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Encouraging domestic innovation by protecting foreign intellectual property

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A B S T R A C T

This paper examines the relationship of respect for foreign intellectual property (IP) and domestic innovation. In a global economy, countries may choose to protect the IP of their own citizens, foreigners, or both or neither. We develop a model that shows that countries will have higher levels of innovation when respecting both domestic and foreign intellectual property. We test this prediction and show that domestic innovation is positively related to respect for both foreign and domestic IP. Intuitively, respect for domestic IP encourages innovation. We demonstrate the less intuitive case that protection of foreign IP further incentivizes domestic innovation.

1. Introduction

Market-based economic institutions are linked to economic growth because they provide an environment in which economic growth and activity can take place (Acemoglu et al., 2005; Góes, 2016; Hall and Jones, 1999). Using the taxonomy of Rodrik (2005), market-creating institutions are linked to economic growth (Bhattacharyya, 2009; Das and Quirk, 2016). Market-creating institutions include property rights and contract enforcement. Openness to international trade has also linked to economic growth (see, for example Frankel and Romer (1999)). This conclusion has been challenged (though not refuted) in the sense that evidence may not be conclusive (Rodríguez and Rodrik, 2000). Innovation is a driver of economic growth (Maradana et al., 2017; Romer, 1990). Grossman and Helpman (1990) noted the links between innovation, trade, and growth but saw a gap in understanding knowledge flows. There has been much subsequent work on knowledge spillovers, but this paper takes a different view, by focusing on the role of certain trade policies and institutional approaches to intellectual property rights (IPRs) that encourage domestic innovation.

We address the question of whether a country will have more domestic innovation if it respects foreign IP (as opposed to only domestic) and answer it affirmatively. More specifically, we evaluate the effect of exogenous variation in the protection of foreign IP on domestic innovation. To answer this question concisely and objectively, we only look at innovation levels and show the effect of foreign IP protection on innovation levels in a partial equilibrium setting. We do not pursue a general model that endogenizes the government's decision to implement the socially optimal degree of foreign IP protection in a general setting that accounts for all macroeconomic interactions. Despite this focus on innovation, there is an indirect link to growth and increased welfare because of the close relationship between innovation and growth.

This question is a small but important part of the link between institutions, trade, and growth. Foreign IP ought to be protected if so doing will increase a country's domestic innovation and thereby increase growth. It also has the compounding effect of encouraging more trade and foreign investment, both of which lead to growth.

IP is unique among factors of production because it is intangible (and thus nonrival) and it exists only if laws define it. These laws, however, are territorial, not global. A country does not have to grant patent protection to foreign inventors. Infringement in a foreign country is punishable only by that foreign country. Mobility of intellectual property between countries is limited not by physical constraints,

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but by treaties and legal enforcement. It is possible to protect domestic IP, but not foreign. Pirating foreign IP may be appealing because it substitutes for organic innovation; many countries have done so and it is a recurring theme in trade negotiations. It is easy to see that victims of IP theft are harmed, but it is important to ask whether IP theft poses any risks to the perpetrator's own long run innovative competitiveness; we show that it does.

Previous literature on economic institutions has considered the welfare effects of openness to trade. Domestic economic institutions have sometimes been discussed in the international trade literature (Khandelwal et al., 2013; Levchenko, 2013). These strands of literature recognize the effects of domestic institutions on trade flows and foreign investment. The missing question is whether domestic institutions (namely IPRs) that affect foreign productive assets materially affect incentives for domestic innovation.

This paper makes a new and unique contribution by building from primitive assumptions to theoretically demonstrate the positive link between protecting foreign IP and encouraging more domestic innovation (i.e., organic innovation, not foreign investment in production of IP-intensive products). There are implications for international trade and competitive advantage from this analysis because, if protecting foreign intellectual property has a positive effect on domestic innovation, then there are domestic incentives for behavior that results in more global innovation. Countries are in turn more willing to trade with and invest in other countries if their intellectual property is protected.

An reason grounded in domestic success for protecting foreign IP is more appealing than a moralistic argument that a poorer country serve the commercial interests of a rich country. This is especially so given the ongoing prominence of IP in international disputes and trade negotiations and the links between innovation and growth. IP infringement has become a major topic in light of accusations that Chinese firms have pirated intellectual property from foreign firms with state complicity.[1] This is especially interesting because some infringers of foreign intellectual property, such as China, are themselves innovators that in recent years have approached the technological frontier. Given the importance of innovation to China's economy and government, it is worth considering the effects that this IP infringement has on its own domestic innovation.

Section 2 describes existing literature on institutions, innovation, growth, and trade and demonstrates a need for an analysis of domestic respect for foreign intellectual property rights. The mathematical model, which relies on primitive microeconomic assumptions to demonstrate a link between domestic innovation and respect for both domestic and foreign intellectual property, is presented in Section 3. This link relies on the fact that intellectual property rights affect the quantity supplied of IP-intensive goods by restricting availability of substitutes, which result from infringement. The model's most important theoretical conclusion is that a country benefits internally when it protects foreign intellectual property because it has higher levels of innovation. Not only is there a global benefit in terms of innovation across all countries, but a country's own domestic levels of innovation increase when it respects foreign intellectual property as well as domestic. We complement this model with an empirical analysis in Section 4, which shows that countries that respect both domestic and foreign intellectual property are more innovative, confirming the conclusions theoretical model.

2. Relevant literature

Although this paper is about the positive effect of protecting foreign IP on domestic innovation, this is only an issue when international trade takes place. For this reason, we review the contributions and shortcomings of relevant international trade literature as well as literature on IPRs.

Heckscher-Ohlin-Vanek (HOV) trade models, which rely on comparative advantage as a driver of specialization, have long been a mainstay of trade research (Heckscher, 1919; Ohlin, 1933; Vanek, 1968; Helpman, 1984). Although not mentioning institutions, they are tacitly assumed to be good given the lack of theft. Their greatest shortcoming for the purposes of our research is the assumption of immobile capital, which is unrealistic now that much capital is intangible IP. Other shortcomings of HOV models, like the reality of intra-industry trade, were addressed by the new trade theory (Grubel and Lloyd, 1975; Krugman, 1979, 1980, 1980; Lancaster, 1980; Helpman and Krugman, 1985). We draw on some of these ideas when we evaluate the classifications of products that countries produce when IP is or is not protected. Bernard et al. (2003) and Melitz (2003) extended this theory to allow for heterogenous firms. Heterogeneous firms in intra-industry trade show an incentive for IP infringement as importers infringe, and then export infringing products.

Focusing on intra-industry trade, Schott (2004) observes that the U.S. imports and exports many goods of the same industrial classification. Countries supplying the U.S. with imports do so at widely varying prices. Schott's (2004) application is the electronics industry in Japan and the Philippines. Japan's industry is more capital-intensive, and it produces substantially different products that are closer to the technological frontier. In Schott's view, no sector is capital-intensive or labor-intensive; rather different products in the same sector are capital-intensive or labor-intensive. This observation leaves much room for intellectual property rights and institutions to influence the mix of goods produced domestically. For example, if a labor-abundant country acquires the know-how needed to copy another country's product by infringing intellectual property, it could start to produce the types of goods made in the capital-abundant country. Schott's insights form the beginning of our model which provides an intuitive area for infringement (same industrial classification) and incentive for it (reciprocal trade flows).

Intellectual property rights have rich subliterature within international trade. Lerner (2009) shows that increases in patent protection result in more patent applications by both residents and foreigners. This complements Allred and Park (2007), who empirically showed the positive effect of patent rights on innovation investment. Maskus and Penubarti (1995) show that strengthening patent protection in developing countries increases bilateral manufacturing imports into such countries. Likewise, stronger patent laws are linked to more research-intensive exports (Maskus and Yang, 2018; Schneider, 2005). R&D spillovers have long been linked to trade. Ideally these are consensual, but they show an intuitive place where IP infringement and theft can take place. Coe and Helpman (1995) found beneficial effects of foreign R&D on domestic productivity. Superficially, this may seem good for an infringer of foreign IP. Fracasso and Marzetti (2015) empirically addressed this issue without assuming that trade flows were proportional to knowledge transfers, thus expanding possibilities for infringement, though the mechanism is unclear. Grossman and Helpman (1991) also found that openness to trade was linked to greater knowledge spillovers.

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[1] The Commission on the Theft of American Intellectual Property (a private organization) issued its *IP Commission 2019 Review* in February 2019, which details China's strategies of intellectual property theft which have centered on forced technology transfers and cybertheft in recent years.

International IP infringement, a major focus of this paper, has been addressed in the literature. Grossman and Lai (2004) discuss developed countries' dissatisfaction with state of IPRs in the developing world which led to the Trade-Related Aspects of Intellectual Property (TRIPs) agreement at the Uruguay Round. Lai (1998) found positive effects on innovation and wages in poorer (southern) countries when their protection of IPRs increases if the mechanism of technology transfer from wealthier (northern) countries is foreign direct investment. This finding was corroborated by Ghosh et al., 2018; Yang and Maskus, 2001 and Yang and Maskus (2009). Palangkaraya et al. (2017) similarly concluded that trade is negatively impacted when poor countries refuse patent protection to foreigners. When the mechanism of knowledge transfer was imitation, or perhaps infringement, the effect of stronger IPRs in southern countries was the opposite and innovation decreased. This result does not refute our argument that protecting foreign IP encourages domestic innovation because stopping "imitation-based innovation" is really just stopping infringement. Incentives for FDI-based or other consensual knowledge spillovers increase. Katila and Mang (2003) write that patent rights affect one firm's decision to collaborate with others on innovation-related projects, showing one mechanism whereby domestic protection of foreign IP could lead to more domestic innovation, a finding complemented by Katila et al. (2008). Providing further support, (Di Vita, 2013) showed that the TRIPs agreement resulted in more homegrown innovation in poorer countries separately from the increase in foreign direct investment.

Much of this literature on international infringement pertains to foreign direct investment or the decision of whether or not to trade. The present-day situation is different for two major reasons. First, some prominent infringers, such as China, have become innovators and are no longer strictly imitators. State-directed industrial policies that encourage piracy and technology transfers can exacerbate any problems this causes. Infringing countries have their own export markets to which they can supply products using infringed western intellectual property. Because they are not far from the technological frontier, the old north-south distinction is less applicable than it once was. Second, refusal by some firms or countries to trade in some products may not thwart infringement. State-directed Chinese investment in foreign countries can facilitate industrial espionage, which is already easier when there are more trade linkages between countries. Trade links between China and the west are numerous enough that the trading relationship is difficult to untangle and there will be adverse welfare consequences on both sides even if ceasing trade could stop IP theft.

3. Model

The model in this section illustrates the implications of institutional approaches to domestic and foreign intellectual property in international trade. When domestic IP is not protected, innovation is discouraged through free riding on research and the resulting competition that drives prices down. For foreign IP, only competition matters. If foreign IP is protected, domestic prices remain higher, thus encouraging innovation to reduce costs or develop improved products. Higher prices for final goods reflect quality improvements and inflation, although most of it has been attributed to quality improvements in recent years (Bils, 2009). This is not as trivial as it sounds; intuitively, pirating IP should reduce costs, produce improved products as well and possibly be a catalyst for follow-up innovation, although this discourages trade and foreign investment.

Protecting foreign IP to promote domestic innovation, and thereby achieving economic growth, is a better strategy for encouraging innovation than pirating it. Our model reaches this conclusion from primitive assumptions. We do not attempt to achieve the greatest possible generality, but rather to provide a sound understanding of the role of the protection of domestic and foreign IP in encouraging innovation. Under reasonable conditions, elaborated in this model, protecting foreign IP leads to more domestic innovation.

