

Patent protection, innovation, and technology transfer in a Schumpeterian economy

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Abstract

This paper analyzes the cross-country effects of intellectual property rights (IPR) protection on the relative wage, innovation, and technology transfer in a North-South quality-ladder model with innovative Northern R&D and adaptive Southern R&D. The degree of IPR protection in two countries differs in terms of patent breadth, which determines the markups of Northern firms and their Southern affiliates, respectively. In this model, stronger IPR protection in the South leads to a permanent decrease in the North-South wage gap, a temporary increase in the Northern innovation rate, and a permanent increase in technology transfer. By contrast, stronger IPR protection in the North leads to a permanent increase in the North-South wage gap, ambiguous effects on the Northern innovation rate, and a permanent decrease in technology transfer. Finally, we perform a quantitative analysis by calibrating the model to the US-China data, and the numerical results support these policy implications in addition to a welfare implication such that strengthening patent protection in one country leads to sizable welfare improvements in both countries.

JEL classification: Innovation; Intellectual Property Rights Protection; North-South Product Cycles; R&D; Technology Transfer.

Keywords: F43; O33; O34; O40.

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1 Introduction

The relationship between intellectual property rights (IPR) protection in developing countries (i.e., the South) and the incentives of developed countries (i.e., the North) to transfer technologies has been a fundamental question in the literature on multinational firms and international trade. This relationship has become even more important since the Trade-Related Intellectual Property Rights (TRIPS) Agreement of the World Trade Organization (WTO), which was signed by WTO members in 1994 to raise the level of IPR protection around the world, especially in developing countries.¹ As a result of international technology transfer, some existing studies argue that strengthening IPR protection in developing countries harms themselves by simply causing income transfer from developing countries to developed countries (e.g., [McCalman \(2001\)](#) and [Park and Lippoldt \(2005\)](#)), but some argue that it could benefit the global economy (e.g., [Gustafsson and Segerstrom \(2011\)](#) and [Tanaka and Iwaisako \(2014\)](#)). Therefore, in order to justify the (dis)advantages of stronger IPR protection in developing countries, this study attempts to reexamine the effects on technology transfer within multinational firms in terms of foreign direct investment (FDI) and on the welfare of both developing and developed countries.²

In addition, most existing studies in multinational firms and technology transfer mainly focus on the role of stronger IPR protection in the South.³ Nevertheless, using the patent rights protection index constructed by [Ginarte and Park \(1997\)](#), [Dinopoulos and Kottaridi \(2008\)](#) report that during the period 1960-2000, the degree of IPR protection increased significantly not only in developing countries (on average by 70%) but also in developed countries (on average by 50%).⁴ In the North-South model setting, stronger IPR protection in the North changes the degree of protection of their intellectual assets, as reflected by the value of patents for innovations. This tends to alter the incentives of Northern firms to conduct research and development (R&D) to develop new innovations and thus generates an reallocation effect on the resources between production and R&D in the North. This resource reallocation in turn affects the amounts of production shifted from the North to the South and the rate of technology transfer accompanied with it. Accordingly, to fully consider the decision of Northern parent firms on innovation and the decision on technology transfer to their Southern affiliates in a more realistic environment, the (long-run) effect of stronger IPR protection in the North should also be taken into consideration.

¹In the current literature, the theoretical and empirical conclusions about the impacts of Southern IPR protection on international technology transfer are mixed. For example, the North-South models by [Glass and Saggi \(2002\)](#) and [Glass and Wu \(2007\)](#) show that stronger IPR protection in the South unambiguously reduces the rate of technology transfer, and the empirical analysis of [Mayer and Pfister \(2001\)](#) and [Pfister and Deffains \(2005\)](#) finds a negative effect of stronger patent rights on location decisions of French multinationals. However, the implication of North-South models by [Helpman \(1993\)](#), [Lai \(1998\)](#), and [Branstetter and Saggi \(2011\)](#) is consistent with the observation in [Lee and Mansfield \(1996\)](#), [Nunnenkamp and Spatz \(2004\)](#), and [Branstetter et al. \(2006\)](#), such that the increase in foreign direct investment by US multinationals results from stronger IPR protection in developing countries. See [Park \(2012\)](#) for a detailed survey.

²The types of technology transfer from developed countries to developing countries can be various, such as FDI, licensing, and illegal imitation. In particular, inward FDI is one of the main modes that becomes increasingly important in developing economies. FDI data from UNCTAD World Investment Report indicate that FDI inflows and inward FDI stock in developing economies grew at an annual rate of about 11.60% and 11.81%, respectively, from 1990 to 2017.

³See, for example, [Dinopoulos and Segerstrom \(2010\)](#) and [Iwaisako et al. \(2011\)](#).

⁴For example, [Park \(2008\)](#) show that from 1960 to 2000, the Ginarte-Park index increase from 3.86 to 4.88 in the US, from 2.85 to 4.67 in Japan, from 3.20 to 4.54 in the UK, and from 2.33 to 4.50 in Germany, respectively.

To properly address the above issues, this study develops a North-South quality-ladder model with semi-endogenous growth that features innovative R&D in the North and adaptive R&D in the South to theoretically and quantitatively analyze the cross-country effects of IPR protection on the wage gap between regions, innovation, and international technology transfer.⁵ Specifically, in this model, Northern firms engage in innovative R&D to develop new higher-quality products, and to increase profit flows, they (in the form of multinational firms) invest in adaptive R&D to transfer their manufacturing of these products from the high-wage North to the low-wage South.⁶ Moreover, to model IPR protection, the analysis in this study focuses on the use of the policy instrument: *patent breadth*, in the North and in the South, respectively. The level of patent breadth captures the degree of protection for the state-of-art technology holders against potential imitations, which determines the monopolistic markups charged by multinational firms and the amount of profits generated by the technology in the two regions. Within this open-economy dynamic general equilibrium framework, we derive the following results.

Stronger patent protection in the South leads to a permanent decrease in the North-South wage gap, a permanent increase in the rate of technology transfer, and a temporary increase in the rate of Northern innovation. Intuitively, a larger patent breadth in the South raises the cost of imitation, which generates more market power to Southern firms by allowing them to charge a higher markup. Hence, the incentives for relocating manufacturing operations to Southern firms increase, yielding a higher demand for R&D labor in the South. Consequently, the wage rate in the South rises relative to the North. Furthermore, given that stronger Southern patent protection increases the incentives for being a Southern firm, more adaptive R&D will be performed, yielding a positive effect on the rate of international technology transfer. As a result, a smaller number of products will be manufactured in the North. Therefore, there is a labor reallocation from production to R&D in the North, which in turn increases the rate of Northern innovation but only temporarily since the model has the semi-endogenous-growth property.

Stronger patent protection in the North leads to a permanent increase in the North-South wage gap, a permanent decrease in the rate of international technology transfer, and an ambiguous effect on the rate of innovation in the North depending on the relative labor force of the two economies. Intuitively, a larger patent breadth in the North increases the profit margin of Northern firms through a larger markup, which decreases the incentives for being multinationals through conducting adaptive R&D. Hence, a lower demand for Southern R&D labor depresses the wage rate in the South relative to the North. Furthermore, given that a larger Northern patent

⁵In Appendix B, we consider an extension in which the model with an alternative R&D specification features fully endogenous growth in the long run. It is shown that the main results of the baseline model would be robust in this extended model.

⁶The empirical study of [Kuemmerle \(1999\)](#) documents that R&D performed by affiliates in developing countries is focused on the absorption of parent-firm technology and on its modification for local markets. [Branstetter et al. \(2006\)](#) show that the significant increases in royalty payments and R&D spending of affiliates are concentrated among those affiliates that make extensive use of their US parent firms' intangible assets and technology imports, respectively. In addition, it is reasonable to assume that Southern affiliates conduct adaptive R&D instead of innovative R&D in our model. [Shimizutani and Todo \(2008\)](#) distinguish the different motives for overseas (innovative and adaptive) R&D. The major motive for overseas innovative R&D is to acquire advanced knowledge that is often tacit and accessible, usually targeting on technologically-advanced countries like "the North" in our model; in contrast, the motive for adaptive R&D is to enhance local sales by satisfying local needs, usually targeting on developing countries like "the South" in our model. Using firm-level panel data from Japanese multinationals, [Shimizutani and Todo \(2008\)](#) found that most of these multinational firms conduct adaptive R&D in developing countries.

breadth has a negative impact on adaptive R&D, the benefits of remaining as Northern firms increase, which in turn reduces the rate of international technology transfer. Finally, as for the impact on the rate of Northern innovation, there are two contrasting effects: a larger Northern patent breadth raises the demand for Northern R&D labor through a larger markup of Northern firms (i.e., the positive effect) but reduces it through more products being manufactured in the North (i.e., the negative effect). The latter negative effect on the rate of Northern innovation via R&D labor in the North becomes weaker if the relative labor force between the North and the South is large. Therefore, there exists a threshold on the North-South ratio of labor force above (below) which the overall effect of stronger patent protection in the North on the innovation rate would be positive (negative).

We calibrate our model to the China-US data to quantify the cross-country effects of IPR protection in terms of patent breadth. Our quantitative analysis shows that increasing the level of patent breadth in China by 1% (percent change) reduces the wage gap between the US and China by 0.900% (percent change), and it raises the average quality per US worker by 0.577% (percent change), implying a temporary higher rate of innovation in the US. The larger patent breadth in China would increase the flow of technology transfer from the US to China by 5.225% (percent change). Additionally, this numerical exercise enables us to perform a welfare analysis. We find that broadening patent breadth in China causes an increase in welfare (in terms of the equivalent variation in consumption) by 2.520% in China and 1.546% in the US. These welfare gains are mostly due to the increase in wages in both countries.

Additionally, increasing the level of patent breadth in the US by 1% raises the wage gap between the US and China by 0.617% and decreases the flow of technology transfer from the US to China by 3.993%. The larger patent breadth in the US would raise the average quality per US worker by 3.218%, implying a temporary higher rate of innovation in the US, since the labor force in the US relative to that in China is sufficiently large in this case. Broadening patent breadth in the US causes an increase in welfare by 7.863% in China and 8.792% in the US. Therefore, broadening patent breadth in the US leads to a significantly larger welfare improvement for the two economies in total than broadening patent breadth in China. Nevertheless, the domestic country tends to benefit more than the foreign country under a strengthening of its home patent protection. The above welfare results highlight the importance of strengthening IPR protection in both developing and developed countries in raising the global economy's welfare, which, to some extent, justifies the objective of TRIPS.

1.1 Literature review

This paper contributes to the theoretical literature on innovation and technology transfer that models IPR protection in forms other than patent breadth. [Yang and Maskus \(2001\)](#) model stronger IPR protection in terms of technology licensing and explore the impacts of reducing licensing costs and improvements in the licensor's share of rents.⁷ [Dinopoulos and Kottaridi \(2008\)](#) analyze the effects of IPR policy on innovation and technology transfer by modeling stronger IPR protection as an increase in patent length and/or a strengthening of patent enforcement. [Gancia and Bonfiglioli \(2008\)](#) study how North-South trade affects the direction of technical progress,

⁷[Tanaka et al. \(2007\)](#) reexamine the policy analysis of the [Yang and Maskus \(2001\)](#) model by studying the steady state and transitional dynamics, respectively.

growth and wage differences, and they model stronger IPR protection by an exogenous fraction of profits earned by successful Southern imitations that accrues to the original innovator. Nevertheless, the analysis of IPR protection in the present paper differs from the above papers by focusing on the scope of products that grants to patented firms to produce, which is captured by the level of patent breadth.⁸ Specifically, in the current quality-ladder model, patent breadth represents the degree of quality by which the government in a region permits the state-of-art technology holders to produce without potential imitations from competitive fringes, which determines the markups and profits of monopolistic firms in the North and the South, respectively. In other words, the different levels of Northern patent breadth and Southern patent breadth captures the difference in the market power of the two economies.

