d(r)$$

with accompanying first order condition for an interior solution

$$\rho\pi\left[N^*\varpi^*-N\varpi\right]=d'(r)\,. \tag{10}$$

Assuming $d'(\tau)=0$, $\lim_{r\to 1} d'(r)=\infty$ and $d''>0$, it is straightforward to show that all designers residing in Source choose the same relevance level, which is less than unity but greater than τ provided $N^*\omega^*>N\omega$. Assuming the second order conditions for an interior

[31] If an initial increase in development leads a large number of a country's 'brains' to leave –perhaps because educational quality has improved--, this mechanism might help explain Chen and Puttinanun's (2005) finding of a U-shaped relationship between development and IPRs.

[32] Our thanks to an anonymous referee for suggesting this extension.

[33] For completeness, note we assume designers residing in Recipient also have the option to shift the relevance of their goods in favor of their overseas market. However, because relevance to the Recipient market would simultaneously decline, Recipient-based designers will forego this opportunity—choosing relevance levels 1 and τ in the Recipient and Source markets—whenever $N^*\omega^*>N\omega$.

maximum hold, designers continue to choose ρ to satisfy (1) in the preceding stage, and Source-born designers for whom relocation costs are relatively small will emigrate.

We are interested in how the endogenous choice of r affects the incentives facing governments when choosing local IPRs. As before, each government recognizes that strengthening its IPRs reduces allocative efficiency, raises investment incentives, and stems some relevance diversion by inducing the marginal migrant to stay home. When relevance is endogenous, a fourth concern emerges. Strengthening Source IPRs has the direct effect of raising expected profits available in the Source market. Designers rooted in Source will take advantage of this increased profitability by increasing the relevance of their products to the Source market.

If quality is relatively unresponsive to IPRs—i.e. if the induced innovation effect of IPRs on ρ is weak—then it is straightforward to show that strict IPRs provide each country with a means for retaining/stealing *virtual* brains via induced changes in r, further incenting each country to set overly-strict IPRs.

If, instead, quality is responsive to IPRs, the story is a little less clear. An IPR-induced increase in ρ amplifies the gap between profits available in small and large markets, making high r even more attractive to Source-based designers. As this indirect effect favors the large Recipient country, it is straightforward to show $dr/d\omega^*$ is unambiguously positive. Accordingly, endogenous relevance choice provides Recipient with an added incentive to set strict local IPRs even when quality is responsive to IPRs.

For Source, the net effect is ambiguous: raising ω makes it more likely that designers will receive monopoly rewards in exchange for catering to the Source market, but the induced increase in ρ makes serving the Recipient market more attractive as well. Although it is straightforward to find cases where the former effect clearly dominates—consider the case where quality is exogenously determined—, we are unable to rule out the possibility that, for some functional forms and parameter values, the latter effect may dominate. In such cases, allowing market relevance to be endogenous would serve to drive large- and small-country IPRs further apart, with large countries tightening their IPRs in a bid to attract virtual talent, and small countries weakening their intellectual protections in an attempt to stem the virtual outflow.

8. Conclusion

Existing models of two key policy issues affecting developing countries – intellectual property protection and brain drain—have so far treated these issues largely in isolation from each other. We study the interactions between these issues by introducing (costly) international mobility of knowledge workers into a model of Nash equilibrium IPR policy choice among countries. Our analysis identifies a number of considerations affecting optimal IPR policy that have not, to our knowledge, been noted before. One of these is a “bidding for brains” effect, which—in contrast to existing IPR models—can generate *excessive* IPR protection in both sending and receiving countries, as both countries attempt to ‘outbid’ each other in providing a hospitable IPR environment for internationally mobile knowledge workers. We conjecture that the "bidding for brains" effect may become empirically relevant as some developing nations begin to contest the developed world's attraction for their knowledge workers.

In addition, we also identify an 'expatriate brains' effect, which – like the well known 'free-riding' effect—can give both brain-receiving and- sending countries incentives to underprotect IPRs relative to the global optimum. Receiving countries will underprotect to the extent that they not do fully value the welfare of immigrant brains living in their country; sending countries can underprotect because the innovations produced by their own emigrants are less appropriate to the needs of sending-country consumers than innovations produced locally. Indeed we point out that one reason why developing countries might prefer little or no IPR protection may be because their knowledge workers have already departed to serve larger, richer markets, where those workers produce ideas and goods that may no longer be valued by developing country consumers.