Consider a market of goods y produced and consumed in two countries, i and j. This market of goods consists of three classes, y_S, y_M, and y_H, respectively resulting from more technology-intensive processes. These are classes of goods based on the need for advanced technology in their production and do not represent specific industries. For example, electronics could be in y_H (avionics equipment), y_M (desktop computers), or y_S, (tape recorders). Likewise, y_H could include smart clothing that monitors the heart rate and y_S could include cotton t-shirts. The point is that, within all industries, goods can be separated into classes based on the technology needed for their production. This is a similar approach to that of Schott's (2004) analysis of intra-industry trade.

The set of firms in country n is denoted by Φ_n, indexed by ϕ, where $\#\Phi_n > 1$. There are two time periods, 1, and 2. In time period 1, firms choose labor for production of goods and new technology. In time period 2, firms only produce output.

3.1. Factors and commodities

Factors include the following:

1. Intellectual property G – endogenously produced with labor.
2. Technology Z – determined by an exogenous initial endowment and the intellectual property produced, or obtained by infringement.
3. Labor L – any amount can be hired at the exogenous, competitively determined wage which may vary between countries. Wage for labor which is used in production of goods is denoted w. Wage for labor to produce G is denoted s.

Production functions are the same for all firms and countries. Let $L_{Xt\phi}$ denote the quantity of labor used to produce X at time t for firm ϕ. Technology at time 1 is exogenous and assumed to be the same for all firms within each country, respectively denoted $Z_{1,j}$ and $Z_{1,i}$. Intellectual property at time 1 for all firms, G_1, is 0. Let $n(\phi) \in \{i, j\}$ denote the country of firm ϕ and $\sim n(\phi)$ denote the foreign country. Commodities y_S, y_M, and y_H are produced using the factors enumerated above. Production functions and the evolution of technology are represented by:

$$\begin{aligned} y_{xt\phi} &= x(L_{y_x t\phi}, Z_{t\phi}) \text{ for } x \in \{S, M, H\} \\ Z_{2\phi} &= Z_{1,n(\phi)} + G(L_{G1\phi}) + A\left(I_{dn(\phi)}\right) \sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} G_{\tilde{\phi},2} + B\left(I_{fn(\phi)}\right) \sum_{\tilde{\phi} \in \Phi_{\sim n(\phi)}} G_{\tilde{\phi},2}. \end{aligned}$$

The term $G(L_{G1\phi})$ represents G created for time 2, formally, $G_{\phi,2} := G(L_{G1\phi})$. The term $A\left(I_d\right)\sum_{\tilde{\phi}\in\Phi_{n(\phi)},\tilde{\phi}\neq\phi} G_{\tilde{\phi},2}$ represents infringement of domestic intellectual property. Infringement of foreign intellectual property is represented by $B\left(I_{fn(\phi)}\right)\sum_{\tilde{\phi}\in\Phi_{\sim n(\phi)}} G_{\tilde{\phi},2}$. The possibility of adopting foreign technology that is not intellectual property is excluded from the model only to reduce clutter. Such would not qualitatively change results.

Intellectual property is protected by a country's domestic institutions $I_{dn(\phi)} \in \mathbb{R}$. Examples of $I_{dn(\phi)}$ include feasibility of obtaining patents, transparent requirements of patentability, enforcement of patents, and legal protection for trade secrets and trademarks. Foreign intellectual property is generally by default not respected, but only in the sense that a inventor must file for a patent in each country. Domestic institutions do have an effect on the treatment of foreign intellectual property. The respect that domestic institutions have for foreign intellectual property is represented by $I_{fn(\phi)} \in \mathbb{R}$, our variable of interest. Examples of $I_{fn(\phi)}$ include permitting foreigners to file patents on equal grounds as citizens, impartial enforcement of patents regardless of owner's nationality, adherence to international agreements like the Agreement on Trade-Related International Aspects of Intellectual Property (TRIPS), ability of foreigners to operate in a country without expropriation of trade secrets, not engaging in industrial espionage, and not permitting trademark infringement. Because higher values correspond to more protection (respect), A and B are decreasing are functions.

$$\frac{\partial A}{\partial I_{dn(\phi)}} \leq 0 \qquad \frac{\partial B}{\partial I_{fn(\phi)}} \leq 0 \quad A(I_{dn(\phi)}) \in [0,1] \qquad B(I_{fn(\phi)}) \in [0,1]$$

3.2. Autarky equilibrium

In autarky there is no trade and firms cannot infringe upon the intellectual property of foreign firms, $B(I_{fn(\phi)}) = 0$. Within each country the inverse demand function representing the price of good x, $p(x) : [0,\infty) \to [0,\infty)$, is a continuous, decreasing, function of the total quantity of x consumed. We assume $p(x)$ is twice differentiable for all $x \neq 0$, and also $p(0) > 0$.[2] We solve for a *symmetric equilibrium*, defined by labor input choices for which all firms maximize profits given labor of other firms, and $L_{xt\phi} = L_{xt\tilde{\phi}}$ for all $\phi, \tilde{\phi}$ within each country.[3] This autarky equilibrium demonstrates the intuitive result that domestic protection for domestic intellectual property is linked to more innovation and lays a foundation for examining domestic protection of foreign intellectual property.

Given $\beta \in (0,1)$, the objective function of firm ϕ is

$$\max_{L_{G1\phi},\{L_{y_x1\phi},L_{y_x2\phi}\}_{x\in\{S,M,H\}}} \sum_{x\in\{S,M,H\}} \left[p\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} y_{x1\tilde{\phi}}\right) y_{x1\phi} + \beta p\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_{n(\phi)x}(L_{y_x1\phi} + \beta L_{y_x2\phi})\right] - s_{n(\phi)} L_{G1\phi}.$$

Note that in time period 2 no labor is allocated to developing G (that is, $L_{G2\phi} = 0$). Symmetric equilibrium allocations are obtained first by assuming labor choices at time 1 are symmetric, then solving for mutual best response labor choices at time 2 as a function of labor at time 1. Best response time 2 labor is shown to be symmetric. Optimizing labor choices at time 1, given time 2 labor as a function of time 1 labor, are unique and symmetric under the conditions shown below.

By imposing the symmetry that optimizing choices of labor at time 1 are identical for all firms, $L_{G1\phi}$, and therefore $Z_{2\phi}$, are the same for all firms in each country. Given $Z_{2\phi}$, at time 2 each firm ϕ solves

$$\max_{L_{y_S2\phi},L_{y_M2\phi},L_{y_H2\phi}} \sum_{x\in\{S,M,H\}} \left[p\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_{n(\phi)x}(L_{y_x2\phi})\right].$$

We use the notation $(S_L)^{-1}$, $(M_L)^{-1}$, and $(H_L)^{-1}$ to represent functions of Z and marginal product of labor determining the quantity of labor used in production. For $x \in \{S, M, H\}$, the first order condition is

$$w_{n(\phi)x} = x_L(L^*_{y_x2\phi}, Z_{2\phi}) \left(p\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} x(L^*_{y_x2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} x(L^*_{y_x2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_x2\phi}, Z_{2\phi})\right)$$

$$\Rightarrow L^*_{y_x2\phi} = (x_L)^{-1}\left(\frac{w_{n(\phi)}}{p\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} x(L^*_{y_x2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}\in\Phi_{n(\phi)}} x(L^*_{y_x2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_x2\phi}, Z_{2\phi})}, Z_{2\phi}\right).$$

Superscript "$*$" denotes the symmetric optimizing value. With assumptions 1 and 2, it is an elementary exercise that a unique symmetric $L^*_{y_x2\phi}$ satisfies these conditions.

Assumption 1. For $x \in \{S, M, H\}$, x_Z, x_L, x_{LZ}, and $x(\cdot,\cdot)$ are weakly positive. Furthermore $\lim_{L\to 0} x_L(L,Z) = \infty$, $\lim_{L\to\infty} x_L(L,Z) = 0$ for all Z, and $x_{ZZ} < 0$, $x_{LL} < 0$. Additionally $\lim_{L\to 0} x(L,Z) = 0$.

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[2] The inverse demand function is allowed to vary for each country, product, and time period, although subscript notation indicating this is not used to reduce clutter. This is consistent with Romer's (1990) monopolistic competition equilibrium with endogenous technological change.

[3] We do not allow for collusion, thus our equilibrium concept is like that of Cournot, but with the addition that firms take into account the effect of their own behavior on other firms.

Assumption 2. For all goods y, there exists $\varepsilon, \eta > 0$ such that for $y \in [0, \varepsilon]$, $p(y) + p'(y)y > \eta$. Furthermore, for all goods y and for all levels of consumption greater than 0, $2p'(y) + yp''(y) \leq 0$.[4]

Because Z_1 is exogenous, the necessary conditions for optimization in period 1 and existence of symmetric optimizing $L^*_{y_x 1\phi}$, follow analogously.

The decision problem for firm ϕ at time 1 regarding L_{G1} is

$$\max_{L_{G1\phi}} \beta \left\{ \sum_{x \in \{S,M,H\}} \left[p\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) x(L^*_{y_x 2\phi}, Z_{2\phi}) - w_{n(\phi)x}(L^*_{y_x 2\phi}) \right] \right\} - s_{n(\phi)} L_{G1\phi},$$

where the optimizing $L^*_{y_x 2\phi}$ depend on $Z_{2\phi}$ and therefore $L_{G1\phi}$. As shorthand, for $x \in \{S, M, H\}$, we use the notation x_L to represent $x_L(L, Z)$, we use $(x_L)^{-1}_Z$ to represent $\frac{\partial (x_L)^{-1}(\cdot, Z)}{\partial Z}$, and we use x_Z to represent $x_Z(L, Z)$. Noting that $Z_{2\phi} = Z_{1,n(\phi)} + G(L_{G1\phi}) + A\left(I_{dn(\phi)}\right) \sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} G_{\tilde{\phi},2}$, the first order condition is

$$s_{n(\phi)} = \beta G'(L_{G1\phi}) \sum_{x \in \{S,M,H\}} \left(p\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) [x_{L\phi}(x_{L\phi})^{-1}_Z + x_{Z\phi}] + p'\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right)^* \right.$$

$$\left. \sum_{\tilde{\phi} \in \Phi_{n(\phi)}} \left(\left[A(I_{dn(\phi)}) + (1 - A(I_{dn(\phi)})) \times 1\{\phi = \tilde{\phi}\} \right] [x_{L\tilde{\phi}}(x_{L\tilde{\phi}})^{-1}_Z + x_{Z\tilde{\phi}}] \right) x(L^*_{y_L 2\phi}, Z_{2\phi}) - w_{n(\phi)x}(x_L)^{-1}_Z \right).$$

This implicitly defines the value of L_{G1} at which the first order condition holds (evaluating each function written in shorthand at $L^*_{y_x 2\phi}, Z_{2\phi}$). We use L^*_{G1} to denote a value which constitutes a symmetric equilibrium.

At optimizing time 2 labor

$$x_{L\phi} = \frac{w_{n(\phi)x}}{p\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) + p'\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) x(L^*_{y_x 2\phi}, Z_{2\phi})} \text{ for } x \in \{S, M, H\},$$

which implies that

$$s_{n(\phi)} = \beta G'(L_{G1\phi}) \sum_{x \in \{S,M,H\}} \left(x_Z \left[p\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) + p'\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) x(L^*_{y_L 2\phi}, Z_{2\phi}) \right] \right.$$

$$\left. + \left[\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} A(I_{dn(\phi)}) [x_{L\tilde{\phi}}(x_{L\tilde{\phi}})^{-1}_Z + x_{Z\tilde{\phi}}] \right] \left[p'\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}}) \right) x(L^*_{y_L 2\phi}, Z_{2\phi}) \right] \right) \tag{1}$$

Prior to providing conditions for existence of a unique equilibrium $L^*_{G1\phi}$, we make the following assumptions:

Assumption 3. Each of the following is bounded on the full support:

$$x_Z, x_{LZ}, x_{ZZ}, p(y) + p'(y)y, 2p'(y) + yp''(y), p'(y)y.$$

[5]

Assumption 4. $G(0) = 0$, $G'(0) > 0$, $G''(L_{G1\phi}) < 0$, and $\lim_{L_{G1\phi} \to \infty} G'(L_{G1\phi}) < 0$.[6]

Proposition 1 states that if $G(L_{G1\phi})$ is sufficiently concave, then there is a value, $L^*_{G1\phi}$, such that if $L_{G1\phi} = L^*_{G1\phi}$ for all ϕ, firms are in a unique symmetric equilibrium.