This study is closely related to the recent research of [Dinopoulos and Segerstrom \(2010\)](#) and [Iwaisako et al. \(2011\)](#), who analyze the effects of IPR protection in North-South quality-ladder models,⁹ but there are significant differences between these studies and ours. First, in a model with innovative R&D in the North and adaptive R&D in the South (i.e., costly FDI), [Dinopoulos and Segerstrom \(2010\)](#) investigate the effects of stronger IPR protection in developing countries on innovation, technology transfer, and welfare,¹⁰ and the form of IPR protection is represented by the exogenous instantaneous probability that Southern affiliates' products are copied.¹¹ By contrast, our study explores the same effects by employing a different IPR policy lever (i.e., broadening patent breadth that enlarges Southern firms' markup). Moreover, [Dinopoulos and Segerstrom \(2010\)](#) show that the long-run welfare effect of stronger IPR protection in the South on domestic consumers is theoretically ambiguous. Despite of the same analytical result in the current study, our paper complements [Dinopoulos and Segerstrom \(2010\)](#) by adding a quantitative analysis to illustrate that such a welfare effect is indeed substantially positive. Second, [Iwaisako et al. \(2011\)](#) explore how strengthening IPR protection in the South by increasing patent breadth affects innovation, FDI, and welfare. Nevertheless, similar to the assumption used in [Helpman \(1993\)](#), [Lai \(1998\)](#), and [Branstetter and Saggi \(2011\)](#), the setting of [Iwaisako et al. \(2011\)](#) assumes that international technology transfer within multinational firms is costless, which is inconsistent with the recent evidence that the R&D spending by affiliates of US multinationals increased considerably.¹² Our study differs from the analysis of [Iwaisako et al. \(2011\)](#) by considering adaptive R&D in Southern affiliates as the approach to transfer intellectual properties that facilitate production from the North to the South. Third, this study takes into account the effects

⁸See Chapter 2 in [Maskus \(2000\)](#) for details about the requirement on WTO member countries to strengthen patent protection in regard to patent breadth by the TRIPS agreement.

⁹See [Gustafsson and Segerstrom \(2010, 2011\)](#) and [Lorenczik and Newiak \(2012\)](#), who explore the effects of IPR protection in a North-South trade model with increasing product variety. Appendix D considers an extension in which the process of innovation is based on variety expansion. It is shown that the analytical results on the cross-country effects of patent protection in this study are robust to the extended model.

¹⁰See [Ohki \(2017\)](#) for a similar analysis in a framework where both Northern and Southern firms incur technology transfer costs.

¹¹[Glass and Saggi \(2002\)](#) and [Glass and Wu \(2007\)](#) study the effects of stronger IPR protection on innovation and technology transfer, with and without costly FDI, respectively, and the mode of IPR protection in their models is similar to that in [Dinopoulos and Segerstrom \(2010\)](#). Nevertheless, the models in [Glass and Saggi \(2002\)](#) and [Glass and Wu \(2007\)](#) assume all innovating R&D being done by industry leaders, rather than free entry into innovative R&D as assumed in [Dinopoulos and Segerstrom \(2010\)](#) and the present paper.

¹²According to The National Science Foundation, the series in International Investment and R&D Data Link reports that the R&D expenditure of the majority-owned foreign affiliate (MOFA) of US multinational companies increased from \$25,351 millions in 2004 to \$38,897 millions in 2010. See <https://www.nsf.gov/statistics/rmlink/> for the details.

of tightening IPR protection in the North, which conforms to the changes in patent rights of developed countries in the last few decades. Nonetheless, the impact of Northern IPR protection is neglected in the above studies. Therefore, to the best of our knowledge, this is the first study that analyzes the cross-country effects of patent breadth in a Schumpeterian growth model with North-South technology transfer and costly FDI.

The present paper is also related to the existing studies of global patent protection. [Lai and Qiu \(2003\)](#) and [Grossman and Lai \(2004\)](#) analyze the welfare incentives of Northern and Southern governments to protect their intellectual property rights by using patent length as the policy instrument in an open-economy variety-expansion model where both regions invest in R&D, whereas the current paper differs from their interesting studies by focusing on the important role of national patent policies in the form of patent breadth in an open-economy quality-ladder model with international technology transfer. In addition, [Chu and Peng \(2011\)](#) explore the effects of patent breadth in a two-country Schumpeterian growth model, but their study focuses on the interaction between developed countries by considering an environment with two Northern economies, both of which undertake innovative activities. This study, instead, examines the impacts of the same patent tool in the presence of North-South product cycles and international technology transfer via FDI, so our study complements the analysis of [Chu and Peng \(2011\)](#) by focusing on the interaction between developed and developing economies. Furthermore, the current study adds to the above studies by providing a quantitative analysis on the welfare implications of patent breadth, which shows that tightening IPR protection in a country can lead to a sizable welfare improvement in both countries.

Finally, the present paper relates to a large body of empirical studies that examine the relationship between Southern IPR protection and FDI. So far, the results in this strand of literature appear to be very mixed. For example, [Primo Braga and Fink \(1998\)](#) find a negative relationship between the degrees of IPR protection in developing countries and overseas sales by US-based multinationals, whereas [Javorcik \(2004\)](#) and [Branstetter *et al.* \(2011\)](#) find that stronger patent rights in reforming countries have a positive effect on FDI in technology-intensive industries. Additionally, [Fosfuri \(2004\)](#) does not find any significant relationship between the strengths of IPR protection and multinational investment. Thus, our North-South quality ladder model complements these empirical studies by providing a theoretical rationale to support the positive effect of IPR protection in developing countries on FDI.¹³

The rest of this paper is organized as follows. Section 2 introduces the model. Section 3 derives the conditions that determine the steady-state equilibrium and the social welfare functions. Section 4 analytically explores the cross-country effects of patent protection. Section 5 performs a quantitative analysis. Section 6 concludes this study.

2 Model

To analyze the respective effects of Northern patent protection and Southern patent protection, we extend the [Dinopoulos and Segerstrom \(2010\)](#) quality-ladder model with multinational firms, which is a recent variant of the North-South R&D-based model originating from the semi-

¹³Nevertheless, the recent analysis of [Chen \(2015, 2018\)](#) shows that stronger IPR protection in developing countries can reduce FDI in a product-cycle model of skills accumulation, without and with costly imitation, respectively.

nal work by [Grossman and Helpman \(1991\)](#). In the model of [Dinopoulos and Segerstrom \(2010\)](#), a global economy consists of a high-wage North and a low-wage South, and labor, which grows at the same rate in the two countries, is the only factor of production in products and R&D. Firms hire Northern workers to engage in innovative R&D to produce new higher-quality products, and such firms are called *Northern quality leaders* since all their production is located in the North. To take the advantage of lower production costs in the South, a Northern quality leader can transfer its manufacturing operations to the South in the form of multinational firms by hiring Southern workers to engage in adaptive R&D, and such a firm is called a *Southern affiliate* since all its production is located in the South. Adaptive R&D is considered as a measure of FDI because it represents the cost that multinational firms incur to transfer their technology to foreign affiliates. To introduce IPR protection, we incorporate patent breadth to protect producers from the threat of imitations, which determines the price-marginal-cost markup in each intermediate-good market. The level of patent breadth in the North is assumed to be higher than the one in the South to capture the fact that IPR protection in developed countries is generally stronger than that in developing countries.

2.1 Households

At time t , the household in the North (South) has a population size of L_t^N (L_t^S). For simplicity, we assume that the population growth rates in both countries are identical and equal to $g_L > 0$. Moreover, each household member in a country has one unit of labor, which is supplied inelastically. Thus, the total size of labor force in the world is $L_t = L_t^N + L_t^S$. Denote by $\alpha \equiv L_t^S/L_t$ the share of Southern labor force and $1 - \alpha$ the share of Northern labor force in the global labor force, respectively.

The lifetime utility function of the representative household in country $i = \{N, S\}$ is given by

$$U \equiv \int_0^{\infty} e^{-(\rho - g_L)t} \ln c_t^i dt, \quad (1)$$

where $\rho > g_L$ is the discount rate and c_t^i is level of consumption per capita in country i . Each household in country i maximizes (1) subject to the following budget constraint:

$$\dot{a}_t^i = (r_t - g_L)a_t^i + w_t^i - c_t^i \quad (2)$$

where in country i , a_t^i is the real value of financial assets per capita, w_t^i is the real wage rate, and r_t is the real interest rate that households in both countries face at time t . Following [Dinopoulos and Segerstrom \(2010\)](#), we assume that there is a global financial market such that the real interest rates in both countries must be equal. In each country, all prices are expressed in terms of the price of consumption goods.

Solving the standard utility-maximization problem gives rise to the familiar Euler equation:

$$\frac{\dot{c}_t^N}{c_t^N} = \frac{\dot{c}_t^S}{c_t^S} = r_t - \rho, \quad (3)$$

which implies that the growth rates of consumption in both countries are identical.

2.2 Final goods

Final goods Y_t are all consumed by households and are produced by perfectly competitive firms that aggregate a unit continuum of intermediate goods $x_t(j)$ using the standard CES aggregator such that

$$Y_t = \left\{ \int_0^1 [x_t(j)]^{\frac{\sigma-1}{\sigma}} dj \right\}^{\frac{\sigma}{\sigma-1}}, \quad (4)$$

where $\sigma > 1$ is the elasticity of substitution between intermediate goods. The market-clearing condition for final goods in the world is

$$Y_t = c_t^N L_t^N + c_t^S L_t^S = [(1 - \alpha)c_t^N + \alpha c_t^S] L_t, \quad (5)$$

where $c_t^N L_t^N$ and $c_t^S L_t^S$ are the aggregate consumption in the North and the South, respectively. Given zero transportation cost,¹⁴ the law of one price holds such that $p_{c,t}^N = \epsilon_t p_{c,t}^S$, where ϵ_t is the exchange rate and $p_{c,t}^N$ ($p_{c,t}^S$) is the price of consumption in the North (South). In this study, all variables are expressed in real terms denominated by units of consumption that have the same value in the two countries. Solving this profit-maximizing problems yields the demand function for $x_t(j)$ such that

$$x_t(j) = \frac{Y_t}{p_t(j)^\sigma}, \quad (6)$$

where $p_t(j)$ is the price of $x_t(j)$.

2.3 Intermediate goods

The differentiated intermediate goods in each industry $j \in [0, 1]$ are produced by a monopolistic quality leader who holds a patent on the latest innovation. This leader's products will not be replaced until a new entrant with a more advanced innovation enters the market, which is known as the *Arrow replacement effect*. Among all intermediate goods, some are produced in the North and the others are produced in the South. If a Northern firm succeeds in inventing a state-of-the-art good, it can register a patent for the good in both the North and the South. Products are mobile across countries, while labor, as the only production factor of intermediate goods, is immobile. The production function of intermediate goods by a quality leader in the North is given by

$$x_t(j) = z^{n_t(j)} L_{x,t}^N(j) \equiv x_t^N(j) \quad (7)$$

where the parameter $z > 1$ measures the step size of a quality improvement, $n_t(j)$ is the number of quality improvements that have occurred in industry j up to time t , and $L_{x,t}^N(j)$ is the amount of Northern labor employed by the quality leader for manufacturing.