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Appendix 1: Proofs

***$d\tilde{z}/d\omega$* and *$d\tilde{z}/d\omega^*$*:**

The full expressions for $d\tilde{z}/d\omega$ and $d\tilde{z}/d\omega^*$ are as follows:

$$\frac{d\tilde{z}^+}{d\omega} = 0 \;\; for\;\; g \notin [-\bar{z}, \underline{z}), \;\; \frac{d\tilde{z}^-}{d\omega} = 0 \;\; for\;\; g \notin (-\bar{z}, \bar{z}\,] \;\;, \;\; \frac{d\tilde{z}^+}{d\omega} = \frac{d\tilde{z}^-}{d\omega} = \frac{dg}{d\omega} = N\pi[\rho^*\tau - \rho] < 0 \;\;\; otherwise$$

and

$$\frac{d\tilde{z}^+}{d\omega^*} = 0 \;\; for\;\; g \notin [-\bar{z}, \bar{z}), \;\; \frac{d\tilde{z}^-}{d\omega^*} = 0 \;\; for\;\; g \notin (-\bar{z}, \bar{z}\,], \;\; \frac{d\tilde{z}^+}{d\omega^*} = \frac{d\tilde{z}^-}{d\omega^*} = \frac{dg}{d\omega^*} = N^*\pi[\rho^* - \tau\rho] > 0 \;\;\; otherwise \cdot$$

Proof of Proposition 1.

Part (a). Differentiating $E(W^G)$ with respect to ω gives $\dfrac{dE(W^G)}{d\omega} = \dfrac{dE(W)}{d\omega} + \dfrac{dE(W^*)}{d\omega}$.

Evaluate $\dfrac{dE(W^G)}{d\omega}$ at Source's non-cooperative best response, $\omega^{NC}(\omega^*)$. Assume for now the constraints $\omega \geq 0$ and $\omega \leq 1$ are non-binding on Source's cooperative policy choice. Then $\left.\dfrac{dE(W)}{d\omega}\right|_{\omega=\omega^{NC}(\omega^*)}$ = 0. Differentiating $E(W^*)$ with respect to ω and evaluating at $\omega^{NC}(\omega^*)$ gives

$$\frac{dE(W^*)}{d\omega} = D^*\frac{dP(M^*)}{d\omega}$$
$$+ N^*[\omega^*\varphi + [1-\omega^*]\mu]\left[\tau D[1-F(\tilde{z})]\frac{d\rho}{d\omega} + [DF(\tilde{z}) + D^*]\frac{d\rho^*}{d\omega} + D[\rho^* - \tau\rho]\frac{dF(\tilde{z})}{d\omega}\right]. \quad \text{(A1)}$$

Substituting in for $d\rho/d\omega$, $d\rho^*/d\omega$ and $dF(\tilde{z})/d\omega$ and taking the limit as $\tau \rightarrow 1$ yields

$$\lim_{\tau \to 1} \left.\frac{dE(W^G)}{d\omega}\right|_{\omega=\omega^{NC}(\omega^*)} \geq \underbrace{N^*\left[\omega^*\varphi + (1-\omega^*)\mu\right]\left[D + D^*\right]\frac{\Psi\rho N\pi}{M}}_{\substack{Un-Internalized\ Benefits \\ To\ Recipient\ Consumers \\ of\ Induced\ Innovation}} + \underbrace{D^*\rho^* N\pi}_{\substack{Un-Internalized\ Benefits \\ to\ Recipient-Born\ Designers \\ from\ higher\ expected\ profits}} \quad \text{(A2)}$$

in which the right-hand term is unambiguously positive. Thus, for ω^* for which Source's non-cooperative policy is unconstrained, $\omega^{NC}(\omega^*) < \omega^G(\omega^*)$.