Proposition 1. *In autarky, there exists a $\overline{G}$ such that if $G''(L_{G1\phi}) < \overline{G}$ for all $L_{G1\phi}$, either all ϕ optimize by choosing $L_{G1\phi} = 0$ or instead there is a unique $L^*_{G1\phi}$ such that if $L_{G1\phi} = L^*_{G1\phi}$ for all ϕ, Eq. (1) holds for all ϕ and firms are in a symmetric equilibrium.*

Proof. See Appendix.

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[4] Assumption 2 implies that $p(y_{x2}) + p'(y_{x2})x(L^*_{y_x 2\phi}, Z_{2\phi}) > \eta$ for small enough y_{x2} because $p'(y) < 0$ and $x(L^*_{y_x 2\phi}, Z_{2\phi}) \leq y_{x2}$. It also guarantees $p(y_{x2}) + p'(y_{x2})x(L^*_{y_x 2\phi}, Z_{2\phi})$ is decreasing in $x(L^*_{y_x 2\phi}, Z_{2\phi})$. If $p'' \leq 0$ it is trivial because $p' < 0$. If $p'' > 0$, this holds because $x(L^*_{y_x 2\phi}, Z_{2\phi}) \leq y_{x2}$. To show that non-trivial inverse demand functions satisfying these conditions do exist, as an example consider $p(y) = \ln(2 - y)$ for $y \in [0, 1]$ and $p(y) = 0$ for $y > 1$.

[5] Notice that assumption 3 does not bound x_L, and in fact assumption (1) posits that this term is unbounded. When using optimal time 2 labor, x_L is pinned down by wage and the inverse demand function, therefore the boundedness of the inverse demand function is sufficient that x_L be bounded for all points at which firms optimize in time 2.

[6] The astute observer will notice that assumption (4) allows for, with sufficiently large $L_{G1\phi}$, marginal technology of labor to be negative. Because firms will never choose such a quantity when optimizing, the function could be redefined to be a constant function after marginal productivity reaches 0, and all results follow identically.

Remark. One may wonder if the constraint on $G''(L_{G1\phi})$ to guarantee uniqueness does so in a trivial manner, namely guaranteeing that only corner equilibria exist. To see that this is not the case, consider a function G, parameters, and functions such that there exists a corner equilibrium at which the right-side of (1) is positive. This is trivially possible by choosing functions where $G'(0)$ is sufficiently small and $x_Z(L^*_{y_x2\phi}, Z_{1n(\phi)})$ is sufficiently large. Solve for the necessary $\overline{G}$ such that a unique equilibrium is guaranteed. Define $\tilde{G}$ such that $\tilde{G}(0) = G(0)$, $\tilde{G}''(L_{G1\phi}) < \overline{G}$ for all $L_{G1\phi}$, and $\tilde{G}'(0)$ sufficiently large such that the right-side of (1) is greater than $s_{n(\phi)}$. It is immediate that such parameters provide a non-trivial equilibrium.

With existence, the main result we garner from autarky is that optimal development of intellectual property is increasing in the quality of domestic institutions. The result does not follow from the present assumptions. In order to achieve this important and intuitive result, we must either make stronger assumptions on the inverse demand function or the production process. Proposition 2 provides a sufficient condition on the inverse demand function for the result.

Proposition 2. *There exists a* $\overline{p}$ *such that if* $p''(y_x) < \overline{p}$ *over the support where* $p > 0$ *for all* x*, then* $L^*_{G1\phi}$ *is weakly increasing in* $I_{dn(\phi)}$.

Proof. See Appendix.

If p'' is negative, then price decreases in quantity at an ever-increasing rate. Demand is thus more inelastic. Many things affect price elasticity, but one of them is the availability of substitutes. If a product is needed and few substitutes are available, demand is less sensitive to price. Intellectual property protection should make demand for IP-intensive goods more inelastic by curtailing the availability of close substitutes. When institutions that protect IPRs are good, and when demand is sufficiently inelastic to enable charging higher prices to recoup the investment cost, there is a greater incentive to innovate, or employ more $L^*_{G1\phi}$. Good institutions coincide with having p'' sufficiently negative. Thus, the restriction that p'' be sufficiently negative is reasonable and the result that $L^*_{G1\phi}$ is weakly increasing in $I_{dn(\phi)}$ is intuitive.

There are two mechanisms driving this result. The first is competition. Increased infringement allows for other firms to increase output and drive down prices. This disincentivizes innovation. The other mechanism is that increased infringement causes a firm's marginal productivity of innovation to decline. Infringement disincentivizes innovation because firms can free ride on the innovation of other firms. It is important to note that firms make optimizing decisions based on given institutions; institutions are determined by government.

The policy regarding the degree of foreign IP protection is likely determined while taking into account firms' innovation and output responses, employment effects, the morality of IP theft, and numerous other factors. Our goal is not to model the complicated objective function of governments, but rather to show the optimizing responses of firms when policies are taken as given. As such, this model shows a partial equilibrium that is designed to illuminate the consequences of a government policy to protect foreign IP. In the long run, as these effects are realized and domestic innovation increases, new political pressures will exist that may influence subsequent government decisions about IP protection. Firms take government policies as given in the near term, but may try to influence them over the long run. These political pressures and their effects on policy are beyond the scope of this paper. This result implicitly assumes a good intellectual property regime that protects novel innovations and does not grant frivolous patents. Frivolous patents may impede innovation. We now consider opening the economy to world trade.

3.3. Equilibrium with international trade

There is a world market faced by firms from each country, with inverse demand functions $p(x)$ for each good x satisfying conditions of assumption (2). Wages are also the same for labor producing each good across countries. Goods are shipped costlessly, which is a simplifying assumption, but is somewhat reasonable given the very low per-unit shipping costs that have resulted from the widespread adoption of the shipping container (Levinson, 2016).

We define a *country-symmetric equilibrium* as labor input choices such that all firms mutually maximize profits given labor of other firms, and in which all $\phi \in \Phi_n$ choose identical labor inputs for $n \in \{i, j\}$.

The objective function of firm ϕ is

$$\max_{L_{G1\phi},\{L_{y_x1\phi},L_{y_x2\phi}\}_{x\in\{S,M,H\}}} \sum_{x\in\{S,M,H\}} \left[p\left(\sum_{\tilde{\phi}} y_{x1\tilde{\phi}}\right) y_{x1\phi} + \beta p\left(\sum_{\tilde{\phi}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_x(L_{y_x1\phi} + \beta L_{y_x2\phi}) \right] - s_{n(\phi)} L_{G1\phi}.$$

We solve for a country-symmetric equilibrium by assuming all $\phi \in \Phi_n$ choose country-symmetric labor at time 1 for $n \in \{i, j\}$ and showing optimal labor at time 2 is country-symmetric. Conditions are then shown such that optimizing labor choices at time 1, given time 2 labor as a function of time 1 labor, are country-symmetric.

By imposing the symmetry that optimizing choices of labor at time 1 are identical for all firms, $L_{G1\phi}$, and therefore $Z_{2\phi}$, are the same for all firms in each country. Given $Z_{2\phi}$, at time 2 each firm ϕ solves

$$\max_{L_{y_S2\phi},L_{y_M2\phi},L_{y_H2\phi}} \sum_{x\in\{S,M,H\}} \left[p\left(\sum_{\tilde{\phi}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_x(L_{y_x2\phi}) \right].$$

The first order condition is

$$\begin{aligned} w_x &= p\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x_L(L^*_{y_x 2\phi}, Z_{2\phi}) + p'\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x_L(L^*_{y_x 2\phi}, Z_{2\phi}) x(L^*_{y_x 2\phi}, Z_{2\phi}) \\ &\Rightarrow L^*_{y_x 2\phi} = (x_L)^{-1}\left(\frac{w_x}{p\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_x 2\phi}, Z_{2\phi})}, Z_{2\phi}\right). \end{aligned}$$

Proving the existence of unique mutual best reply time 2 labor inputs is not as simple as in autarky, and we provide a formal proof.

Proposition 3. *If there exist L_{G1i} and L_{G1j} such that $L_{G1\phi} = L_{G1n(\phi)}$ for all ϕ, then there exist unique $L^*_{y_x 2i}$ and $L^*_{y_x 2j}$ such that if $L^*_{y_x 2\phi} = L^*_{y_x 2n(\phi)}$ for all ϕ, the necessary conditions hold for all ϕ.*

Proof. See Appendix.

It is analogous that country-symmetric labor input choices for production at time 1 exist and are unique. The derivation of the equation which implicitly defines $L_{G1\phi}$ is parallel to the case of autarky and results in

$$\begin{aligned} s_{n(\phi)} = \beta G'(L_{G1\phi}) \sum_{x \in \{S,M,H\}} \Bigg(& x_Z \left[p\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_L 2\phi}, Z_{2\phi}) \right] \\ & + \left(\left[\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} A(I_{dn(\phi)})[x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}] \right] + \left[\sum_{\tilde{\phi} \in \Phi_{\sim n(\phi)}} B(I_{f\sim n(\phi)})[x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}] \right] \right) \\ & \times \left[p'\left(\sum_{\tilde{\phi}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_L 2\phi}, Z_{2\phi}) \right] \Bigg) \end{aligned} \tag{2}$$

Proposition 4 states that, with sufficiently concave G, there exist values, $L^*_{G1n(\phi)}$, such that $L_{G1\phi} = L^*_{G1n(\phi)}$ for all ϕ defines a unique country-symmetric equilibrium.

Proposition 4. *There exists a $\overline{G}$ such that if $G''(L_{G1\phi}) < \overline{G}$ for all $L_{G1\phi}$, exactly one of (I) and (II) hold.*

- (I) *there exists a unique pair of $L^*_{G1n(\phi)}$ such that if $L_{G1\phi} = L^*_{G1n(\phi)}$ for all ϕ one of the following holds.*
    - (i) *Eq. (2) holds with equality for all ϕ.*
    - (ii) *$L^*_{G1k} = 0$, $L^*_{G1\sim k} \neq 0$, and Eq. (2) holds with equality for all $\phi \in \Phi_{\sim k}$ for some $k \in \{i, j\}$.*
- (II) *a country-symmetric equilibrium is characterized by $L_{G1\phi} = 0$ for all ϕ.*

Proof. See Appendix.

The condition providing uniqueness does not imply a corner equilibrium. This follows by an argument similar to the argument for the case of autarky. Existence of a unique equilibrium requires sufficiently concave production of technology. Romer's (1986; 1990) models with innovation and knowledge displaying increasing returns to scale may make this requirement of concave production distasteful for some readers, but there are several logical reasons why production may be concave. First, production of knowledge and technology must be concave, not production of goods. In our model, G is a function of labor allocated to its production L_G. Second, knowledge and technology themselves may have increasing returns, but it is more reasonable to assume diminishing returns to specific knowledge creating activities (e.g. R&D). Moreover, knowledge and technology may not have increasing returns as individual pieces of knowledge are specific to a production process and cannot be infinitely applied to others. This is true regardless of the strength of IP laws.

The alternative to this assumption is to make stronger assumptions on functions or even impose specific functional forms. Such an approach is less robust and almost certainly less realistic than concave production of G. Our goal is to provide an elegant paradigm in which implications of infringement are understood and to avoid extraneous assumptions in so doing.