In order to take advantage of cheaper labor force in the South, the quality leader in the North also has an incentive to shift its production to the South. The shift requires adaptive R&D for

¹⁴Appendix E considers an extension in which the North-South trade costs in terms of transportation are positive. It is shown that the analytical results on the cross-country effects of patent protection in the baseline model are also robust to the extended model. Moreover, a decrease in trade costs has no impacts on the rate of technology transfer and the Northern innovation rate, but it has ambiguous effects on the relative wage rate, depending on the countries' purchasing power.

the Northern quality leader to transfer technology to its foreign affiliate. Without conducting adaptive R&D to modify it to the local market, the production technology possessed by the Northern quality leader can not be used by foreign producers. Once technology transfer is complete, the Southern affiliate of the Northern leader can produce intermediate goods as a monopolist according to

$$x_t(j) = \delta z^{n_t(j)} L_{x,t}^S(j) \equiv x_t^S(j) \quad (8)$$

where $\delta > 0$ is a labor-productivity parameter, capturing the productivity of Southern labor relative to Northern labor. $L_{x,t}^S(j)$ is the number of Southern labor employed by the foreign affiliate for production. Notice that with the state-of-the-art technology, the condition for the presence of FDI incentives must hold such that the marginal cost of production in the South has to be smaller than the counterpart in the North, i.e., $w_t^S / (\delta z^{n_t(j)}) < w_t^N / z^{n_t(j)}$.

To analyze the pricing strategy of each category of intermediate-good firms, we examine how these firms operate in equilibrium by taking into account the responses of their potential rivals. First, we consider the case for Northern quality leaders. On the one hand, we assume that IPR protection in the North is incomplete. Therefore, one type of potential rivals against a current Northern quality leader is Northern imitators who are able to gain access to the latest production technology. On the other hand, the current Northern quality leader, as it shifts the production to the South, can make use of cheaper labor in the South where the protection of IPR is weaker. Thus, another type of potential rivals against a current Northern quality leader is the foreign affiliate of the previous Northern leader, who adopt the second-latest-generation production technology that is one step behind the newest one. Moreover, to introduce IPR instruments that can be set by the policymakers, we follow [Goh and Olivier \(2002\)](#) to assume that the strength of IPR protection determines the imitation cost, and define by $\mu_t^N > 1$ the level of patent breadth in the North controlled by Northern patent authority. Accordingly, given the productivity $z^{n_t(j)}$, Northern imitators pay a marginal cost (i.e., $\mu_t^N w_t^N / z^{n_t(j)}$) that is higher than the Northern quality leader's counterpart (i.e., $w_t^N / z^{n_t(j)}$).¹⁵

Define by $\omega_t \equiv w_t^N / w_t^S$ the relative wage rate between the North and the South. To ensure the existence of two-way product cycles, we impose the following assumption:

Assumption 1. $\omega_t \delta < z / \mu_t^N$.

Specifically, the assumption $\omega_t \delta < z / \mu_t^N$ implies $w_t^S / (\delta z^{n_t(j)-1}) > \mu_t^N w_t^N / z^{n_t(j)} > w_t^N / z^{n_t(j)}$, which implies that when the next innovation arrives, the manufacturing process shifts back to the North; both the Northern quality leader and Northern imitators have a cost advantage to win over the Southern affiliate of the previous Northern leader.

Then, after the return of production to the North occurs, Assumption 1 indicates that the strongest rival against the Northern leader is Northern imitators. Thus, similar to [Iwaisako and Futagami \(2013\)](#), the breadth of Northern patent protection μ_t^N determines the current Northern quality leader's markup and its maximum (optimal) price. This feature captures the insight in [Gilbert and Shapiro \(1990\)](#) that "breadth as the ability of the patentee to raise price". The standard

¹⁵See [Li \(2001\)](#) for the detailed discussion on incomplete patent breadth in a quality-ladder growth model.

Bertrand price competition leads to the monopolistic price given by

$$p_t^N(j) = \frac{\mu_t^N w_t^N}{z^{n_t(j)}} \leq \underbrace{\frac{\sigma}{\sigma-1} \frac{w_t^N}{z^{n_t(j)}}}_{\text{unconstrained price}}, \quad (9)$$

which is the limit price of the Northern leader against the Northern competitive fringes that undertake potential imitations. The unconstrained price is referred to the case in which patent protection in the North is completed and monopolists are able to charge the highest price determined by the intermediate goods market. Consequently, the range of Northern patent breadth is given by $1 < \mu_t^N \leq \sigma/(\sigma-1)$.

Next, consider the case for the affiliate of the Northern leader who moves the locus of production to the South to make use of a lower wage rate in the South. Define by μ_t^S the level of patent breadth in the South, which is controlled by Southern patent authority. In this study, we assume that patent protection in the North is stricter than in the South such that $\mu^S < \mu^N$.¹⁶ Hence, incomplete patent protection in the South attracts Southern imitators who also get access to the latest-generation technology. In this case, the most competitive rival for this affiliate is Southern imitators, since given the previously stated condition $\omega_t \delta > 1$, the marginal cost of Southern imitators is lower than that of Northern imitators (i.e., $\mu_t^S w_t^S / (\delta z^{n_t(j)}) < \mu_t^N w_t^N / z^{n_t(j)}$).¹⁷ Nevertheless, the current affiliate is protected the policy of Southern patent authority because it enters the Southern market through conducting adaptive R&D. Accordingly, similar to the pricing strategy of the Northern leader, the highest price set by the Southern affiliate is given by

$$p_t^S(j) = \frac{\mu_t^S w_t^S}{\delta z^{n_t(j)}} < \underbrace{\frac{\sigma}{\sigma-1} \frac{w_t^S}{\delta z^{n_t(j)}}}_{\text{unconstrained price}}, \quad (10)$$

where the range of Southern patent breadth is $1 < \mu_t^S < \sigma/(\sigma-1)$.

Define the aggregate quality index across industries $j \in [0, 1]$ as

$$Q_t \equiv \int_0^1 q_t(j) dj, \quad (11)$$

where $q_t(j) = [z^{n_t(j)}]^{\sigma-1}$. This is also the average quality index given a unit measure of intermediate-good industries in the global economy. The labor demands for an average-quality product produced by a Northern leader and a Southern affiliate can be expressed, respectively, by

$$\bar{L}_{x,t}^N = \int_0^1 L_{x,t}^N(j) dj = Q_t Y_t \left(\mu_t^N w_t^N \right)^{-\sigma}, \quad (12)$$

¹⁶According to [Dinopoulos and Kottaridi \(2008\)](#), the average level of patent protection in developed countries was roughly 33% higher than the counterpart in developing countries during 1960-2000.

¹⁷In addition, Assumption 1 implies that when technology transfer is completed, the marginal cost of the Southern affiliate of the previous leader (i.e., $w_t^S / (\delta z^{n_t(j)-1})$) is larger than that of Northern imitators' (i.e., $\mu_t^N w_t^N / (\delta z^{n_t(j)})$), making Southern imitators the strongest rival against the Southern affiliate of the current leader.

$$\bar{L}_{x,t}^S = \int_0^1 L_{x,t}^S(j) dj = \frac{Q_t Y_t}{\delta} \left(\frac{\delta}{\mu_t^S w_t^S} \right)^\sigma. \quad (13)$$

Using these equations, the labor demands for product j are expressed by

$$L_{x,t}^N(j) = \frac{q_t(j)}{Q_t} \bar{L}_{x,t}^N; \quad L_{x,t}^S(j) = \frac{q_t(j)}{Q_t} \bar{L}_{x,t}^S. \quad (14)$$

The instantaneous profit of the Northern leader is given by

$$\pi_t^N(j) = p_t^N(j) x_t^N(j) - w_t^N(j) L_{x,t}^N(j) = \left(\mu^N - 1 \right) q_t(j) \frac{w_t^N Y_t}{(\mu_t^N w_t^N)^\sigma}, \quad (15)$$

where (7), (8), (12), and (13) are applied. Furthermore, the monopoly profit of the Southern affiliate of the Northern leader is given by

$$\pi_t^S(j) = p_t^S(j) x_t^S(j) - w_t^S L_{x,t}^S(j) = \left(\mu_t^S - 1 \right) q_t(j) \frac{w_t^S Y_t}{\delta} \left(\frac{\delta}{\mu_t^S w_t^S} \right)^\sigma, \quad (16)$$

where again (7), (8), (12), and (13) are used.¹⁸

To ensure that moving the locus of production to the South is attractive to the Northern leader such that $\pi_t^S(j) > \pi_t^N(j)$, the following assumption is imposed:

Assumption 2. $\delta \omega_t > \left[\frac{(\mu_t^N - 1)(\mu_t^S)^\sigma}{(\mu_t^S - 1)(\mu_t^N)^\sigma} \right]^{\frac{1}{\sigma - 1}}$.

This assumption implies that the benefit of shifting production to the South with a lower wage rate, after taking into account the labor productivity difference δ , must compensate for the potential loss due to a lower degree of patent protection in the South.

2.4 Innovative and adaptive R&D

Innovative R&D is all performed by entrepreneurs in the North. By employing an amount of $L_{r,t}^N(j)$ of Northern labor to engage in innovative R&D in industry j , an R&D entrepreneur will succeed in inventing a newer generation of product in the industry with an instantaneous probability such that

$$\lambda_t^N(j) = \frac{Q_t^\xi L_{r,t}^N(j)}{\beta q_t(j)}, \quad (17)$$

where the term $Q_t^\xi / [\beta q_t(j)]$ represents the productivity in innovative R&D. $\beta > 0$ is an exogenous parameter, and $q_t(j)$ reflects the decrease in the productivity of R&D labor as the product quality increases. The consideration of decreasing R&D labor productivity (i.e., increasing research com-

¹⁸Given the production technology $z^{n_t(j)}$ in the market, the profit flow of a new Northern quality leader in industry j by successfully introducing the more advanced technology $z^{n_t(j)+1}$ is $z^{\sigma-1} (\mu_t^N - 1) q_t(j) w_t^N Y_t / (\mu_t^N w_t^N)^\sigma$. This profit has to exceed the Southern affiliate's profit $\pi_t^S(j)$ for the return of production to the North to occur, implying $(\delta \omega_t) / z < \Psi_t$, where $\Psi_t \equiv \{ [(\mu_t^N - 1)(\mu_t^S)^\sigma] / [(\mu_t^S - 1)(\mu_t^N)^\sigma] \}^{1/(\sigma-1)}$. This condition is indeed guaranteed by Assumption 1, since Ψ_t is greater than unity for $\mu_t^S \in (1, \mu_t^N)$, which ensures $\delta \omega_t < 1 / \mu_t^N < \Psi_t$ to hold.

plexity) is used to eliminate the counterfactual scale effects.¹⁹ This setting follows the theoretical studies such as [Segerstrom \(1998\)](#) and [Segerstrom \(2000\)](#) and is consistent with recent empirical findings from [Bloom et al. \(2020\)](#). In addition, to facilitate our quantitative analysis in Section 5, Q_t^ξ is introduced to capture the intertemporal knowledge spillover effect, and the parameter $\xi \in [0, 1)$ measures the degree of this externality.

Denoted by $v_t^N(j)$ the expected value of owning the most recent innovation in industry j . The free entry into R&D implies the following zero-expected-profit condition for innovative R&D:

$$v_t^N(j)\lambda_t^N(j) = w_t^N L_{r,t}^N(j) \Leftrightarrow v_t^N(j) = \beta w_t^N q_t(j) Q_t^{-\xi}, \quad (18)$$

where (17) is used.