For ω^* such that the non-negativity binds Source's non-cooperative policy choice, then the claim $\omega^G(\omega^*) \geq \omega^N(\omega^*)$ holds trivially as a result of the non-negativity constraint on ω^G. Finally, for ω^* such that the constraint $\omega^{NC} \leq 1$ binds, then $\left.\dfrac{dE(W^G)}{d\omega}\right|_{\omega=\omega^{NC}(\omega^*)}$ is greater than $\left.\dfrac{dE(W^*)}{d\omega}\right|_{\omega=\omega^{NC}(\omega^*)}$, the latter of which is positive in the limit as $\tau \rightarrow 1$ by (A2); consequently, for any ω^* such that $\omega^{NC}(\omega^*)=1$, $\omega^G(\omega^*)$ similarly equals unity by constraint.

In sum, for τ sufficiently large, Source's non-cooperative best response function lies everywhere either to the left of, or coincides with, $\omega^G(\omega^*)$.

By similar arguments, it is straightforward to show that $\omega^{*G}(\omega) \geq \omega^{*NC}(\omega)$ with $\omega^{*G}(\omega) > \omega^{*NC}(\omega)$ for ω such that $\omega^{*G}(\omega) > 0$ and $\omega^{*NC}(\omega) < 1$; i.e. Recipient's non-cooperative best response function lies everywhere either below, or in coincidence with, $\omega^{*G}(\omega)$.

Part (b): As per the proof of part (a), the non-cooperative best response functions lies weakly inside/below the global welfare maximizing best responses. Thus, when $N=N^*$ and equilibria are therefore symmetric, $\omega_e^{NC}=\omega_e^{*NC}\leq\omega_e^{G}=\omega_e^{*G}$ (with $\omega_e^{NC}=\omega_e^{*NC}<\omega_e^{G}=\omega_e^{*G}$ when $\omega_e^{G}=\omega_e^{*G}>0$ and $\omega_e^{NC}=\omega_e^{*NC}<1$) when τ is sufficiently large.■

Proof of Proposition 2. Taking the limit of (A1) as $\tau\to 0$ gives

$$\lim_{\tau\to 0}\left.\frac{dE(W^*)}{d\omega}\right|_{\omega=\omega^{NC}(\omega^*)} = -\rho^* N^* Df(\tilde{z})\rho N\pi\underbrace{[\omega^*\varphi+(1-\omega^*)\mu]}_{\substack{\text{Brain Drain Costs}\\ \text{Inflicted On}\\ \text{Recipient Consumers}}} < 0.$$

Following steps similar to those for the proof of Proposition 1 part (a) confirms $\omega^{NC}(\omega^*)\geq\omega^{G}(\omega^*)$ with inequality whenever $\omega^{G}(\omega^*)<1$ and $\omega^{NC}(\omega^*)>0$ when τ is sufficiently small.■

Proof of Proposition 3: Differentiate W^G with respect to ω^*, evaluate at $\omega^{*NC}(\omega)$, and take the limit as $\tau\to 0$ to get

$$\lim_{\tau\to 0}\left.\frac{dE(W^G)}{d\omega^*}\right|_{\omega^*=\omega^{*NC}(\omega)} = \rho^* N^*\pi\,[\,\underbrace{DF(\tilde{z})}_{\substack{\text{Un-Internalized}\\ \text{Revenues}\\ \text{Earned By}\\ \text{Immigrants}}} - \underbrace{N[\omega\varphi+(1-\omega)\mu]}_{\substack{\text{Brain Drain Costs}\\ \text{Inflicted On}\\ \text{Source Consumers}}}\rho Df(\tilde{z})] \qquad \text{(A3)}$$