We next turn attention to the main purpose of our model. Proposition 5 states that $L_{Gi1\phi}$ is weakly increasing in $I_{dn(\phi)}$ and $I_{f\sim n(\phi)}$.

Proposition 5. *There exists a $\overline{p}$ such that if $p''(y_x) < \overline{p}$ over the support where $p > 0$ and for all x, then equilibrium $L_{G1\phi}$ is weakly increasing in $I_{dn(\phi)}$,$I_{fn(\phi)}$ and $I_{f\sim n(\phi)}$.*

Proof. Fix L_{G1i} and L_{G1j}. By a similar argument as shown in the proof of proposition 2, there exists a $\overline{p}$ such that if $p'' < \overline{p}$ then the right side of (2) is increasing for all ϕ in each of $I_{dn(\phi)}$, $I_{fn(\phi)}$, and $I_{f\sim n(\phi)}$. Now the value of $L_{G1\phi}$ at which (2) holds with equality is increasing in all IPR variables for all ϕ. All derivatives will have a similar expression as the first two lines of the relevant derivative in the proof of proposition 2. If p'' is sufficiently negative, this term will dominate and the first derivatives will be positive. □

As before, for domestic institutions, competition and free-riding are the mechanisms whereby infringement due to poor institutions disincentivizes innovation. If intellectual property can be infringed, other firms increase output and drive down prices. In such a setting firms have less incentive to innovate. This model also assumes that the intellectual property regime not only protects intellectual property rights, but that these rights are defined in a way that preserves incentives for true innovation. That is, novel technology should be protected, but protecting frivolous and trivial inventions only creates arbitrary monopolies and could stifle further innovation.

Innovation increases when foreign countries respect intellectual property only through the mechanism of competition. When foreign infringement declines, foreign competition declines. This puts upward pressure on prices and incentivizes innovation.

Innovation increases when domestic laws respect foreign intellectual property both because of reduced competition and because of a reduction in free-riding. If domestic firms cannot infringe foreign intellectual property, prices for imports are higher and domestic (and foreign) incentives for innovation are increased. Respect for foreign intellectual property could attract more foreign direct investment which could result in knowledge spillovers and more domestic innovation.

As demonstrated above, $L_{G1\phi}$ is increasing in $I_{dn(\phi)}$ and $I_{f\sim n(\phi)}$ when p'' is sufficiently negative. There are situations in which this may not hold. If a technologically savvy infringing country exports its infringing products to countries that do not produce them (e.g. third world countries), its demand curve may be more elastic because these other countries may be more price sensitive. China has a history of doing this and, with its Belt and Road Initiative, has invested much in developing countries, often including assistance with operation and technical know-how.[7] China's "infringement" is closer to theft in some cases as pirating trade secrets is said to be a major problem and a reason for an American trade policy response.[8] Although trade secrets are not protected in the same way as patents, they are productive assets and misappropriation is punishable in many cases. The model's results hold whether trade secrets or patents are the type of intellectual property in question and may even be stronger in the case of trade secrets, given the amount of frivolous patents.

When domestic laws do not sufficiently respect foreign intellectual property, p'' may not be sufficiently negative and $L_{G1\phi}$ may not be increasing, at least not in $I_{f\sim n(\phi)}$. $L_{G1\phi}$ may still increase in domestic institutions if the country protects its own innovators who produce goods other than those produced by the country from whom it infringes. This is possible because p is specific to each good and intellectual property, although involving an institutional framework, is protection granted separately to each good. Moreover, this shows the intuitive importance to a country of having foreign countries respect its intellectual property.

The simple conclusion in both the autarky and trade equilibria that innovation increases in the protection of intellectual property is simple and intuitive. The more interesting conclusion from the trade equilibrium is that domestic respect for foreign intellectual property is beneficial for the country's own domestic innovation. This is not only a global benefit, but a direct benefit within a country from respecting foreign intellectual property.

3.4. Impact on market structure

To this point we have considered the number of firms to be exogenous. We evaluate the impact of intellectual property protection on market structure, defined by the number of firms. Note that all firms within each country are identical, $\#\Phi_n$ is the number of firms in country n, and the objective function is shown at the beginning of Section 3.3. We add a fixed cost, χ, to this objective function, to be paid by all firms that operate in the two time period model. This fixed cost does not alter any previous analysis, but the existence of this fixed cost allows for profits to be negative. We assume before time 1 that firms enter or exit until equilibrium profits are 0.[9] We denote the equilibrium number of firms that satisfy this condition as $\#\Phi_n^*$.

The number of firms in equilibrium is possibly not unique. Should a firm enter, all other companies can steal the technological innovations of the new firm, benefiting those companies, and possibly increasing profits, thus inducing more entry. In contrast, when a new firm enters there is competition and prices push down. Because of the two competing factors, we formalize a sufficient condition such that the first factor cannot dominate, and equilibrium is unique. The condition prevents cases in which stealing technology allows production to be increased so much that companies desire for competitors to enter just so technology can be stolen. Because this event is not prevalent in real life, we posit this condition as reasonable. For elegance, in this section we posit that countries are symmetric in all wages, $Z_{1,n(\phi)}$, and I variables.

Proposition 6. *With fixed cost χ and the described entry/exit condition, there exists $\overline{x_{ZZ}}$ and $\overline{x_{LL}}$ such that if $x_{ZZ} < \overline{x_{ZZ}}$ and $x_{LL} < \overline{x_{LL}}$ for all input levels, then there exists an unique and symmetric equilibrium number of firms in each country, $\#\Phi_n^*$.*

Proof. See appendix

With existence of a unique equilibrium, we turn attention to the market structure implications of IP protection in equilibrium. Increasing an I variable decreases the free technology a firm can acquire by stealing. There are two competing effects (1) less free technology will decrease production (contributing to lower profits) and (2) decreased production will drive prices up (contributing to higher profits). If demand is sufficiently inelastic (as assumed previously), then the second effect will dominate and profits increase with IP protection, resulting in a larger equilibrium $\#\Phi_n^*$.

Proposition 7. *There exists $\overline{x_{ZZ}}$, $\overline{x_{LZ}}$, and $\overline{p}$ such that if $x_{ZZ} < \overline{x_{ZZ}}$, $x_{LZ} < \overline{x_{LZ}}$, and $p'(y) < \overline{p}$, then $\#\Phi_n^*$ is increasing in $I_{dn(\phi)}$, $I_{fn(\phi)}$, and $I_{f\sim n(\phi)}$.*

Proof. See appendix

With sufficiently inelastic demand, the decrease in production due to IP protection, which reduced technology, is associated with an increase in profits (akin to moving toward the collusive outcome). This initial change is then met with re-optimization of firms due to being able to steal less technology. With the second derivatives of production sufficiently low, this re-optimization results in minimal changes regarding labor inputs, thus profits remain high.

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[7] Prasso, Sheridan. "China's Digital Silk Road Is Looking More Like an Iron Curtain" *Bloomberg*. 10 January 2019. https://www.bloomberg.com/news/features/2019-01-10/china-s-digital-silk-road-is-looking-more-like-an-iron-curtain (accessed 01.04.19).

[8] O'Keeffe, Kate. "U.S. Adopts New Battle Plan to Fight China's Theft of Trade Secrets" *Wall Street Journal*. 12 November 2018. https://www.wsj.com/articles/u-s-deploys-new-tactics-to-curb-chinas-intellectual-property-theft-1542027624 (accessed 01.04.19).

[9] That is, net entry will occur until entry of one more firm would cause negative profits.

3.5. Long-run effects

Our analysis considers the implications of intellectual property protection on innovation and market structure in a two-period model. Our results could be interpreted as representing implications in the “long run” in the sense that the second period is the “long run” for firms to develop new technology. One may be curious if analysis would differ in a repeated two-period model; in each time period composed of two sub-time periods, firms take the intellectual property protection laws as given, enter or exit until the 0 profit condition holds, optimize their labor and production choices, and carry their technological abilities over to the next time period.

In this framework, the long-run effects of intellectual property protection on innovation and market structure are unambiguous. In each time period, larger I increases entry (proposition 7) and also innovation by all firms in the market (proposition 5). Thus the total amount of innovation is monotonically and unambiguously increasing in IP protection as the process is repeated.

3.6. Discussion

The model provides sufficient conditions such that when intellectual property is respected, firms have greater incentive to innovate. We have not considered the optimization problem of governments, which are the decision makers that influence the quality of institutions.

Our model shows that a government seeking to maximize innovation faces a simple optimization problem, namely to maximize the quality of IP protection subject to costs. A government seeking to maximize technology, output, or a complicated objective function taking into account all macroeconomic conditions faces a non-trivial optimization problem. When governments alter institutions there are two resulting changes, which are (1) domestic firms increase innovation and (2) global technology is less diffused and less available due to reduced infringement, which would result in numerous changes to the competitive structure of markets and employment. Providing rigorous theorems regarding conditions for one channel to dominate requires very stringent conditions, and thus are not the focus of this paper.

The model’s conclusions are about innovation and market structure, not employment or production. Firms optimize in response to the government’s policy along with many other variables. These firm optimizations may cause a country to have less innovation, but temporarily have more production by infringing foreign intellectual property. This will happen if the firm’s optimization leads to temporary profits from infringement. Over the long term, income will not increase relative to the frontier because continued growth requires innovation. Innovation always suffers when intellectual property is not respected, whether foreign or domestic. These subsequent effects might induce the government to revise its policies, which firms must accept and optimize accordingly. We leave it as a general statement that improving institutions has an ambiguous effect on output, at least in the short run, but an unambiguous positive effect on global levels of innovation that holds for both the short run and long run.

4. Empirics

The main conclusion of the theoretical model in this paper is that a country will be more innovative and produce more IP-intensive goods if it respects both foreign and domestic intellectual property. The goal of the empirical analysis in this section is to test the conclusion that protection of foreign IP is linked to more domestic innovation.

Difficulties arise because measurement of IPR protections is often subjective, and more objective data are generally available only for developed economies, most of which protect intellectual property quite well, both foreign and domestic. Measures of innovation are also subjective and available mostly for developed economies. Even objective measures, like the numbers of patents granted, have a subjective component because judgments must be made about the extent to which patents represent major innovation and which countries tend to grant frivolous patents.

4.1. Data

Many research papers have used the index created by Ginarte and Park, 1997. We instead use the World Economic Forum’s (WEF) Global Competitiveness Index (GCI) because it includes variables that separately capture protection of foreign and domestic IP. Most variables in the GCI come from the WEF’s Executive Opinion Survey, which is a survey of business executives in most of the countries of the world. The WEF’s stated goal in administering this survey is to understand economic and business conditions in countries for which statistical data are sparsely available. In 2018, the survey received 16,658 responses from 140 countries, which are aggregated to produce summary values for each country. Although survey data are not the best source of data, they are the best data available for testing the validity of our theoretical model’s conclusions. More objective data are not available for the needed of sample of countries that includes less-developed economies that are less innovative and do not have good IPR protections. In addition to GCI data, this paper also uses some data from the World Bank for covariates regarding GDP, trade flows, and payments for the use of foreign IP.

Cross-country regressions have been criticized because of heterogeneity across countries and sensitivity to specification (Maskus, 2012; Rodríguez and Rodrik, 2000), but we adopt a panel fixed effects approach for several reasons. The first is that in this era of multinational firms, location of production, administration, and research activities is dependent on firm and country characteristics (Carr et al., 2001). Firm-level regressions present as much or more difficulty than cross-country regressions because multinational firms are associated with multiple countries. International differences that cannot readily be controlled remain in these analyses. Our research question is best suited for a regression approach. An empirical technique similar to ours was recently used by Bilir (2014) and other cross-country regression approaches have been used in evaluating economic institutions by Góes, 2016 and Das and Quirk (2016).