Adaptive R&D in the South is performed by local entrepreneurs and the Southern affiliates of Northern industry leaders. The modeling of adaptive R&D in this study follows that in [Dinopoulos and Segerstrom \(2010\)](#) that attempts to capture the substantial resource expenditure and inherent uncertainty associated with international technology transfer, including the training of foreign workers, learning about local customs, culture and regulations, etc.²⁰ By employing $L_{r,t}^S(j)$ units of Southern labor into adaptive R&D, the Southern affiliate of a Northern leader in industry j will succeed in shifting the production to the South with an instantaneous probability such that

$$\lambda_t^S(j) = \frac{Q_t^\xi L_{r,t}^S(j)}{\gamma q_t(j)}, \quad (19)$$

where $Q_t^\xi / [\gamma q_t(j)]$ measures the labor productivity in adaptive R&D. $\gamma > 0$ is an exogenous parameter. Similar to the process in innovative R&D, $q_t(j)$ in the denominator of (19) reflects the increasing research complexity, and Q_t^ξ captures the intertemporal knowledge spillover effect. Denote by $v_t^S(j)$ the firm value of the Southern affiliate of a Northern leader. Thus, the expected net profit for the Northern quality leader to invest in adaptive R&D is $v_t^S(j) - v_t^N(j)$. The free-entry condition implies the zero-expected-profit for adaptive R&D, which can be expressed as

$$\left[v_t^S(j) - v_t^N(j) \right] \lambda_t^S(j) = w_t^S L_{r,t}^S(j) \Leftrightarrow v_t^S(j) - v_t^N(j) = \gamma w_t^S q_t(j) Q_t^{-\xi}, \quad (20)$$

where (19) is applied.

Moreover, we follow the standard treatment in this class of models to focus on a symmetric equilibrium in which $\lambda_t^N(j) = \lambda_t^N$ and $\lambda_t^S(j) = \lambda_t^S$.²¹

¹⁹See [Jones \(1999\)](#) for a detailed discussion on how semi-endogenous growth models remove scale effects.

²⁰[Fors \(1997\)](#) reports that the average amount of R&D performed abroad by Swedish multinationals greatly contributed to total R&D costs per firm, whereas [Norbäck \(2001\)](#) shows that Swedish multinationals that have established R&D labs in a foreign country are more willing to transfer technology and production to such a country.

²¹[Cozzi et al. \(2007\)](#) provide a theoretical justification for the symmetric equilibrium in this strand of Schumpeterian growth model. See [Chu et al. \(2019\)](#) for the same treatment in a monetary Schumpeterian growth model with North-South technology transfer.

2.5 Stock market

The Hamilton-Jacobi-Bellman equation for $v_t^N(j)$ is given by

$$r_t v_t^N(j) = \pi_t^N(j) - w_t^S L_{r,t}^S(j) - \lambda_t^N(j) v_t^N(j) + \lambda_t^S(j) [v_t^S(j) - v_t^N(j)] + \dot{v}_t^N(j),$$

which is also the no-arbitrage condition that determines the value of $v_t^N(j)$. In equilibrium, the return on the asset $v_t^N(j)$, $r_t v_t^N(j)$ on the left-hand side (LHS), equals the sum of the terms on the right-hand side (RHS), including (i) the flow profit $\pi_t^N(j)$; (ii) the expenditure for adaptive R&D $w_t^S L_{r,t}^S(j)$; (iii) the expected capital loss due to creative destruction $\lambda_t^N(j) v_t^N(j)$; (iv) the expected capital gain once adaptive R&D is successful $\lambda_t^S(j) [v_t^S(j) - v_t^N(j)]$; and (v) the potential capital gain $\dot{v}_t^N(j)$. Using (20), the above equation is reduced to

$$r_t v_t^N(j) = \pi_t^N(j) - \lambda_t^N(j) v_t^N(j) + \dot{v}_t^N(j). \quad (21)$$

Similarly, the no-arbitrage condition that determines the value of $v_t^S(j)$ is given by

$$r_t v_t^S(j) = \pi_t^S(j) - \lambda_t^N(j) v_t^S(j) + \dot{v}_t^S(j). \quad (22)$$

The LHS of this equation is also the return on the asset $v_t^S(j)$, and this asset return is the sum of the terms on the RHS including (i) the monopolistic profit as an affiliate $\pi_t^S(j)$; (ii) the expected capital loss due to creative destruction $\lambda_t^N(j) v_t^S(j)$; and (iii) the potential capital gain $\dot{v}_t^S(j)$.

2.6 Decentralized equilibrium

Definition 1. *The equilibrium is defined as a time path of prices, $\{r_t, w_t^N, w_t^S, p_t^N(j), p_t^S(j), v_t^N, v_t^S\}_{t=0}^\infty$, a time path of allocations, $\{c_t^N, c_t^S, Y_t, x_t^N(j), x_t^S(j), L_{x,t}^N(j), L_{x,t}^S(j), L_{r,t}^N(j), L_{r,t}^S(j)\}_{t=0}^\infty$, for $j \in [0, 1]$, and a time path of patent-policy instruments $\{\mu_t^N, \mu_t^S\}_{t=0}^\infty$.*

Moreover, at each instance of time,

- the representative household in the North maximizes lifetime utility taking $\{r_t, P_t, w_t^N\}$ as given;
- the representative household in the South maximizes lifetime utility taking $\{r_t, P_t, w_t^S\}$ as given;
- competitive final-good firms produce Y_t to maximize profits taking $\{p_t^N(j), p_t^S(j)\}$ as given;
- Northern quality leaders choose $p_t^N(j)$ and produce $x_t^N(j)$ to maximize profits taking w_t^N as given;
- Southern affiliates choose $p_t^S(j)$ and produce $x_t^S(j)$ to maximize profits taking w_t^S as given;
- entrepreneurs in the North employ $L_{r,t}^N(j)$ to perform innovative R&D taking $\{r_t, w_t^N, v_t^N\}$ as given;
- Southern affiliates of Northern quality leaders employ $L_{r,t}^S(j)$ to perform adaptive R&D taking $\{r_t, w_t^S, v_t^S\}$ as given;
- the final-good market clears such that $Y_t = c_t^N L_t^N + c_t^S L_t^S$;
- the labor-market-clearing conditions hold in both countries; and
- the exchange rate is determined by the law of one price such that $\epsilon_t = p_{c,t}^N / p_{c,t}^S$.

3 Steady-state equilibrium

In this section, we solve the steady-state equilibrium and analyze how a stationary time path of Southern and Northern patent-policy tools (i.e., $\{\mu^S, \mu^N\}$) affects innovation in the North and international technology transfer, respectively.²² To do so, we first derive the steady-state number of each type of industries and the expression of quality index. Then, we specify the steady-state labor market conditions in the two countries and construct the Southern and Northern steady-state conditions of technology transfer and innovation. Finally, we derive the steady-state welfare functions of the countries.

3.1 Industry composition and quality dynamics

There are two types of industries in the intermediate-good sector, the Northern quality leaders and the Southern affiliates. Denote θ_t^N and θ_t^S as the steady-state measure of these two types of industries, respectively. Then, these measures of all industries must add up to one such that

$$\theta_t^N + \theta_t^S = 1. \quad (23)$$

Each industry can switch randomly across these two categories with probabilities, depending on the Poisson arrival rates of innovative and adaptive R&D. In the steady state, the measure of industries in each type must be constant such that the flow in and flow out of Southern affiliates must be equal. This relation can be established as the following equation:

$$\underbrace{\theta_t^N \lambda^S}_{\text{flow into affiliates}} = \underbrace{\theta_t^S \lambda^N}_{\text{flow out of affiliates}}. \quad (24)$$

Straightforwardly, this equation can be also stated as the flow out and flow in of Northern quality leaders. Solving (23) and (24) yields the measure of these industries such that

$$\theta_t^N = \frac{\lambda^N}{\lambda^N + \lambda^S}, \quad (25)$$

$$\theta_t^S = \frac{\lambda^S}{\lambda^N + \lambda^S}. \quad (26)$$

By definition, the aggregate quality index across industries $j \in [0, 1]$ is given by

$$Q_t \equiv \int_0^1 q_t(j) dj = \int_0^1 \kappa^{n_t(j)} dj, \quad (27)$$

²²In Appendix C, we show that the equilibrium dynamics of this model are evaluated by a 4×4 dynamic system with two state variables and two control variables. Due to its complexity, the dynamic property of our model is explored numerically. It is shown that local determinacy is characterized by a saddle-path stability.

where $\kappa \equiv z^{\sigma-1} > 1$ is a composite parameter that is increasing in the quality step size z . This quality index can be further decomposed into the following two components:

$$Q_t = Q_t^N + Q_t^S = \int_{\theta_t^N} q_t(j) dj + \int_{\theta_t^S} q_t(j) dj. \quad (28)$$

The following lemma provides the steady-state expression for the measure of each component of the aggregate quality.

Lemma 1. *In the steady state, the two components of the aggregate quality can be expressed as*

$$\frac{Q_t^N}{Q_t} = \frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S}, \quad (29)$$

$$\frac{Q_t^S}{Q_t} = \frac{\lambda^S}{\kappa \lambda^N + \lambda^S}. \quad (30)$$

Proof. See Appendix A.1. □

3.2 Northern labor market

The labor-market-clearing condition in the North is given by

$$L_t^N = L_{x,t}^N + L_{r,t}^N = \int_{\theta_t^N} L_{x,t}^N(j) dj + \int_0^1 L_{r,t}^N(j) dj. \quad (31)$$

The amount of labor employed for production by Northern quality leaders is

$$L_{x,t}^N = \int_{\theta_t^N} \frac{q_t(j)}{Q_t} \bar{L}_{x,t}^N dj = \frac{Q_t^N}{Q_t} \bar{L}_{x,t}^N, \quad (32)$$

where (14) is used in the first equality. Using (17), the amount of labor employed for innovative R&D is given by

$$L_{r,t}^N = \beta \lambda^N Q_t^{1-\xi}, \quad (33)$$

where the symmetry condition $\lambda^N(j) = \lambda^N$ is imposed. Substituting (32) and (33) into (31), together with (29), yields the Northern labor-market-clearing condition in per capita terms such that

$$1 = \frac{\bar{L}_{x,t}^N}{L_t^N} \frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S} + \beta \lambda^N \Phi, \quad (34)$$

where $\Phi_t \equiv Q_t^{1-\xi} / L_t^N = \Phi$ is defined as the average quality per Northern worker, which is constant over time in any steady-state equilibrium.

3.3 Southern labor market

The labor-market-clearing condition in the South is given by

$$L_t^S = L_{x,t}^S + L_{r,t}^S = \int_{\theta_i^S} L_{x,t}^S(j) dj + \int_{\theta_i^N} L_{r,t}^S(j) dj. \quad (35)$$

The amount of labor employed for production by Southern affiliates is

$$L_{x,t}^S = \int_{\theta_i^S} \frac{q_t(j)}{Q_t} \bar{L}_{x,t}^S dj = \frac{Q_t^S}{Q_t} \bar{L}_{x,t}^S, \quad (36)$$

where (14) is used in the first equality. Using (19) and imposing the symmetry condition $\lambda_t^S(j) = \lambda^S$, we can show the amount of labor employed for adaptive R&D such that

$$L_{r,t}^S = \gamma \lambda^S Q_t^{1-\xi} \frac{Q_t^N}{Q_t}. \quad (37)$$

Substituting (36) and (37) into (35), coupled with (29) and (30), yields the Southern labor-market-clearing condition in per capita terms such that

$$1 = \frac{\lambda^S}{\kappa \lambda^N + \lambda^S} \left[\frac{\bar{L}_{x,t}^S}{L_t^S} + \frac{\gamma \kappa \lambda^N (1 - \alpha)}{\alpha} \Phi \right], \quad (38)$$

where $L_t^N / L_t^S = (1 - \alpha) / \alpha$ is used.