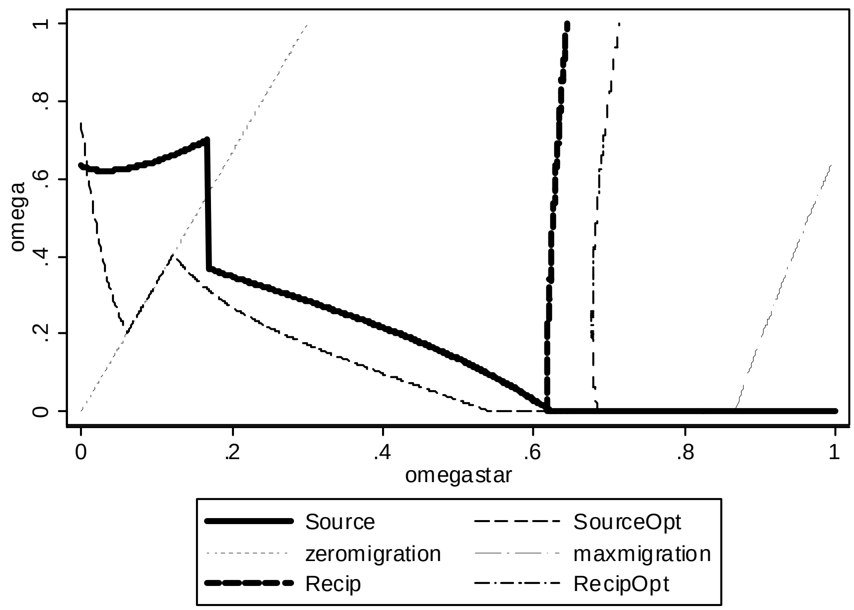
provided the constraint $\omega^{*NC}\in[0,1]$ is non-binding. When countries are symmetric, equilibrium values are also symmetric: $\omega_e^{NC}=\omega_e^{*NC}$, $\omega_e^{G}=\omega_e^{*G}$. When $N=N^*$ then $\tilde{z}=0$ and $\lim_{\tau\to 0}\left.\frac{dE(W^G)}{d\omega^*}\right|_{\omega^*=\omega^{*NC}(\omega)}$ is less than or equal to $-N^2\rho^2\pi Df(\tilde{z})[\omega\pi+(1-\omega)\mu]<0$ at any symmetric equilibrium whenever the $\omega^{*NC}\leq 1$ constraint is non-binding. If instead $\omega_e^{*NC}=\omega_e^{NC}=1$ then either $\lim_{\tau\to 0}\left.\frac{dE(W^G)}{d\omega^*}\right|_{\omega^*=\omega^{*NC}(\omega)}$ is negative at the symmetric equilibrium, in which case $\omega_e^{*G}=\omega_e^{G}<\omega_e^{*NC}=\omega_e^{NC}=1$, or $\lim_{\tau\to 0}\left.\frac{dE(W^G)}{d\omega^*}\right|_{\omega^*=\omega^{*NC}(\omega)}$ is non-positive, and so $\omega_e^{*G}=\omega_e^{G}=\omega_e^{*NC}=\omega_e^{NC}=1$. Finally, if the non-negativity constraint binds non-cooperative policy makers, then $\omega_e^{*G}=\omega_e^{G}=\omega_e^{*NC}=\omega_e^{NC}=0$.■

Proof of Proposition 4: As $N\to 0$, the final term in (A3) goes to zero and $F(\tilde{z})\to F(D(N^*\omega^*\pi)^{1+\Psi}/[1+\Psi])>0$, indicating Recipient's non-cooperative policy is too weak from a global welfare perspective provided $D>0$.

Appendix 2: Illustration of the Expatriate Brains Effect

Here we examine numerically the equilibrium implications of the *expatriate brains* effect. As noted, this effect is more likely when Source's market size is small, when τ is low, but when Source is relatively well endowed with innovative talent. To illustrate this effect—it does not apply to the China vs US parameterization of our model—we assume $\tau = .1$, and let $D = .009$; all other functional forms and parameter values are the same as in Section 6. Reaction functions, shown in Figure A1, indicate a Nash equilibrium in which the Source "free rides" at zero protection.

Figure A1: Reaction Functions, *N*=.3, *D*=.009, *τ*=.1, *a*=5



In contrast, when we set *a* to zero (but maintain all other parameter values used to generate Figure A1 simulation), we find Source now chooses to protect IPRs in the Nash equilibrium; see Figure A2. In this sense, for the right parameter values, brain drain to the North can "cause" low Southern IPRs.[34]

[34] Of course, there is no single developing country with a market (*N*) as large as China's, but much better endowed with innovative talent. Another example that produces the same outcome, however, would have *N*=.1 (about the size of Russia), with *τ*=.03 and Russia as well endowed with innovative talent as the U.S. (*D=.003*).

Figure A2: Reaction Functions, N=.3, D=.009, τ=.1, a=0