Variable descriptions and summary statistics are given in Table 1. Of the GCI variables, only the covariate for the domestic market (sum of GDP and net imports) and the covariate for the value of exports are not survey-based. Because of missing observations for some countries, the cross-sectional dimension of the sample is 112. The panel runs from 2008 to 2017. We employ a fixed effects panel ordinary least squares approach to estimate four regression models that use as dependent variables production process sophistication, nature of competitive advantage, firm R&D, the extent to which foreign direct investment introduces new technology into a country, and the logged number of triadic patents. Each model includes all variables from Table 1 other than the five dependent variables as explanatory variables.

Table 1
Variable descriptions and summary statistics.

Variable	Source	Description	Unit	Mean	SD	Min.	Max.
Outcome variables							
Sophistication of Production	WEF GCI	Degree of production process sophistication	Index 1-7	3.884	1.052	1.983	6.607
Competitive Advantage	WEF GCI	Extent to which int'l competitive advantage is in unique products, not primary sector	Index 1-7	3.676	1.044	1.926	6.511
R&D	WEF GCI	Extent to which firms invest in R&D	Index 1-7	3.321	0.887	1.629	6.120
FDI Transfer	WEF GCI	Extent to which FDI introduces new technology into a country	Index 1-7	4.576	0.665	2.355	6.434
Log Triadic Patents	OECD	Triadic patents in force	Nat. Log	4.074	2.573	−2.906	9.868
Independent variables							
Innovative Capacity	WEF GCI	Extent of companies' innovation capacity	Index 1-7	3.547	0.932	1.526	6.120
Int'l Dist. Control	WEF GCI	Extent of domestic firms' control of int'l distribution	Index 1-7	3.995	0.631	2.282	5.712
Domestic Market	WEF GCI	Sum of GDP + net imports, normalized	Index 1-7	3.546	1.223	1	7
Value of Exports	WEF GCI	Value of exports, normalized	Index 1-7	4.317	1.159	1	7
IP Protection	WEF GCI	Extent to which IPRs are protected	Index 1-7	3.856	1.127	1.575	6.479
Foreign Ownership	WEF GCI	Extent of prevalence of foreign ownership	Index 1-7	4.700	0.853	1.959	6.681
Trade Openness	WEF GCI	Extent to which non-tariff barriers are ***not*** burdensome	Index 1-7	4.458	0.670	2.223	6.659
FDI Openness	WEF GCI	Extent to which FDI rules are ***not*** restrictive	Index 1-7	4.623	0.833	1.405	6.677
Non-Price Preferences	WEF GCI	Extent to which buyers choose based on product attributes, not lowest price	Index 1-7	3.509	0.754	1.751	5.716
GDP Per Capita	World Bank	Per capita real GDP, rescaled div. by 1,000	2010 US$	14.746	19.441	0.213	108.577
IP Payments	World Bank	Payments to foreigners for use of IP	% of GDP	0.007	0.023	−0.0002	0.272
IP Receipts	World Bank	Receipts from foreigners for use of IP new technology into a country	% of GDP	0.003	0.010	−0.0002	0.139
Market Dominance	WEF GCI	Extent to which corporate activity is spread among many firms	Index 1-7	3.817	0.793	2.029	6.207
Imports/GDP	World Bank	Imports as a percent of GDP	% of GDP	51.247	30.092	11.349	249.075
Exports/GDP	World Bank	Exports as a percent of GDP	% of GDP	45.829	32.315	0.901	252.587
Tax Rate	WEF GCI	Taxes as a percent of profits, normalized	Index 1-7	43.916	28.688	0.200	292.400
High Protection	GIPC/Park	GIPC Score $>$ 22 or Park Index $>$ 4.5	Binary	0.166	0.372	0	1

The first and second dependent variables, sophistication of production and competitive advantage, indicate the extent to which a country is innovative and produces technologically advanced goods. The third, research and development, measures investment in innovation, but not outcomes. The fourth, FDI transfers, measures the extent to which foreign investment introduces new technology into a country and thus indicates the presence of foreign technology in a country, but not necessarily theft or infringement of intellectual property. Triadic patents are patents for the same object obtained in the United States, European Union, and Japan, and are a measure of globally valuable innovation that avoids bias from country-specific rules for granting national patents. The fifth dependent variable is the natural log of the number of triadic patents held by residents of a country, and this transformation corrects for a heavily skewed distribution.

The explanatory variables of greatest interest are the domestic control of international distribution, IP protection, and IP payments. These three variables capture the extent to which domestic IP is protected in foreign countries, the protection of IP within a country generally (especially domestic IP), and the protection (and use) of foreign IP, respectively. The last explanatory variable, a dummy for high protection, is based on the U.S. Chamber of Commerce's Global IP Protection Index and Park's 2008 patent protection index. Its effect is only estimated in models without country fixed effects and reflects differences for countries known to have strong IP protection (e.g., United States, most of Europe, Japan, Singapore). Including this binary variable separates countries with strong protection of both foreign and domestic IP from those that lack either. With this dummy, we show that the effect on domestic innovation of protecting foreign IP is more pronounced for countries with high overall IP protection.

IP payments directly measures technology transfers, but indirectly measures the usefulness of foreign IP and reflects a country's decision not to pirate or infringe it. Because our model endogenizes market structure, issues of reverse causality have little relevance. IP payments as a percent of GDP tends to be higher for trade-dependent countries, such as those in western Europe, so controls for both imports and exports as a percent of GDP are essential, along with controlling for GDP per capita.

China has an export-oriented economy, yet its value for IP payments places it among countries that are less trade-dependent and less economically advanced. The corresponding value for the United States is not high, but this reflects its status as a relatively closed economy. Most noteworthy concerning the U.S.-China distinction is that the U.S. value is around 50% greater than China's and this divergence has widened as China has exported more technologically advanced goods in recent years and IP theft has become a major issue in trade disagreements. This higher value for the United States is despite the fact that only Japan exceeds it in ownership of triadic patents, meaning the United States is a major source of global innovation that also makes substantial payments to foreigners for the use of their IP.

4.2. Econometric techniques

For each dependent variable, we estimate three specifications. All use the same explanatory variables, but one uses country fixed effects, another uses year fixed effects, and the last uses both country and year fixed effects. Each of these models has unique value that is seen by comparing coefficients across models.

Country fixed effects remove all cross-sectional time-invariant variation. Coefficients indicate within-country changes that would result from changing an explanatory variable. Although time is not controlled, stationarity should be a minimal issue because most of the survey variables are not integrated. Coefficients for a country fixed effects model answer questions analogous to "How will innovation in country x change when it chooses to respect IPRs, holding all time-invariant characteristics constant?"

In contrast, year fixed effects remove variation across time, allowing for a focus on the cross-sectional dimension. The data used in this paper have much more variation across countries than within countries; many variables showed little change within a country from 2008 to 2017. Coefficients using year fixed effects represent change from one country to another as opposed to one year to another. This coefficient embodies an assumption that, in addition to changing the explanatory variable, unobserved characteristics also change to be more like the other countries already in the direction of the variable change. Year fixed effects models answer the question like “How much more innovative are countries that respect IPRs compared to those that do not?” Only when answering this question can the binary variable for high protection have an estimated effect.

Two-way fixed effects, which are a very common econometric technique, answer yet a different question. Time de-meaning transform’s each country’s variables to be their differences from averages across time. Coefficients represent average values for all of the time series in the panel. Cross-sectional de-meaning transforms them to be relative to the cross-sectional mean. Coefficients represent averages for all cross sections in the panel. Applying both transformations results in values for each variable that represent a country’s distance from average as the average changes with time. Data observations show a country relative to itself as its position among all other countries changes over time. Coefficients are averages of the already-averaged coefficients from each time series or cross section. Effectively, these coefficients represent the effect that a country’s change in a variable has on its distance from the average of the dependent variable over time compared to another country’s (which made no such change) distance from the dependent variable average over time (Kropko and Kubinek, 2020).

Letting K denote the set of covariates in Table 1 that are not used as outcomes, the three equations of estimation are

$$y_{it} - \hat{\bar{y}}_i = \sum_{\kappa \in K} \beta_\kappa (\kappa_{it} - \hat{\bar{\kappa}}_i) + \varepsilon_{it}, \tag{3}$$

$$y_{it} - \hat{\bar{y}}_t = \sum_{\kappa \in K} \beta_\kappa (\kappa_{it} - \hat{\bar{\kappa}}_t) + \varepsilon_{it}, \text{ and} \tag{4}$$

$$y_{it} - \hat{\bar{y}}_t - (\widehat{\overline{y_{it} - y_t}})_i = \sum_{\kappa \in K} \beta_\kappa (\kappa_{it} - \hat{\bar{\kappa}}_t - (\widehat{\overline{\kappa_{it} - \kappa_t}})_i) + \varepsilon_{it}, \tag{5}$$

where y_{it} denotes the outcome of interest and $\bar{x}_z$ denotes the average of x over z. Hats on means denote estimates and show the loss in degrees of freedom from using fixed effects. All three specifications answer different questions and comparing the coefficients across models provides greater understanding than using any single model alone.

4.3. *Sophistication of production*

The models in Table 2 show the effects of foreign and domestic IPRs on the sophistication of production processes in a country, answering our research question. Recall from the beginning of Section 3 that the “goods” in the model were classes of all categories of good that varied according to the technology embodied in them. This variable, Sophistication of Production, captures this. The country fixed effects specification in the left-most column, which estimates (3), shows the results that can be expected for any country that makes changes, holding all time-invariant characteristics constant. Protection of foreign and domestic IPRs positively predicts production process sophistication, as shown by coefficients on IP protection and IP payments. Foreign respect of domestic IP is also significant, as shown by International Distribution Control, something seen to be important in the discussion at the end of Section 3.

The coefficient on IP Payments is one of our most important results because it shows that countries that respect foreign IP do produce more sophisticated products, confirming our theoretical model. Respect for foreign IP not only causes new technology to be introduced, but production processes broadly become more sophisticated. The significance of this result is notable because it is significant with both country and year fixed effects separately. Simply respecting foreign IP without adopting other institutional improvements results in more sophisticated production processes; significance of this variable in introducing technology through FDI, which highlights a mechanism, is not significant with country fixed effects.

Year fixed effects have broadly similar results to country fixed effects, indicating that countries that respect IP also have more sophisticated production. There is less significance with the two-way model, but point estimates are intuitive. Some coefficients change significance and even sign across models, but these changes are intuitive and highlight long run effects. Trade barriers matter more when cross-sectional variation is present, implying that a country may still develop behind trade barriers, but that the most sophisticated countries have fewer of them. Increasing a country’s GDP may do little for sophistication, but the most sophisticated countries are wealthier. Likewise, higher taxes are harmful ceteris paribus, but the year fixed effects model picks up the fact that higher-income, higher-tax developed countries are more sophisticated.

The coefficient on IP protection is significant only with country fixed effects, but this is the most relevant specification because all other country-specific unobservables are held constant. Moreover, a bivariate regression using all three equations shows that it is positive and significant at the 1% level, indicating that the insignificance in other specifications is due to correlation with other factors.

4.4. *Nature of competitive advantage*

The nature of competitive advantage in unique goods as opposed to the primary sector likewise has interesting results, but significance is strongest with the year and two-way fixed effects models. This should not be surprising because sophistication of production has mostly domestic implications, but competitive advantage pertains more to international trade. Like sophistication of production, competitive advantage refers to technologically-advanced goods across the economy, not specific goods, consistent with our theoretical model. Intuitively, there should be more significance when the cross-sectional dimension matters more, implying that a country must reach a certain level of innovation to have this competitive advantage. As with production process sophistication, IP protection is significant at the 1% level in bivariate regressions, implying a collinearity issue (Table 3).

Table 2
Product sophistication.