3.4 Innovation and technology transfer

Differentiating (27) with respect to time t yields the growth rate of the quality index such that

$$\dot{Q}_t = \int_0^1 \left[\kappa^{n_i(j)+1} - \kappa^{n_i(j)} \right] \lambda_t^N dj = (\kappa - 1) \lambda_t^N Q_t. \quad (39)$$

Differentiating the log of $\Phi_t = Q_t^{1-\xi} / L_t^N$ with respect to time yields

$$\frac{\dot{\Phi}_t}{\Phi_t} = (1 - \xi) \frac{\dot{Q}_t}{Q_t} - \frac{\dot{L}_t^N}{L_t^N} = (1 - \xi)(\kappa - 1) \lambda_t^N - g_L. \quad (40)$$

Since Φ_t is stationary in the steady state, (40) implies that the steady-state arrival rate of innovation is completely determined by the exogenous population growth rate given by

$$\lambda^N = \frac{g_L}{(1 - \xi)(\kappa - 1)}. \quad (41)$$

This feature originates from the insight that the increasing research complexity acts as a counteractive force to growing R&D inputs. As discussed in [Segerstrom \(2000\)](#) and [Dinopoulos and Segerstrom \(2010\)](#), any increase in R&D inputs leading to a higher product quality makes product more complex and harder for researchers to find further improvements. As a consequence, a

growing R&D labor employment is required to maintain a constant innovation rate over time. In the model, R&D labor is only determined by the exogenous population growth rate, which leads the steady-state arrival rate of innovation to be exogenously pinned down.

Furthermore, from (21) and (22), the values of assets for the Northern quality leader and the Southern affiliate in the steady state can be expressed as

$$v_t^N(j) = \frac{\pi_t^N(j)}{\rho + \lambda^N}, \quad (42)$$

$$v_t^S(j) = \frac{\pi_t^S(j)}{\rho + \lambda^N}. \quad (43)$$

Substituting (15) and (42) into (18) yields the following *steady-state innovative R&D condition*:

$$\left(\mu^N - 1\right) \frac{\bar{L}_{x,t}^N}{Q_t^{1-\xi}} = \beta(\rho + \lambda^N). \quad (44)$$

Similarly, substituting (15), (16), (42) and (43) into (20) yields the following *steady-state adaptive R&D condition*:

$$\left(\mu^S - 1\right) \frac{\bar{L}_{x,t}^S}{Q_t^{1-\xi}} - \omega \left(\mu^N - 1\right) \frac{\bar{L}_{x,t}^N}{Q_t^{1-\xi}} = \gamma(\rho + \lambda^N), \quad (45)$$

where $\omega = w_t^N/w_t^S$ is the steady-state relative wage, which will be shown to be a function of the patent instruments $\{\mu^N, \mu^S\}$ in the next section.

Next, substituting (44) into (34) yields the *Northern steady-state condition* such that

$$1 = \beta\lambda^N\Phi \left\{ \frac{\kappa(\rho + \lambda^N)}{(\mu^N - 1)(\kappa\lambda^N + \lambda^S)} + 1 \right\}, \quad (46)$$

which contains two endogenous variables $\{\Phi, \lambda^S\}$ and features a positive slope and a positive Φ -intercept in the $\{\Phi, \lambda^S\}$ space as shown in Figure 1, where "North" represents the Northern steady-state condition. The intuition behind the positive slope of the Northern steady-state condition can be explained as follows. At each instant of time, an increase in λ^S implies that more products are manufactured in the South but less in the North, which in turn leads to a reallocation of labor in the North from production to innovative R&D due to the resource constraint on Northern labor. Thus, the increase in Northern R&D labor raises the average quality per Northern worker (i.e., Φ) in the steady state.

Then, substituting (44) into (38), together with (45), yields the *Southern steady-state condition* such that

$$1 = \frac{\Phi\lambda^S(1-\alpha)}{\alpha(\kappa\lambda^N + \lambda^S)} \left\{ \frac{(\rho + \lambda^N) [\gamma + \beta\omega(\mu^N, \mu^S)]}{\mu^S - 1} + \gamma\kappa\lambda^N \right\}, \quad (47)$$

where the relation $L_t^N/L_t^S = (1-\alpha)/\alpha$ is used. This condition also contains two endogenous variables $\{\Phi, \lambda^S\}$ but features a negative slope, with no intercepts, in the $\{\Phi, \lambda^S\}$ space in Figure 1, where "South" represents the Southern steady-state condition. Intuitively, at each instant of time, an increase in λ^S implies that more products are manufactured in the South, which in turn

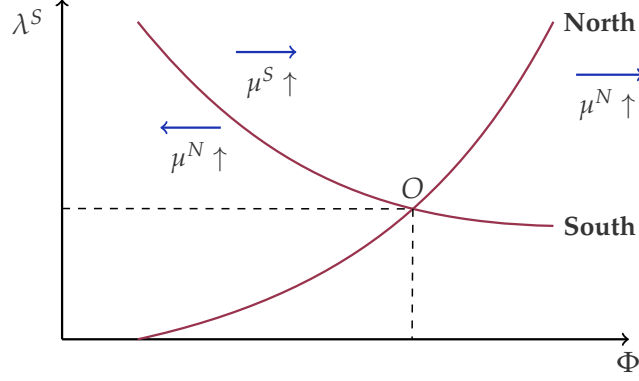


Figure 1: The steady-state equilibrium.

reallocates labor in the South from adaptive R&D to production due to the resource constraint on Southern labor. Therefore, according to (37) that specifies the level of adaptive R&D labor (i.e., $L_r^S = \gamma \kappa L_t^N \Phi \lambda^N \lambda^S / (\kappa \lambda^N + \lambda^S)$), a higher λ^S can be consistent with a smaller L_r^S only when the difficulty level $\Phi = Q^{1-\xi} / L^N$ decreases sufficiently (i.e., technologies become sufficiently easy to be transferred to the South). Summing up, (46) and (47) are the two conditions that implicitly solve for the steady-state values of $\{\Phi, \lambda^S\}$. The intersection at point O in Figure 1 determines the unique steady-state values for Φ and λ^S .

3.5 Social welfare

In this section, we derive the steady-state social welfare in each country.²³ Imposing balanced growth on (1) yields the steady-state welfare of the Northern household given by

$$U^N = \frac{1}{\rho - g_L} \left(\ln c_0^N + \frac{g}{\rho - g_L} \right), \quad (48)$$

where $g = g_L / [(1 - \xi)(\sigma - 1)]$ is the growth rate of consumption (as well as final goods) per capita, which depends on exogenous parameters due to the semi-endogenous growth property. Therefore, the steady-state level of welfare is determined by the balanced-growth level of consumption. According to (2), using balanced growth condition $\dot{a}_t^N / a_t^N = g$ yields

$$c_t^N = (\rho - g_L) a_t^N + w_t^N. \quad (49)$$

The balanced-growth level of consumption c_0^N is thus a sum of asset income $(\rho - g_L) a_0^N$ and wage income w_0^N . Similar conditions also apply to the Southern case. To explicitly derive a_0^N and a_0^S , we follow [Dinopoulos and Segerstrom \(2010\)](#) to assume that the asset from innovative R&D in the North is owned by the Northern household whereas the asset from adaptive R&D in the South is owned by the Southern household. Under this assumption, we show in Lemma 2 that

²³A more complete welfare analysis should take into account the dynamic transition of the household's utility from the initial steady state to the final one. However, such an analysis is much more challenging both analytically and numerically in this class of models. Therefore, the welfare analysis in this study follows the usual treatment in the literature to focus on steady-state welfare. See, for example, [Acemoglu and Akcigit \(2012\)](#) and [Chu et al. \(2019\)](#).

the balanced-growth levels of consumption $\{c_0^N, c_0^S\}$ can be expressed as a function of $\{w_0^N, w_0^S\}$, as similar to [Chu et al. \(2019\)](#).

Lemma 2. *The balanced-growth level of consumption can be expressed as*

$$c_0^N = \underbrace{\beta(\rho - g_L)\Phi w_0^N}_{\text{asset income}} + \underbrace{w_0^N}_{\text{wage income}} = w_0^N I^N, \quad (50)$$

$$c_0^S = \underbrace{\gamma(\rho - g_L) \frac{\lambda^S \Phi (1 - \alpha)}{\alpha(\kappa \lambda^N + \lambda^S)} w_0^S}_{\text{asset income}} + \underbrace{w_0^S}_{\text{wage income}} = w_0^S I^S, \quad (51)$$

$$w_0^S = \left(\Phi L_0^N \right)^{\frac{1}{(1-\xi)(\sigma-1)}} \left\{ \underbrace{\left(\mu^N \omega \right)^{1-\sigma} \frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S}}_{\text{quality leaders}} + \underbrace{\left(\frac{\mu^S}{\delta} \right)^{1-\sigma} \frac{\lambda^S}{\kappa \lambda^N + \lambda^S}}_{\text{foreign affiliates}} \right\}^{\frac{1}{\sigma-1}}, \quad (52)$$

where $\{I^N, I^S\}$ denote the consumption-wage ratio in the North and the South.

Proof. See [Appendix A.2](#). □

Due to the complexity of the analytical welfare analysis, we perform a quantitative analysis to examine the effects of both Southern and Northern IPR protection on steady-state welfare in [Section 5](#).

4 Patent policy, innovation, and technology transfer

In this section, we explore the effects of Southern and Northern patent policy $\{\mu^S, \mu^N\}$ on the innovation rate λ^N and the technology transfer rate λ^S , respectively. Before doing so, we examine the effects of these patent-policy tools on the relative wage ω . From [\(12\)](#) and [\(13\)](#), we obtain

$$\frac{\bar{L}_{x,t}^S}{Q_t} = \frac{1}{\delta} \left(\frac{\delta \mu^N \omega}{\mu^S} \right)^\sigma \frac{\bar{L}_{x,t}^N}{Q_t}. \quad (53)$$

Dividing [\(44\)](#) by [\(45\)](#) and making use of [\(53\)](#) yield the following *steady-state relative-wage condition*:

$$\frac{\gamma}{\beta \omega^\sigma} + \omega^{1-\sigma} = \delta^{\sigma-1} \left(\frac{\mu^N}{\mu^S} \right)^\sigma \frac{\mu^S - 1}{\mu^N - 1}, \quad (54)$$

which is an implicit function that pins down the steady-state equilibrium value of the relative wage $\omega(\mu^N, \mu^S)$. The following proposition shows the effects of patent policy in each country on the relative wage.

Proposition 1. *Strengthening patent protection in the South lowers the relative wage rate between the North and the South, whereas strengthening patent protection in the North raises the relative wage rate.*

Proof. See [Appendix A.3](#). □

Proposition 1 can be explained as follows. As shown in (16), strengthening Southern patent protection grants a larger market power to Southern affiliates by allowing them to charge a higher markup. Given the wage rates, this raises the benefits of being Southern affiliates, which increases the incentives for conducting adaptive R&D. Thus, the value of Southern firms $v_t^S(j)$ as indicated in (43) (relative to the value of Northern firms as indicated in (42)) tends to rise. Then, the zero-profit condition for adaptive R&D in (20) implies that the increase in the reward for adaptive R&D must correspondingly cause an increase in the R&D cost. This yields a positive effect on the demand for Southern R&D labor. Consequently, strengthening Southern patent protection raises the wage rate in the South relative to the North.

By contrast, given the wage rates, strengthening Northern patent protection raises the benefits of remaining as a Northern quality leader through a higher markup. This decreases the incentives for adaptive R&D, and the firm value $v_t^S(j)$ as shown in (43) (relative to the value of Northern firms as shown in (42)) tends to decline. According to the zero-profit condition for adaptive R&D in (20), a decrease in the reward for adaptive R&D corresponds to a decrease in the R&D cost, yielding a negative effect on the demand for Southern R&D labor. Therefore, strengthening Northern patent protection reduces the wage rate in the South relative to the North.