	Sophistication of production		
Innovative Capacity	0.247^{***}	0.348^{***}	0.289^{***}
	(0.030)	(0.036)	(0.045)
Int'l Dist. Control	0.213^{***}	0.403^{***}	0.166^{***}
	(0.040)	(0.050)	(0.033)
Domestic Market	−0.050	-0.218^{***}	0.086
	(0.084)	(0.081)	(0.105)
Value of Exports	0.098^{**}	0.273^{**}	-0.250^{***}
	(0.048)	(0.107)	(0.093)
IP Protection	0.096^{**}	0.060^{*}	0.077^{*}
	(0.042)	(0.036)	(0.042)
Foreign Ownership	−0.058	0.070	−0.008
	(0.048)	(0.044)	(0.046)
Trade Openness	0.007	0.041	0.034
	(0.039)	(0.034)	(0.038)
FDI Openness	−0.050	0.038	0.041
	(0.039)	(0.046)	(0.037)
Non-Price Preferences	0.048	0.152^{***}	0.153^{***}
	(0.046)	(0.056)	(0.047)
GDP Per Capita	0.007	0.011^{***}	−0.003
	(0.010)	(0.002)	(0.007)
IP Payments	2.664^{**}	1.338^{***}	0.901
	(1.063)	(0.405)	(1.190)
IP Receipts	−3.454	−5.274	−2.154
	(5.372)	(3.364)	(4.222)
Market Dominance	0.142^{***}	0.012	0.097^{**}
	(0.045)	(0.035)	(0.038)
Imports/GDP	0.001	−0.0002	−0.002
	(0.002)	(0.001)	(0.002)
Exports/GDP	−0.001	−0.001	0.005^{**}
	(0.002)	(0.002)	(0.002)
Tax Rate	-0.004^{*}	0.004^{***}	−0.002
	(0.002)	(0.001)	(0.001)
High Protection		0.255^{***}	
		(0.073)	
County FE	√	–	√
Year FE	–	√	√
N	855	855	855

Notes: Standard errors clustered at the country level in parentheses. $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$.

In these models and in those predicting production process sophistication, intellectual property protections matter. For predicting competitive advantage, which has mostly international implications, control of international distribution matters more than any other IP variable.

4.5. Firm R&D

Firm R&D can be predicted with considerably more significance than the other variables. IP Protection and International Distribution Control are all significant. This is not surprising as it is domestic IP protection (and its overseas respect) that matters at early stages of innovation. As with the other outcome variables, IP protection is highly significant only in the country fixed effects model, which is the most relevant. In bivariate regressions, it is highly significant across all specifications. In contrast to sophistication of production and competitive advantage, R&D captures innovative effort, not outcomes (Table 4).

Trade openness presents an interesting case. The models indicate that more burdensome trade barriers encourage research and development. These models do not clearly indicate a reason, but it is possible that less burdensome trade barriers make it easier to pirate trade secrets or otherwise misappropriate innovation; they may also insulate research-oriented firms from foreign competition. This explanation has plausibility because the variable refers to non-tariff trade barriers, not tariffs. Importantly, this variable is not significant in predicting competitive advantage.

4.6. FDI and technology transfer

As a dependent variable, the extent to which foreign direct investment introduces new technology into a country has unique meaning because it intuitively should be related to the protection for foreigners' intellectual property. If other variables that hypothetically capture respect of foreign IP are positively correlated with it, then use of these variables as proxies for respect of foreign IP are supported (Table 5).

In all three specifications, the domestic firms' control of international distribution is positive and significant at the 1% level, implying that foreigners do not introduce new technology into a country if they cannot control its subsequent use. This is one of our strongest empirical results and is made stronger by its significance in all other models, implying that newly-introduced technology does help a country become more innovative and globally competitive.

Payments for the use of foreign IP are positive and significant and have a large coefficient, but only with year fixed effects. Countries that pay more for foreign IP attract more foreign technology, which is already seen to improve their competitive positions, but this is more

Table 3
Nature of competitive advantage.

	Competitive advantage		
Non-Price Preferences	0.144***	0.232***	0.241***
	(0.053)	(0.085)	(0.054)
Innovative Capacity	0.157***	0.460***	0.183***
	(0.046)	(0.106)	(0.055)
Int'l Dist. Control	0.230***	0.404***	0.172***
	(0.050)	(0.078)	(0.049)
Domestic Market	−0.037	0.061	0.394***
	(0.100)	(0.115)	(0.150)
Value of Exports	−0.037	−0.239*	−0.628***
	(0.058)	(0.136)	(0.143)
IP Protection	0.034	−0.001	0.021
	(0.050)	(0.087)	(0.048)
Foreign Ownership	−0.051	−0.059	−0.054
	(0.046)	(0.073)	(0.045)
Trade Openness	−0.014	−0.010	0.008
	(0.047)	(0.089)	(0.047)
FDI Openness	0.003	0.075	0.057
	(0.043)	(0.077)	(0.044)
IP Payments	0.737	0.562	−0.807
	(1.342)	(0.861)	(1.358)
IP Receipts	0.296	−0.630	1.801
	(3.494)	(4.186)	(2.938)
GDP Per Capita	0.009	0.010***	0.005
	(0.010)	(0.003)	(0.009)
Market Dominance	−0.061	0.015	−0.079
	(0.062)	(0.088)	(0.057)
Imports/GDP	0.002	0.003	−0.003
	(0.002)	(0.002)	(0.003)
Exports/GDP	−0.003	0.002	0.007**
	(0.002)	(0.003)	(0.003)
Tax Rate	−0.003*	0.002	−0.002*
	(0.002)	(0.003)	(0.001)
High Protection		0.547***	
		(0.155)	
County FE	√	–	√
Year FE	–	√	√
N	855	855	855

Notes: Standard errors clustered at the country level in parentheses. *** $p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

of a long run phenomenon that is less pertinent to exogenous variation in protection of foreign IP. It likely reflects the fact that paying more for IP requires a higher level of national income and an institutional environment conducive to innovation and investment. This result, important as it is, is very intuitive. Its value for confirming our theoretical model is outweighed by the significance of IP payments in predicting production sophistication, which is significant with both country and year fixed effects (separately, not two-way).

4.7. *Triadic patents*

Triadic patents are reported for fewer countries than our other variables, and they show considerably less within-country variation, resulting in very little significance in country fixed effects models. This does not contradict this paper's theory because it stems from the fact that building an economy with innovation sufficiently valuable to merit protection in the most advanced markets is a slow process, but our panel is only for ten years. The other models we estimate show that innovation increase when foreign IP is protected; this model shows that, over time and with institutional changes and sufficient income, this innovative potential becomes very substantial. The signs and significance are consistent with out theory.

A large presence in foreign markets and a higher survey value of IP protection are strongly positively correlated with more triadic patents, along with openness to trade.

Although openness to trade, neither imports nor exports as percent of GDP is significant. As expected, the binary variable for strong IP protection is highly significant. Because this binary variable captures a variety of IP protection measures, this specification shows that countries that do adopt stronger IPRs will have more globally valuable innovation (Table 6).

Triadic patents are closely linked to a country's trading orientation and the global value of its innovation. National patents may capture domestic innovation and better reflect incremental advances in IPR protection, but they are an inferior measure because examination standards and enforcement vary substantially. Triadic patents show a broadly applicable standard of novelty, but they rely on the global value of the innovation.

4.8. *Empirics overview*

The main conclusion of the theoretical model is that countries are more innovative and produce more IP-intensive goods if they respect both foreign and domestic intellectual property.

Table 4
Firm R&D.

	R&D		
Non-Price Preferences	0.225***	0.147***	0.229***
	(0.046)	(0.043)	(0.049)
Innovative Capacity	0.243***	0.712***	0.286***
	(0.028)	(0.054)	(0.037)
Int'l Dist. Control	0.114***	0.115**	0.155***
	(0.042)	(0.048)	(0.039)
Domestic Market	−0.070	0.209***	−0.042
	(0.097)	(0.078)	(0.112)
Value of Exports	−0.025	−0.267***	−0.0001
	(0.044)	(0.094)	(0.093)
IP Protection	0.126***	0.068	0.074*
	(0.035)	(0.043)	(0.039)
Foreign Ownership	−0.011	0.011	0.004
	(0.040)	(0.031)	(0.041)
Trade Openness	−0.078*	−0.176***	−0.098**
	(0.040)	(0.042)	(0.040)
FDI Openness	0.037	0.051	0.018
	(0.036)	(0.035)	(0.037)
IP Payments	1.153	0.096	1.639
	(1.025)	(0.543)	(1.036)
IP Receipts	−1.806	3.347	−2.462
	(3.499)	(4.070)	(3.543)
GDP Per Capita	−0.007	−0.002	−0.009
	(0.007)	(0.002)	(0.007)
Market Dominance	0.116**	0.061	0.128**
	(0.055)	(0.051)	(0.057)
Imports/GDP	0.001	−0.003	0.001
	(0.002)	(0.002)	(0.002)
Exports/GDP	−0.0001	0.006**	0.0001
	(0.002)	(0.002)	(0.002)
Tax Rate	0.0004	−0.002*	0.0004
	(0.001)	(0.001)	(0.001)
High Protection		0.156**	
		(0.069)	
County FE	√	–	√
Year FE	–	√	√
N	855	855	855

Notes: Standard errors clustered at the country level in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 5
FDI and technology transfer.

	FDI transfer		
Non-Price Preferences	0.045	−0.100	0.012
	(0.050)	(0.061)	(0.057)
Innovative Capacity	−0.042	0.021	0.005
	(0.037)	(0.058)	(0.056)
Int'l Dist. Control	0.252***	0.213***	0.205***
	(0.040)	(0.066)	(0.038)
Domestic Market	0.014	0.028	0.011
	(0.090)	(0.113)	(0.132)
Value of Exports	−0.080	0.044	−0.063
	(0.052)	(0.132)	(0.147)
IP Protection	−0.041	0.043	0.017
	(0.045)	(0.050)	(0.046)
Foreign Ownership	0.169***	0.292***	0.146***
	(0.047)	(0.052)	(0.049)
Trade Openness	0.045	−0.033	0.041
	(0.041)	(0.049)	(0.042)
FDI Openness	0.198***	0.318***	0.203***
	(0.045)	(0.045)	(0.046)
IP Payments	0.913	4.360***	−0.519
	(1.539)	(0.742)	(1.525)
IP Receipts	−1.037	−5.593	1.199
	(3.748)	(4.300)	(3.816)
GDP Per Capita	−0.005	−0.003*	0.004
	(0.006)	(0.002)	(0.007)
Market Dominance	−0.014	−0.047	−0.032
	(0.052)	(0.058)	(0.050)
Imports/GDP	0.001	−0.004*	0.001
	(0.002)	(0.002)	(0.002)

Table 5 (*Continued*)

	FDI transfer		
Exports/GDP	0.00004	0.005	0.0002
	(0.002)	(0.003)	(0.003)
Tax Rate	−0.001	−0.001	−0.002
	(0.002)	(0.002)	(0.002)
High Protection		0.002	
		(0.075)	
County FE	√	–	√
Year FE	–	√	√
N	855	855	855

Notes: Standard errors clustered at the country level in parentheses. *** $p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 6
Log triadic patents.

	Log triadic patents		
Non-Price Preferences	−0.038	−0.086	0.102
	(0.119)	(0.245)	(0.130)
Innovative Capacity	0.060	0.522*	0.078
	(0.092)	(0.297)	(0.086)
Int'l Dist. Control	−0.012	0.153	−0.083
	(0.115)	(0.212)	(0.112)
Domestic Market	0.503	0.288	0.898
	(0.413)	(0.633)	(0.595)
Value of Exports	0.056	1.652**	−0.524
	(0.299)	(0.824)	(0.533)
IP Protection	−0.076	0.525***	−0.104
	(0.113)	(0.182)	(0.117)
Foreign Ownership	0.051	−0.295	0.089
	(0.100)	(0.213)	(0.107)
Trade Openness	0.084	0.381**	0.085
	(0.090)	(0.177)	(0.097)
FDI Openness	−0.091	−0.257	0.021
	(0.087)	(0.211)	(0.092)
IP Payments	−1.168	−1.127	−3.169
	(1.665)	(1.506)	(2.307)
IP Receipts	−2.699	10.992	−0.960
	(4.510)	(7.741)	(5.417)
GDP Per Capita	0.021*	0.024***	0.017
	(0.011)	(0.009)	(0.010)
Market Dominance	−0.006	−0.195	−0.026
	(0.098)	(0.237)	(0.098)
Imports/GDP	−0.015	0.010	−0.021
	(0.014)	(0.017)	(0.015)
Exports/GDP	0.017	−0.020	0.028*
	(0.013)	(0.019)	(0.016)
Tax Rate	−0.005	0.009	−0.003
	(0.006)	(0.009)	(0.005)
High Protection		1.046***	
		(0.294)	
County FE	√	–	√
Year FE	–	√	√
N	458	458	458

Notes: Standard errors clustered at the country level in parentheses. *** $p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Using data from the Global Competitiveness Index, we empirically test this and show that the theoretical model's conclusions are well supported. The econometric models predicting firm R&D, compared to the other econometric models, indicates that IP protection matters for outcomes of innovation efforts, but not for efforts alone. IP protection is an encouragement for innovation, but more importantly, it encourages its commercial implementation.

5. Conclusion

Innovation is needed to produce increasingly technologically-advanced goods. Intellectual property rights guarantee that profits from innovation are appropriated by the firm that owns them and are thus an incentive for innovation. International trade, as well as innovation, has been decisively linked to economic growth. Likewise, intellectual property rights have also been linked to innovation and growth. When goods are traded across countries and when firms outsource some of their production to foreign countries, international recognition of intellectual property is an issue. This issue has often been overlooked in the international trade literature.

Respect for domestic intellectual property intuitively is an incentive for domestic innovative activity. If a country chooses not to respect foreign intellectual property, foreign innovators are harmed. In this paper, we address the relationship between respect of foreign intellectual property, as well as domestic, and technological innovation. Using primitive microeconomic assumptions, and the fact that intellectual property rights make demand curves steeper by restricting availability of substitutes, we demonstrate that a country will be more innovative if it respects both domestic and foreign intellectual property. Respect for foreign intellectual property is thus not only best for global innovation, but it yields domestic advantages as well in terms of technological advances and competitive advantage.

Our theoretical conclusion has strong empirical support. The World Economic Forum's Global Competitiveness Index includes countries for which objective data on innovation and research are sparse. These are the countries that tend not to respect intellectual property very well, in contrast to developed countries that are wealthy, innovative, and have good intellectual property right protection. Using the Global Competitiveness Index, we demonstrate that countries that protect foreigners' intellectual property as well as their own have more technologically sophisticated production processes and are more globally competitive with unique products; these countries also have more triadic patents. Intuitively, foreign respect of domestic intellectual property is also strongly linked to innovation, something our theoretical model also showed.

The econometric specifications we employ exploit different dimensions of variation - cross-sectional, time, or both, each with a different implication. Controlling for time and letting the cross-sectional dimension vary produces the greatest explanatory power and significance. Because unobserved economic and political institutions affect the results, it is clear that a country needs not only to adopt a strong intellectual property rights regime to succeed in innovative efforts, but it needs a broad economic structure conducive to innovation and trade that includes intellectual property rights. In conclusion, intellectual property rights for both citizens and foreigners are conducive to domestic innovation and competitive advantage. It is in each country's best interest to protect the intellectual property of its own citizens as well as foreigners.

Authors' contribution

Conceptualization – Robert Gmeiner, Methodology – Robert Gmeiner and Michael Gmeiner, Formal analysis (mathematical proofs) – Michael Gmeiner, Formal analysis (regression models) – Robert Gmeiner, Writing (original draft) – Robert Gmeiner and Michael Gmeiner, Writing (review and editing) – Robert Gmeiner and Michael Gmeiner, Data Curation – Robert Gmeiner, Supervision – Robert Gmeiner.

Appendix: Proofs

Proof of Proposition 1:

Proof. Because all functions are continuous, the right-side of (1) is continuous. We impose symmetry in the choice of $L_{G1\phi}$. We show that with sufficiently negative $G''(L_{G1\phi})$, the right-side of (1) is monotonically decreasing in the symmetric $L_{G1\phi}$ which is chosen and approaches negative infinity. Thus the unique symmetric equilibrium is defined by the value of $L_{G1\phi}$ at which (1) holds with equality (if one) or a corner solution (if none).

An algebraic expression for $(x_L)_Z^{-1}$ can be written by applying the implicit function theorem to the first order condition in (1) at time 2. For brevity let y_x denote $\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})$. This expression is

$$\frac{\partial L^*_{y_x 2\phi}}{\partial Z_{2\phi}} = -\left(x_{LZ}(L^*_{y_x 2\phi}, Z_{2\phi})\left(p(y_x) + p'(y_x)x(L^*_{y_x 2\phi}, Z_{2\phi})\right) x_L(L^*_{y_x 2\phi}, Z_{2\phi})\left(p'(y_x)x_Z + p''(y_x)x(L^*_{y_x 2\phi}, Z_{2\phi})x_Z + p'(y_x)x_Z\right)\right) /$$
$$\left(x_{LL}(L^*_{y_x 2\phi}, Z_{2\phi})\left(p(y_x) + p'(y_x)x(L^*_{y_x 2\phi}, Z_{2\phi})\right) x_L(L^*_{y_x 2\phi}, Z_{2\phi})\left(p'(y_x)x_L + p''(y_x)x(L^*_{y_x 2\phi}, Z_{2\phi})x_L + p'(y_x)x_L\right)\right).$$

$$\beta G''(L_{G1\phi})\zeta + \beta G'(L_{G1\phi})\frac{\partial \zeta}{\partial L_{G1\phi}}$$
$$\beta G''(L_{G1\phi})\zeta + \beta G'(L_{G1\phi})\left(\frac{\partial \zeta}{\partial Z_{2\phi}}\frac{\partial Z_{2\phi}}{L_{G1\phi}} + \sum_{\tilde{\phi} \in n(\phi), \tilde{\phi} \neq \phi}\frac{\partial \zeta}{\partial Z_{2\tilde{\phi}}}\frac{\partial Z_{2\tilde{\phi}}}{\partial L_{G1\phi}}\right) \geq$$
$$\beta G''(L_{G1\phi})\zeta + \beta G'(0)| \left(\frac{\partial \zeta}{\partial Z_{2\phi}}\frac{\partial Z_{2\phi}}{L_{G1\phi}} + \sum_{\tilde{\phi} \in n(\phi), \tilde{\phi} \neq \phi}\frac{\partial \zeta}{\partial Z_{2\tilde{\phi}}}\frac{\partial Z_{2\tilde{\phi}}}{\partial L_{G1\phi}}\right)|$$

Proof of Proposition 2:

Proof. We show the condition is sufficient for the right-side of (1) to be increasing in $I_{dn(\phi)}$. Because the right-side is decreasing in $L_{G1\phi}$, the value of $L_{G1\phi}$ at which equality holds is increasing in $I_{dn(\phi)}$.

We first show that $\left[\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi}[x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}]\right] \geq 0$. By contradiction suppose the quantity is negative. This implies the production of firm ϕ at time (2) is locally decreasing in $Z_{2\phi}$. By assumption (1), x_Z, x_L, and x_{LZ} are weakly positive. It must be that $L_{y_x 2\tilde{\phi}}$ is decreasing in $Z_{2\phi}$, and x_L is increasing in $Z_{2\phi}$. Because output is decreasing in $Z_{2\phi}$, $p\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L^*_{y_x 2\phi}, Z_{2\phi})$ is increasing in $Z_{2\phi}$ by assumption (2). Therefore the right-side of the firm's first order condition at time 2 is increasing, implying it cannot not hold. Therefore $\left[\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi}[x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}]\right] \geq 0$.

To reduce clutter, let $y_x = \left(\sum_{\tilde{\phi} \in \Phi_{n(\phi)}} x(L^*_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right)$. The derivative with respect to $I_{dn(\phi)}$ is

$$\begin{aligned}
&\beta G'(L_{G1\phi}) \sum_{x \in \{S,M,H\}} \Big(A'(I_{dn(\phi)})G(L_{G1\phi})(\#\Phi_{n(\phi)} - 1)x_{ZZ} \left[p(y_x) + p'(y_x)x(L^*_{y_L 2\phi}, Z_{2\phi})\right] + x_Z(\#\Phi_{n(\phi)} - 1)A'(I_{dn(\phi)})G(L_{G1\phi}) \left(x_Z + x_L(x_L)_Z^{-1}\right) \\
&\left[p'(y)\#\Phi_{n(\phi)} + p''(y)\#\Phi_{n(\phi)}x(L^*_{y_L 2\phi}, Z_{2\phi}) + p'(y)\right] + A'(I_{dn(\phi)}) \left[\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} [x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}]\right] \left[p'(y_x)x(L^*_{y_L 2\phi}, Z_{2\phi})\right] \\
&+A(I_{dn(\phi)}) \left(A'(I_{dn(\phi)})G(L_{G1\phi})(\#\Phi_{n(\phi)} - 1)\#\Phi_{n(\phi)}p''(y_x) \left(x_Z + x_L(x_L)_Z^{-1}\right) x(L^*_{y_L 2\phi}, Z_{2\phi}) + A'(I_{dn(\phi)})G(L_{G1\phi})(\#\Phi_{n(\phi)} - 1)p'(y_x) \left(x_Z + x_L(x_L)_Z^{-1}\right)\right) \\
&\sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} [x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}] + A(I_{dn(\phi)}) \left[p'(y_x)x(L^*_{y_L 2\phi}, Z_{2\phi})\right] A'(I_{dn(\phi)})G(L_{G1\phi})(\#\Phi_{n(\phi)} - 1) \sum_{\tilde{\phi} \in \Phi_{n(\phi)}, \tilde{\phi} \neq \phi} \frac{d[x_{L\tilde{\phi}}(x_{L\tilde{\phi}})_Z^{-1} + x_{Z\tilde{\phi}}]}{dZ}\Bigg)
\end{aligned}$$

By assumption (2) and the argument in the first paragraph of the proof, the first three lines are positive. The sign and magnitude of the fourth through sixth lines cannot be determined without additional assumptions.