Having established the effects of Southern and Northern patent policy $\{\mu^S, \mu^N\}$ on the relative wage rate ω , we are now in position to explore their effects on the rate of innovation λ^N and the rate of international technology transfer λ^S . First, the following proposition illustrates the results regarding the impacts of an increase in μ^S on λ^N and λ^S .

Proposition 2. *Strengthening patent protection in the South yields (i) a temporary higher rate of innovation in the North, and (ii) a higher rate of technology transfer from the North to the South.*

Proof. See Appendix A.4. □

Proposition 2 can be explained as follows. Graphically, a higher μ^S shifts the South curve to the right in Figure 1, whereas this change in μ^S does not affect the North curve, leading to a rise in both Φ and λ^S . Intuitively, a rise in μ^S increases the profit margin of the Southern affiliate in (16). This makes it more attractive for firms to engage in adaptive R&D in the South by changing the relative asset values. To see this, combining (18) and (20), and substituting (54) into the resulting equation yield

$$\frac{v_t^S(j)}{v_t^N(j)} = \frac{\pi_t^S(j)}{\pi_t^N(j)} = \left(\frac{\gamma}{\beta}\right) \frac{1}{\omega(\mu^N, \mu^S)} + 1, \quad (55)$$

where (42) and (43) are used in the first equality, and (15), (16) and (54) are used in the second equality. Recall that a higher μ^S decreases the relative wage rate ω ; therefore, it also increases $v_t^S(j)/v_t^N(j)$. In this case, more adaptive R&D will be performed, so a higher μ^S yields a positive effect on the rate of international technology transfer λ^S . Moreover, the higher rate of technology transfer to the South implies a smaller number of products being manufactured in the North. The lower demand for Northern production labor causes a reallocation of labor in the North from manufacturing to innovative R&D. As a consequence, the rate of Northern innovation λ^N increases in the short run, which is associated with a higher average quality per Northern worker Φ in the long run, as implied by (40).

Next, the following proposition illustrates the results regarding the impacts of an increase in μ^N on λ^N and λ^S .

Proposition 3. *Strengthening patent protection in the North yields (i) a temporary higher (lower) rate of innovation in the North if the North-South ratio of labor force is sufficiently large (small), and (ii) a lower rate of technology transfer from the North to the South.*

Proof. See Appendix A.5. □

Proposition 3 can be explained as follows. Figure 1 shows that a higher μ^N shifts the North curve to the right whereas it shifts the South curve to the left, resulting in an unambiguously decreasing effect on λ^S and an ambiguous effect on Φ .²⁴ Intuitively, as for the impact on λ^S , a higher μ^N increases the profit margin of the Northern quality leaders through allowing for a higher markup in (15). This increases the innovative R&D firm value relative to the adaptive R&D firm value (i.e., $v_t^S(j)/v_t^N(j)$ declines), as explained in Proposition 2.²⁵ In other words, conducting adaptive R&D becomes less attractive. Thus, less international technology transfer occurs (i.e., a lower λ^S) under a stronger degree of Northern patent protection (i.e., a higher μ^N).

As for the effect on Φ , one can see from (15) that, a strengthening of Northern patent protection μ^N causes two contrasting effects as follows. On the one hand, as aforementioned, a larger μ^N increases the profit margin of Northern quality leaders, which increases the incentives for innovative R&D. This tends to reallocate labor from production to R&D in the North. On the other hand, a larger μ^N decreases the technology transfer rate λ^S (according to Proposition 3 (ii)), which implies that more products will be manufactured in the North. This tends to reallocate labor from R&D to production in the North. Accordingly, whether a larger Northern patent breadth μ^N increases the average quality per Northern worker Φ in the long run depends on the interplay between the positive effect of μ^N on Northern R&D labor through markup and the negative effect through product manufacturing.

We find that this interplay is determined by the relative labor force between the North and the South, i.e., $(1 - \alpha)/\alpha$. To see this, we use $\lambda_t^S(j) = \lambda_t^S$ and (37) to derive

$$\lambda_t^S = \frac{L_{r,t}^S}{\gamma Q_t^N} = \frac{1}{\gamma \Phi} \frac{L_{r,t}^S}{(1 - \alpha)L_t} \frac{Q_t}{Q_t^N}, \quad (56)$$

where the second equality uses $\Phi = Q_t/L_t^N$ and $L_t^N = (1 - \alpha)L_t$. In the steady state, Q_t^N/Q_t is given by (29), and hence, (56) can be reexpressed as

$$\Phi = \frac{1}{\gamma} \underbrace{\frac{\kappa \lambda^N + \lambda^S(\mu^N)}{\kappa \lambda^N \lambda^S(\mu^N)}}_A \underbrace{\frac{L_{r,t}^S}{(1 - \alpha)L_t}}_B, \quad (57)$$

where the term A is decreasing in λ^S . Consider that λ^S is a function of μ^N in the steady-state equilibrium. In this case, the term A captures the positive effect of μ^N on Φ by increasing the

²⁴Precisely, if an increase in μ^N shifts the North curve to the right in a larger (smaller) magnitude than the South curve to the left, then an increase (decrease) in Φ emerges in response.

²⁵Similarly, combining (18) and (20) yields $v_t^S(j)/v_t^N(j) = (\gamma/\beta)/\omega(\mu^N, \mu^S) + 1$, which shows that $v_t^S(j)/v_t^N(j)$ is decreasing in μ^N .

Northern quality leaders' profit margin, given that an increase in μ^N decreases λ^S and increases A and Φ . Nevertheless, the term B captures the negative effect of μ^N on Φ by increasing the Northern labor demand in product manufacturing, given that an increase in μ^N decreases $L_{r,t}^S$, and thus B and Φ .

Therefore, one can see that, when the Southern labor force relative to the Northern counterpart (i.e., $\alpha/(1-\alpha)$) is sufficiently small, the decrease in the number of products manufactured by Southern affiliates is not significant, implying a small increase in the Northern manufacturing operations. Hence, the negative effect B via products manufacturing becomes relatively weak to be dominated by the positive effect A via markup, causing a reallocation of labor in the North from manufacturing to innovative R&D. As a result, the rate of Northern innovation λ^N increases in the short run, and the average quality per Northern worker Φ increases in the long run, as implied by (40). By contrast, when the Southern labor force relative to the Northern counterpart (i.e., $\alpha/(1-\alpha)$) is sufficiently large, the decrease in the number of products manufactured by Southern affiliates is significant. In the case of a large increase in the Northern manufacturing operations, the negative effect B through product manufacturing becomes relatively strong to dominate the positive effect A through markup. Consequently, the resulting mechanism reverses; the rate of Northern innovation λ^N decreases in the short run, and the average quality per Northern worker Φ decreases in the long run.

5 Quantitative analysis

In this section, we calibrate our model to numerically evaluate the effects of the Northern and Southern patent instruments, respectively. Specifically, we consider China as the South and the US as the North to explore the welfare implications of patent protection in each country. To do so, we first describe the calibration strategy in Section 5.1. Section 5.2 then provides the benchmark quantitative results, and Section 5.3 shows the results of robustness checks by altering the values of some parameters and empirical moments.

5.1 Calibration

To perform this numerical analysis, the strategy is to assign steady-state values to the following structural parameters $\{\rho, \sigma, \alpha, \mu^N, \mu^S, \delta, \kappa, \beta, \gamma, z, \xi\}$. We follow [Acemoglu and Akcigit \(2012\)](#) to choose a value of 0.05 for the discount rate ρ . Moreover, we follow [Acemoglu et al. \(2018\)](#) to set the elasticity of substitution σ to 2.9 for capturing the empirical estimate of [Broda and Weinstein \(2006\)](#). Using the data from the World Development Indicators on the labor force sizes of the US and China, the parameter α is set to 0.829 to be consistent with the relative labor force.²⁶ As for the market-level values of the Northern patent instrument μ^N and the Southern instrument μ^S , we choose $\mu^N = 1.3$ according to the estimates of average markup ratio for the US in [Christopoulou and Vermeulen \(2012\)](#) and $\mu^S = 1.25$ according to the estimates for China in [Lu and Yu \(2015\)](#).²⁷ As for the North-South relative wage rate ω , it is about 20.101 from 2002 to 2013

²⁶The data is available at <http://wdi.worldbank.org/tables>, Table 2.2, Labor Force Structure.

²⁷Using the data from the Annual Survey of Industrial Production (ASIP), [Lu and Yu \(2015\)](#) show that the average markup of most Chinese two-digit manufacturing industries is approximately between 1 and 1.3, and we choose a value of 1.25 within this range.

according to the data from the Conference Board on manufacturing hourly compensation costs between the US and China.²⁸ Then, we choose a value of $\delta = 0.0625$ to ensure that Assumptions 1 and 2 are satisfied given the parameter values chosen above.

As for κ , γ , and β , given that it is the relative R&D productivity γ/β (rather than their individual values) that determines the values of variables in equilibrium, we then only need to calibrate κ and γ/β by using (i) the growth rate of labor force; (ii) the arrival rate of innovation; and (iii) the relative R&D intensity between the US and China.²⁹ For g_L , we follow Jones and Williams (2000) to set it to 1.44% to correspond to the long-run growth rate of the US labor force. For λ^N , we choose an empirically plausible value of 5% and explore the other values in the robustness analysis.³⁰ For the relative R&D intensity, according to the OECD database, the gross domestic spending on R&D for the US and China is about 2.596% and 1.226% of their respective GDP.³¹ To capture this relative R&D intensity indicator, we construct the corresponding expression such that $[w_0^N L_{r0}^N / (w_0^N L_{r0}^N + c_0^N L_0^N)] / [w_0^S L_{r0}^S / (w_0^S L_{r0}^S + c_0^S L_0^S)] = 2.117$.³² Together with equations (46), (47) and (54), $\{\kappa, \gamma/\beta\}$ and the equilibrium values of $\{\Phi, \lambda^S\}$ are simultaneously solved. Given the calibrated value of κ , equation (41) pins down the externality of intertemporal knowledge spillover ζ , and the definition of $\kappa = z^{\sigma-1}$ determines the value of quality step size z . All above calibrated values are reported in Table 1.

Table 1: Parameter values

ρ	σ	α	μ^N	μ^S	δ	κ	γ/β	z	ξ
0.05	2.9	0.829	1.3	1.25	0.0625	2.609	8.854	1.656	0.821

5.2 Benchmark estimation results

Given the benchmark calibrated parameter values, we now perform the following experiments by enhancing patent protection in China and the US, respectively. We start off by exploring the situation in China. As reported in Table 2, we find that the average quality per Northern worker Φ increases by 0.577% (percent change) in response to a permanent 1% (percent change) rise in the level of patent breadth μ^S in China, implying a temporary higher rate of innovation λ^N in the North according to (40). Moreover, the international technology transfer rate λ^S increases correspondingly by 5.225% (percent change). When expressing the welfare changes as the usual equivalent variation in consumption, we find that a tightening of patent policy in China leads

²⁸The data are included in International Compensations of Hourly Compensation Costs in Manufacturing, 2016 - China and India, Table 4.

²⁹It is the value of $\beta\Phi$, which is independent of β , that affects equilibrium variables in the model. Therefore, we normalize β to unity for simplicity only when reporting the value of Φ .

³⁰Studies in the literature have considered different values for the arrival rate of innovation. For instance, Caballero and Jaffe (2002) estimate the mean rate of creative destruction to be roughly 3.5%, whereas Lanjouw (1998) shows that the probability of obsolescence ranges from 7% to 12%. Thus, we consider an intermediate value of 5% within this range.