Proof of Proposition 3

Proof. Suppose there exist $L_{y_x 2n(\phi)}$ such that $L_{y_x 2\phi} = L_{y_x 2n(\phi)}$ for all ϕ. Assumption (2) implies that

$$\begin{aligned}
&p\left(\sum_{\tilde{\phi}} x(L_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}} x(L_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L_{y_x 2n(\phi)}, Z_{2n(\phi)}) = p\left(\#\Phi_k x(L_{y_x 2k}, Z_{2k}) + \#\Phi_{\sim k} x(L_{y_x 2\sim k}, Z_{2\sim k})\right) \\
&+ p'\left(\#\Phi_k x(L_{y_x 2k}, Z_{2k}) + \#\Phi_{\sim k} x(L_{y_x 2\sim k}, Z_{2\sim k})\right) x(L_{y_x 2k}, Z_{2k})
\end{aligned}$$

is decreasing in $x(L_{y_x 2k}, Z_{2k})$ for $k \in \{i, j\}$.[10] Therefore for all $L_{y_x 2\sim k}$, the conditions of assumptions (1) and (2) guarantee that there is a unique $\tilde{L}_{y_x 2k}$ such that the necessary conditions hold for all $\phi \in \Phi_k$ when $L_{y_x 2\phi} = \tilde{L}_{y_x 2k}$ for $\phi \in \Phi_k$ and $L_{y_x 2\phi} = L_{y_x 2\sim k}$ for $\phi \in \Phi_{\sim k}$. (Or there is a corner solution at 0 if firms in country $\sim k$ produce sufficiently large quantities). This is an elementary exercise similar to the foregone exercise regarding autarky.

$$L_{y_x 2i} = \tilde{L}_i(\tilde{L}_j(L_{y_x 2i}))$$

Existence of a solution is almost trivial. It is immediate that $L_{y_x 2i} = 0$ causes the left-side to be zero, and therefore weakly less than the right-side. The right-side is also bounded above due to concavity of production, the Inada condition of production as labor approaches infinity, and the fact that price decreases in output. Therefore there exist sufficiently large $L_{y_x 2i}$ such that the left side is greater than the right.

$$\begin{aligned}
&p\left(\sum_{\tilde{\phi}} x(L_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) + p'\left(\sum_{\tilde{\phi}} x(L_{y_x 2\tilde{\phi}}, Z_{2\tilde{\phi}})\right) x(L_{y_x 2\phi}, Z_{2\phi}) = \\
&p\left(\#\Phi_i x(L_{y_x 2i}, Z_{2i}) + \#\Phi_j x(L_{y_x 2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L_{y_x 2i}, Z_{2i}) + \#\Phi_j x(L_{y_x 2j}, Z_{2j})\right) x(L_{y_x 2j}, Z_{2j})
\end{aligned}$$

is decreasing in $x(L_{y_x 2i}, Z_{2i})$.[11] Therefore if $L^1_{y_x 2j} \geq L^2_{y_x 2j}$ the right side of the first order condition is lower for all firms under $(L^1_{y_x 2i}, L^1_{y_x 2j})$ compared to under $(L^2_{y_x 2i}, L^2_{y_x 2j})$ (note that x_L is decreasing in L). This contradicts that necessary conditions hold for all firms at both pairs. Therefore $L^1_{y_x 2j} < L^2_{y_x 2j}$. This implies $x_L(L^1_{y_x 2j}, Z_{2j}) > x_L(L^2_{y_x 2j}, Z_{2j})$ and $x_L(L^1_{y_x 2i}, Z_{2i}) < x_L(L^2_{y_x 2i}, Z_{2i})$ by assumption (2).

$$p\left(\#\Phi_i x(L_{y_x 2i}, Z_{2i}) + \#\Phi_j x(L_{y_x 2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L_{y_x 2i}, Z_{2i}) + \#\Phi_j x(L_{y_x 2j}, Z_{2j})\right) x(L_{y_x 2k}, Z_{2k}).$$

---

[10] Specifically, the derivative of $p(nq + mp) + p'(nq + mp)q$ with respect to q is $p'(nq + mp)n + p'(nq + mp) + p''(nq + mp)q$. Trivially $n + 1 \geq 2$ in this context. If $p'' < 0$ the result is trivial. Now if $p'' > 0$ the result follows because $q \leq nq + mp$.

[11] Specifically, the derivative of $p(nq + mp) + p'(nq + mp)q$ with respect to p is $p'(nq + mp)m + p''(nq + mp)mq$. This must be less than 0 because $p'(nq + mp)m + p''(nq + mp)m(nq + mp) < 0$ by assumption (2). If $p'' < 0$ the result is trivial. If $p'' > 0$ the result follows by assumption (2) because $q \leq nq + mp$.

[12]

$$p\left(\#\Phi_i x(L^1_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^1_{y_x2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L^1_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^1_{y_x2j}, Z_{2j})\right) x(L^1_{y_x2j}, Z_{2j}) \geq$$
$$p\left(\#\Phi_i x(L^2_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^2_{y_x2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L^2_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^2_{y_x2j}, Z_{2j})\right) x(L^2_{y_x2j}, Z_{2j})$$

and $x_L(L^1_{y_x2j}, Z_{2j}) > x_L(L^2_{y_x2j}, Z_{2j})$. Therefore the right-side of the first order condition for firms in country j is unambiguously larger when labor choices are $L^1_{y_x2j}$ and $L^1_{y_x2i}$. The left-side is unchanged. This is a contradiction.

$$p\left(\#\Phi_i x(L^1_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^1_{y_x2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L^1_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^1_{y_x2j}, Z_{2j})\right) x(L^1_{y_x2i}, Z_{2i}) <$$
$$p\left(\#\Phi_i x(L^2_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^2_{y_x2j}, Z_{2j})\right) + p'\left(\#\Phi_i x(L^2_{y_x2i}, Z_{2i}) + \#\Phi_j x(L^2_{y_x2j}, Z_{2j})\right) x(L^2_{y_x2i}, Z_{2i})$$

And also $x_L(L^1_{y_x2i}, Z_{2i}) < x_L(L^2_{y_x2i}, Z_{2i})$. Therefore the right-side of the first order condition for firms in country i is unambiguously smaller when labor choices are $L^1_{y_x2j}$ and $L^1_{y_x2i}$. The left-side is unchanged. This is a contradiction. □

Proof of Proposition 4

Proof. Fix L_{G1j} and assume all ϕ in country j choose $L_{G1\phi} = L_{G1j}$. Also suppose all ϕ in country i choose $L_{G1\phi} = L_{G1i}$, and consider increasing L_{G1i}. By an identical argument to that in the proof of proposition 1, there exists a $\overline{G}_i$ such that if $G''(L_{G1\phi}) < \overline{G}_1$ for all $L_{G1\phi}$, the right side of (2) is monotonically decreasing in L_{G1i} and approaches negative infinity. There is either a unique value of L_{G1i} such that Eq. (2) holds for all $\phi \in \Phi_i$ or there is a corner solution of 0. Define $\overline{G}_j$ analogously. In what follows suppose $G''(L_{G1\phi}) < \min\{\overline{G}_i, \overline{G}_j\}$.

Define $\tilde{L}_i(L_{G1j})$ to be the value of L_{G1i} which solves Eq. (2) given L_{G1j} if any, and 0 otherwise. By continuity of all functions, this function is continuous. Define $\tilde{L}_j(L_{G1i})$ analogously. Mutual best reply labor choices are defined by the levels of L_{G1j} and $\tilde{L}(L_{G1j})$ that satisfy:

$$\tilde{L}_j(\tilde{L}_i(L_{G1j})) = L_{G1j}.$$

Existence of a solution is almost trivial. It is trivial that $L_{G1j} = 0$ causes the right-side to be zero, and therefore weakly less than the left-side. The left-side is bounded above due to $G'(L_{G1\phi})$ limiting to a value less than 0. Therefore there exists sufficiently large L_{G1j} such that the right side is greater than the left side. Due to each side being continuous, existence is immediate.

$$\frac{\partial \tilde{L}_j(L_{G1i})}{\partial L_{G1i}} = -\frac{\beta G'(L_{G1j})\frac{\partial \zeta_j}{\partial L_{G1i}}}{\beta G''(L_{G1j})\zeta_j + \beta G'(L_{G1j})\frac{\partial \zeta_j}{\partial \tilde{L}_{j(L_{G1i})}}}$$

Proof of Proposition 6

Proof. The objective function with the addition of the fixed cost is:

$$\max_{L_{G1\phi}, \{L_{y_x1\phi}, L_{y_x2\phi}\}_{x \in \{S,M,H\}}} \sum_{x \in \{S,M,H\}} \left[p\left(\sum_{\tilde{\phi}} y_{x1\tilde{\phi}}\right) y_{x1\phi} + \beta p\left(\sum_{\tilde{\phi}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_x(L_{y_x1\phi} + \beta L_{y_x2\phi}) \right] - s_{n(\phi)} L_{G1\phi} - \chi$$

$$\beta p\left(\sum_{\tilde{\phi}} y_{x2\tilde{\phi}}\right) y_{x2\phi} - w_x(\beta L_{y_x2\phi}) - s_{n(\phi)} L_{G1\phi}$$

$$\sum_{x \in \{S,M,H\}} \left(|p(0) \int_{L_{G1\phi^1}}^{L^2_{G1\phi}} \int_{L^1_{y_x2\phi}}^{L^2_{y_x2\phi}} x(L_{y_x2\phi}, Z_{2\phi}) dL_{y_x2\phi} dZ_{2\phi}| + |w_x \beta(L^2_{y_x2\phi} - L^1_{y_x2\phi})| + |s_{n(\phi)}(L^2_{G1\phi} - L^1_{G1\phi})| \right).$$

---

[12] Specifically, the derivative of $p(nq+mp) + p'(nq+mp)q$ with respect to $nq+mp$ is less than or equal to $p'(nq+mp) + p'(nq+mp)\frac{-1}{n} + p''(nq+mp)q = p(nq+mp)(1 - 1/n) + p''(nq+mp)q$. This is weakly negative if $p(nq+mp)(n-1) + p''(nq+mp)nq$ is weakly negative. Trivially $n - 1 \geq 1$ in this context. If $p'' < 0$ the result is trivial. If $p'' > 0$ the result follows by assumption (2) because $nq \leq nq + mp$.

Proof of Proposition 7

Proof. It suffices to show that with fixed $\#\Phi_n^*$ that equilibrium profit is monotonically increasing in each of the I variables.

Consider fixed values of $I_{dn(\phi)}, I_{fn(\phi)}, I_{f\sim n(\phi)}$, wages, and $Z_{1,n(\phi)}$ that define equilibrium $\#\Phi_n^*$, and choices of all forms of labor, thus defining equilibrium production and technology in each time period.

Ignoring the fixed cost that, the profit function is:

$$\sum_{x\in\{S,M,H\}}\left[p\left(\sum_{\tilde\phi}y_{x1\tilde\phi}\right)y_{x1\phi}+\beta p\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)y_{x2\phi}-w_x(L_{y_x1\phi}+\beta L_{y_x2\phi})\right]-s_{n(\phi)}L_{G1\phi}.$$

$$\sum_{x\in\{S,M,H\}}\left[\beta p'\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\sum_{\tilde\phi}\left(x_z\left(G'(L_{G1\tilde\phi})\frac{\partial L_{G1\tilde\phi}}{\partial I}+\frac{\partial z}{\partial I}\right)+x_L\frac{\partial L_{y_x2\tilde\phi}}{\partial I}\right)y_{x2\phi}+\beta p\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\right.$$
$$\left.\left(x_z\left(G'(L_{G1\phi})\frac{\partial L_{G1\phi}}{\partial I}+\frac{\partial z}{\partial I}\right)+x_L\frac{\partial L_{y_x2\phi}}{\partial I}\right)-w_x\left(\beta\frac{\partial L_{y_x2\phi}}{\partial I}\right)\right]-s_{n(\phi)}\frac{\partial L_{G1\phi}}{\partial I}.$$

$$\sum_{x\in\{S,M,H\}}\left[\beta p'\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\left(\sum_{\tilde\phi}x_z\frac{\partial z}{\partial I}\right)y_{x2\phi}+\beta p\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\left(x_z\frac{\partial z}{\partial I}\right)\right]$$
$$+\sum_{x\in\{S,M,H\}}\left[\beta p'\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\sum_{\tilde\phi}\left(x_z\left(G'(L_{G1\tilde\phi})\frac{\partial L_{G1\tilde\phi}}{\partial I}\right)+x_L\frac{\partial L_{y_x2\tilde\phi}}{\partial I}\right)y_{x2\phi}+\beta p\left(\sum_{\tilde\phi}y_{x2\tilde\phi}\right)\right.$$
$$\left.\left(x_z\left(G'(L_{G1\phi})\frac{\partial L_{G1\phi}}{\partial I}\right)+x_L\frac{\partial L_{y_x2\phi}}{\partial I}\right)-w_x\left(\beta\frac{\partial L_{y_x2\phi}}{\partial I}\right)\right]-s_{n(\phi)}\frac{\partial L_{G1\phi}}{\partial I}.$$

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