³¹The indicator for China is available during the period of 1991-2016. Both indicators for the US and China are available in <https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm>.

³²The subscript of time 0 indicates that the economy is on the initial balanced-growth path before being intervened by changes in patent policy.

to a welfare gain of 2.520% in China. From Lemma 2, we know that the change in c_0^S comes from the changes in w_0^S and I^S . The numerical result shows that as μ^S rises by 1%, w_0^S increases by 2.396%, whereas c_0^S increases by 2.520%. This means that I^S increases marginally by 0.124%, which implies a rise in the household's asset-wage income ratio. Finally, although the rise in μ^S narrows the wage gap ω by 0.900% (percent change), it still raises the wage rate in the US ω_0^N by 1.492%.³³ The increase in ω_0^N in turn causes a welfare gain of 1.546% in the US, but the size is smaller than that in China.

Table 2: Benchmark simulation

	Φ	λ^S	ω	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln c_0^N$	$\Delta \ln c_0^S$
	2.940	0.0194	20.101	-	-	-	-
$\Delta \mu^S$	2.957	0.0204	19.920	1.492%	2.396%	1.546%	2.520%
$\Delta \mu^N$	3.034	0.0186	20.225	8.488%	7.873%	8.792%	7.863%

Furthermore, Table 2 displays that a permanent 1% (percent change) increase in the level of patent breadth μ^N in US raises the average quality per Northern worker Φ by 3.218% (percent change), as the result of the North-South ratio of labor force (i.e., $(1 - \alpha)/\alpha$) is relatively large as shown in Proposition 3.³⁴ In this case, the positive effect of a larger μ^N through price markup outweighs the negative effect via products manufacturing, raising the incentives for Northern innovation. Correspondingly, Φ rises permanently and the innovation rate λ^N in the North rises temporarily. In addition, the rate of technology transfer λ^S decreases by 3.993% (percent change); it is caused in part by a decrease in adaptive R&D because of a lower level of Southern R&D labor, and an reinforcing effect from the increase in Φ also makes the technology transfer from the US to China more difficult. Moreover, the US-China wage gap ω enlarges by 0.617% (percent change), and the wage rates in both countries increase significantly (i.e., 8.488% in the US and 7.873% in China) in response to a larger μ^N . Accordingly, a strengthening of patent protection in the US yields a welfare gain of 8.792% in the US and 7.863% in China, respectively. In contrast to the changes caused by a larger μ^S in China, more welfare gains in the two countries are achieved by stronger patent protection in the US, because of the substantial increases in the wage rates of both countries. Apparently, in the above policy experiments, the domestic country benefits more than the foreign country from a strengthening of its home patent protection.

We also consider the cases in which both countries strengthen their patent protection simultaneously. The first column in Table 3 displays the result for which μ^S increases by 1% and μ^N increases by 1.5% (percent change), indicating a higher relative patent breadth μ^N/μ^S . The second column displays the results for which μ^S increases by 1% and μ^N increases by 0.5% (percent change), indicating a lower relative patent breadth μ^N/μ^S . In the last column, both μ^S and μ^N increase by the same magnitude of 1%. As expected, the rises in the average quality per Northern worker (i.e., Φ), the Northern and Southern wage rates (i.e., $\Delta \omega_0^N$ and $\Delta \omega_0^S$), and the

³³According to International Labour Organization Global Wage Report 2018/19, the increase in the real average wages of emerging G20 economies (by triple) is more significant than the counterpart of advanced G20 economies (by 9%) during 1999-2017.

³⁴According to (A.12), the threshold value Γ in this numerical analysis is 0.0039, which is smaller than the calibrated value of $(1 - \alpha)/\alpha = 0.206$.

Northern and Southern welfare (i.e., Δc_0^N and Δc_0^S) become more significant. In addition, the rate of international technology transfer λ^S increases in the latter two cases. This implies that raising the level of Southern patent protection can still enhance the transfer of technology to the South, despite the counteracting effect of the increase in the level of Northern patent protection to some extent. However, Northern patent protection tends to play a more prominent role than Southern patent protection in affecting the relative wage rate, and therefore ω increases.

Table 3: Simultaneous rises in both countries' IPR

	$\Delta\Phi$	$\Delta\lambda^S$	$\Delta\omega$	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln c_0^N$	$\Delta \ln c_0^S$
$\Delta\mu^S < \Delta\mu^N$	5.385%	-0.930%	0.006%	14.004%	13.997%	14.506%	14.113%
$\Delta\mu^S > \Delta\mu^N$	2.187%	3.077%	0.587%	5.756%	6.344%	5.963%	6.463%
$\Delta\mu^S = \Delta\mu^N$	3.790%	1.026%	0.289%	9.922%	10.211%	10.280%	10.324%

5.3 Robustness check

We now perform two robustness checks on our numerical exercise. Specifically, we first consider alternative values of the innovation-arrival rate and then of the relative R&D intensity.

5.3.1 Innovation-arrival rate

Given the various estimates of the US innovation-arrival rate in the existing literature, such as [Lanjouw \(1998\)](#) and [Caballero and Jaffe \(2002\)](#), in this subsection we consider two alternative values of the innovation-arrival rate $\lambda^N \in \{0.1, 0.15\}$. Having other parameter values remain unchanged as in the benchmark, we perform the same policy experiment by raising μ^S and μ^N by 1%, respectively. Based on the numerical results as displayed in [Table 4](#), it can be seen that a higher long-run innovation arrival rate λ^N tends to mitigate the effects of both the Southern patent instrument μ^S and the Northern patent instrument μ^N on all economic variables, except the relative wage ω . For example, in the case of $\lambda^N = 0.1$, raising the degree of IPR in China causes a smaller increase in the average quality per US worker Φ (i.e., 0.544%) and the rate of international technology transfer λ^S (i.e., 5.095%), as compared to the benchmark case (i.e., 0.577% and 5.225%, respectively). Similar patterns of the results are found when raising the degree of IPR in the US, that is, a rise of 3.072% in the average quality per US worker Φ and a decline of 3.834% in the international technology transfer rate λ^S , as compared to 3.218% and 3.993%, respectively, in the benchmark. As for the welfare effects, a strengthening of IPR protection in either country leads to less welfare gains in contrast to the benchmark. However, despite of these small changes in the magnitudes of each economic variable, the overall pattern of the cross-country effects of IPR policy is consistent with the benchmark case. In other words, strengthening IPR in a country yields to itself (than the foreign country) a larger welfare improvement.

5.3.2 R&D intensity

To conduct this robustness check, we consider two scenarios. First, as argued in [Comin \(2004\)](#), the data on R&D expenditure reported by US firms are likely to underestimate the resources

Table 4: Simulation under $\lambda^N \in \{0.1, 0.15\}$

	$\Delta\Phi$	$\Delta\lambda^S$	$\Delta\omega$	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln c_0^N$	$\Delta \ln c_0^S$
$\lambda^N = 0.1$							
$\Delta\mu^S$	0.544%	5.095%	-0.899%	1.389%	2.293%	1.423%	2.372%
$\Delta\mu^N$	3.072%	-3.834%	0.617%	8.079%	7.465%	8.271%	7.459%
$\lambda^N = 0.15$							
$\Delta\mu^S$	0.529%	5.032%	-0.899%	1.341%	2.245%	1.365%	2.303%
$\Delta\mu^N$	3.000%	-3.759%	0.617%	7.889%	7.274%	8.029%	7.270%

devoted to innovation-related activities.³⁵ Thus, we use the data from the most recent Science and Engineering Indicators 2018 to consider a higher measure for the US R&D intensity in 2015 at the value of 3.9%.³⁶ With the R&D intensity in China unchanged, we reexamine the quantitative results under a larger US-China relative R&D intensity, which is 3.181 now. Then, preserving the other parameter values as in the benchmark, we report in Table 5 the re-calibrated values and the new quantitative results.³⁷ Given that the relative productivity of the Southern manufacturing labor to the Northern one becomes lower (i.e., a lower δ) and that the relative productivity of adaptive R&D to innovative R&D becomes higher (i.e., a lower γ/β), increasing Southern patent breadth μ^S by 1% yields a larger increase in the average quality per US worker Φ (i.e., 0.705% versus 0.577% in the benchmark) and in the international technology transfer rate λ^S (i.e., 5.563% versus 5.225% in the benchmark). In contrast, increasing Northern patent breadth μ^N by 1% leads to a smaller increase in Φ (i.e., 3.127% versus 3.218% in the benchmark) and a larger decrease in λ^S (i.e., -4.079% versus -3.993% in the benchmark). As compared to the benchmark case, a smaller size in the wage increase and the welfare gain is observed when enhancing IPR protection in both countries. Nevertheless, again, the overall pattern of the cross-country effects of IPR policy still holds as in the benchmark estimation.

Table 5: Simulation under a larger relative R&D intensity.

δ	κ	γ/β	z	ξ	Φ	λ^S	ω
0.0585	2.298	5.434	1.549	0.778	2.998	0.0202	20.101
	$\Delta\Phi$	$\Delta\lambda^S$	$\Delta\omega$	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln c_0^N$	$\Delta \ln c_0^S$
$\Delta\mu^S$	0.705%	5.563%	-0.940%	1.417%	2.362%	1.485%	2.457%
$\Delta\mu^N$	3.127%	-4.079%	0.642%	6.512%	5.872%	6.813%	5.864%

Second, when considering the fact that the R&D expenditure share of GDP in China has increased sharply from 0.639% in 1997 to 2.108% in 2016 whereas the US counterpart remains roughly constant according to OECD data, it is reasonable to redo the numerical exercise under a lower US-China relative R&D intensity. Thus, we consider an alternative case by using the data for the period 1997-2016 during which the relative R&D intensity between the US and China is

³⁵See Jones (2016) for a detailed discussion.

³⁶See details in <https://www.nsf.gov/statistics/2018/nsb20181/report>, Table 4-10.

³⁷The value of δ is adjusted to ensure that both Assumptions 1 and 2 hold.

1.886. The re-calibrated parameters and equilibrium variables under this value of relative R&D intensity are reported in Table 6.³⁸ Differing from the case under a larger relative R&D intensity, a higher value of δ and of γ/β causes a tightening of Southern patent protection μ^S by 1% to yield a smaller increase in the average quality per US worker Φ (i.e., 0.526% versus 0.577% in the benchmark) and in the international technology transfer rate λ^S (i.e., 5.090% versus 5.225% in the benchmark). Additionally, this set of parameter values causes a tightening of Northern patent policy μ^N by 1% to yield a larger increase in Φ (i.e., 3.248% versus 3.218% in the benchmark) and a larger decrease in λ^S as well (i.e., -4.033% versus -3.993% in the benchmark). Finally, although the welfare effects of strengthening IPR protection in this case become larger, the pattern that the domestic country benefits more from strengthening its home IPR protection continues to hold.

Table 6: Simulation under a smaller relative R&D intensity.

δ	κ	γ/β	z	ζ	Φ	λ^S	ω
0.0644	2.685	10.639	1.682	0.829	2.916	0.0185	20.101
	$\Delta\Phi$	$\Delta\lambda^S$	$\Delta\omega$	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln c_0^N$	$\Delta \ln c_0^S$
$\Delta\mu^S$	0.526%	5.090%	-0.886%	1.437%	2.327%	1.487%	2.082%
$\Delta\mu^N$	3.248%	-4.033%	0.736%	9.016%	8.282%	9.321%	8.271%

6 Conclusion

In this study, we analyze the cross-country effects of IPR protection on the relative wage, innovation, and technology transfer in an open-economy Schumpeterian growth model with North-South product cycles. The IPR regime takes patent breadth as the policy instrument in both countries to capture the impacts of market power on R&D incentives of Northern and Southern firms. We find that broadening patent breadth in the South leads to a permanent decrease in the North-South wage gap, a temporary increase in the Northern innovation rate, and a permanent increase in technology transfer. Nevertheless, broadening patent breadth in the North leads to a permanent increase in the North-South wage gap, ambiguous effects on the Northern innovation rate, and a permanent decrease in technology transfer. In particular, the relative labor force between the economies plays a critical role in disambiguating the effect of Northern patent protection on innovation. By calibrating the model to the China-US data, we perform a quantitative analysis and the results are consistent with the above policy implications. In addition, our numerical analysis shows that the effect of tightening patent protection in either country is significantly welfare-improving, but the policy change in the US generates larger effects on the global economy than that in China. Furthermore, when home IPR protection is strengthened, the domestic country receives more welfare gains than the foreign country. Therefore, the welfare analysis of this study presents an example that sheds some light on the justification for (both developed and developing) countries to make the upgrading of their IPR, following the agreement on TRIPS.

³⁸Again, the value of δ is adjusted to guarantee that both Assumptions 1 and 2 hold.

There are two potential dimensions to extend the present paper. First, the effects of patent breadth on innovation and technology transfer could be investigated in a framework with different modes of international technology transfer that abstract from FDI, such as licensing in [Yang and Maskus \(2001\)](#) and [Tanaka *et al.* \(2007\)](#) and imitation in [Gustafsson and Segerstrom \(2010\)](#) and [Lorenzlik and Newiak \(2012\)](#). Second, the current model explores the effects of patent breadth based on a growth-theoretic framework in which there is free entry to innovative R&D activities and all firms have access to the same technology. To characterize the important properties of the innovation process, these effects could be reexamined in a framework in which industry leaders are sufficiently more productive in innovative R&D than follower firms so that all innovating R&D is done by industry leaders, as in [Glass and Saggi \(2002\)](#) and [Glass and Wu \(2007\)](#). These crucial issues can represent interesting directions for future research.

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Appendix A : Proofs of propositions and lemmas

A.1 Proof of Lemma 1

We follow [Dinopoulos and Segerstrom \(2010\)](#) to provide the proof. The dynamics of the quality index for Q_t^N and Q_t^S are, respectively, given by

$$\begin{aligned}\dot{Q}_t^N &= \int_{\theta_t^N} [\kappa^{n_t(j)+1} - \kappa^{n_t(j)}] \lambda_t^N dj + \int_{\theta_t^S} \kappa^{n_t(j)+1} \lambda_t^N dj - \int_{\theta_t^N} \kappa^{n_t(j)} \lambda_t^S dj \\ &= (\kappa - 1) \lambda_t^N Q_t^N + \kappa \lambda_t^N Q_t^S - \lambda_t^S Q_t^N,\end{aligned}\tag{A.1}$$

and

$$\dot{Q}_t^S = \int_{\theta_t^N} \kappa^{n_t(j)} \lambda_t^S dj - \int_{\theta_t^S} \kappa^{n_t(j)} \lambda_t^N dj = \lambda_t^S Q_t^N - \lambda_t^N Q_t^S.\tag{A.2}$$

Since the industry composition is stationary over time in the steady state, the growth rate of the average quality in the North and the counterpart in the South must be equal to each other and they are constant over time. Therefore, we have

$$\frac{\dot{Q}_t^N}{Q_t^N} = \frac{\dot{Q}_t^S}{Q_t^S}.\tag{A.3}$$

Substituting (A.1) and (A.2) into (A.3), together with $Q_t = Q_t^N + Q_t^S$, yields (29) and (30).

A.2 Proof of Lemma 2

Following [Dinopoulos and Segerstrom \(2010\)](#), we assume that the Northern household finances innovative R&D in equilibrium such that $A_t^N = a_t^N L_t^N = \int_{\theta_t^N + \theta_t^S} v_t^N(j) dj = \int_0^1 v_t^N(j) dj = \beta w_t^N Q_t^{-\xi} \int_0^1 q_t(j) dj = \beta w_t^N Q_t^{1-\xi}$, where the third equality is obtained by using (18). Hence, we have

$$a_t^N = \beta w_t^N \frac{Q_t^{1-\xi}}{L_t^N} = \beta w_t^N \Phi.\tag{A.4}$$

Using (49) and (A.4), we can derive c_0^N as shown in Lemma 2.

Moreover, we assume that the Southern household finances adaptive R&D and receives dividends equal to the difference between the foreign affiliate profits and the Northern quality-leader profits. Thus, in equilibrium, the total value of Southern assets is given by $A_t^S = a_t^S L_t^S$, where

$$A_t^S = \int_{\theta_t^S} [v_t^S(j) - v_t^N(j)] dj = \int_{\theta_t^S} \gamma w_t^S q_t(j) Q_t^{-\xi} dj = \gamma w_t^S Q_t^S Q_t^{-\xi},\tag{A.5}$$

where the second equality uses (20) and the last equality applies the definition of Q_t^N in (28). Thus, we obtain

$$a_t^S = \gamma w_t^S \frac{Q_t^S}{Q_t} \frac{Q_t^{1-\xi}}{L_t^N} \frac{L_t^N}{L_t^S} = \gamma w_t^S \frac{\lambda^S \Phi (1 - \alpha)}{\alpha (\kappa \lambda^N + \lambda^S)},\tag{A.6}$$

where Q_t^S/Q_t stems from Lemma 1. Using the relation $c_t^S = w_t^S + (\rho - g_L) a_t^S$, we obtain c_0^S as

shown in Lemma 2.

Finally, the expression of w_0^S is obtained by substituting (9) and (10) into the aggregate price index such that

$$\begin{aligned}
& \left\{ \int_0^1 [p_t(j)]^{1-\sigma} dj \right\}^{\frac{1}{1-\sigma}} = 1 \\
& \Leftrightarrow \left\{ \int_{\theta_t^N} \left[\frac{\mu^N w_t^N}{z^{n_t(j)}} \right]^{1-\sigma} dj + \int_{\theta_t^S} \left[\frac{\mu^S w_t^S}{\delta z^{n_t(j)}} \right]^{1-\sigma} dj \right\}^{\frac{1}{1-\sigma}} = 1 \\
& \Leftrightarrow w_t^S \left\{ (\mu^N \omega)^{1-\sigma} Q_t^N + \left(\frac{\mu^S}{\delta} \right)^{1-\sigma} Q_t^S \right\}^{\frac{1}{1-\sigma}} = 1 \\
& \Leftrightarrow w_t^S = Q_t^{\frac{1}{\sigma-1}} \left\{ (\mu^N \omega)^{1-\sigma} \frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S} + \left(\frac{\mu^S}{\delta} \right)^{1-\sigma} \frac{\lambda^S}{\kappa \lambda^N + \lambda^S} \right\}^{\frac{1}{\sigma-1}},
\end{aligned} \tag{A.7}$$

where we have used the definitions of Q_t^N and Q_t^S in (28), and Q_t^N/Q_t and Q_t^S/Q_t from Lemma 1. Then, using $Q_0 = (\Phi L_0^N)^{1/(1-\xi)}$ yields w_0^S as shown in Lemma 2.

A.3 Proof of Proposition 1

First, we examine the effect of μ^S on ω . Define the RHS of (54) as

$$f(\mu^N, \mu^S) \equiv \delta^{\sigma-1} \left(\frac{\mu^N}{\mu^S} \right)^\sigma \frac{\mu^S - 1}{\mu^N - 1}.$$

Differentiating $f(\mu^N, \mu^S)$ with respect to μ^S yields

$$\frac{\partial f(\mu^S, \mu^N)}{\partial \mu^S} > 0 \Leftrightarrow \underbrace{\delta^{\sigma-1} \frac{(\mu^N)^\sigma}{(\mu^N - 1)(\mu^S)^{\sigma+1}}}_{>0} [\mu^S - \sigma(\mu^S - 1)] > 0, \tag{A.8}$$

because $\mu^S < \sigma/(\sigma - 1)$. Given the LHS of (54) is a decreasing function of ω , an increase in μ^S that raises $f(\mu^N, \mu^S)$ leads to a lower ω .

Next, we examine the effect of μ^N on ω . Similarly, differentiating $f(\mu^N, \mu^S)$ with respect to μ^N yields

$$\frac{\partial f(\mu^S, \mu^N)}{\partial \mu^N} < 0 \Leftrightarrow \underbrace{\delta^{\sigma-1} \frac{(\mu^S - 1)(\mu^N)^{\sigma-1}}{(\mu^S)^\sigma}}_{>0} \frac{[\sigma(\mu^N - 1) - \mu^N]}{(\mu^N - 1)^2} < 0, \tag{A.9}$$

because $\mu^N < \sigma/(\sigma - 1)$. Again, given that the LHS of (54) is a decreasing function of ω , a decrease in μ^N that reduces $f(\mu^N, \mu^S)$ leads to a higher ω .

A.4 Proof of Proposition 2

Given the result in Proposition 1 such that $\omega(\mu^N, \mu^S)$ is decreasing in μ^S , it is easy to show graphically, according to Figure 1, that a rise in μ^S shifts the Southern steady-state R&D curve (47) to the right, whereas it has no impact on the Northern steady-state R&D curve (46). Thus, both Φ and λ^S increase in response. According to (40), a permanent higher Φ must be associated with a temporary increase in the innovation rate λ^N above its steady-state level $\lambda^N = g_L/(\sigma - 1)$. This completes the proof for Proposition 2.

A.5 Proof of Proposition 3

First, according to (46) and (47), we can show graphically in Figure 1 that an increase in μ^N shifts the North curve to the left and the South curve to the right, leading to an unambiguously negative effect on λ^S . This completes the proof for (ii).

As for (i), rewriting λ^S from (46) to

$$\lambda^S = \frac{\beta\kappa\lambda^N\Phi(\rho + \lambda^N)}{(\mu^N - 1)(1 - \beta\lambda^N\Phi)} - \kappa\lambda^N, \quad (\text{A.10})$$

and substituting it into (47) to solve for Φ yields

$$\Phi = \frac{1}{\rho + \lambda^N\mu^N} \left[\frac{\alpha(\rho + \lambda^N)}{(1 - \alpha)\chi_1} + \frac{\mu^N - 1}{\beta} \right], \quad (\text{A.11})$$

where

$$\chi_1 = \frac{(\rho + \lambda^N)(\gamma + \beta\omega)}{\mu^S - 1} + \gamma\kappa\lambda^N.$$

Differentiating Φ with respect to μ^N yields

$$\begin{aligned} & \frac{\partial\Phi}{\partial\mu^N} \geq 0 \\ \Leftrightarrow & \frac{-\lambda^N}{(\rho + \lambda^N\mu^N)^2} \left\{ \frac{\alpha(\rho + \lambda^N)}{(1 - \alpha)\chi_1} + \frac{\mu^N - 1}{\beta} \right\} + \frac{1}{\rho + \lambda^N\mu^N} \left\{ -\frac{\alpha(\rho + \lambda^N)}{(1 - \alpha)\chi_1^2} \frac{\beta(\rho + \lambda^N)}{\mu^S - 1} \frac{\partial\omega}{\partial\mu^N} + \frac{1}{\beta} \right\} \geq 0 \\ \Leftrightarrow & -\lambda^N \left\{ \frac{\alpha(\rho + \lambda^N)}{(1 - \alpha)\chi_1} + \frac{\mu^N - 1}{\beta} \right\} + (\rho + \lambda^N\mu^N) \left\{ \frac{1}{\beta} - \frac{\alpha(\rho + \lambda^N)}{(1 - \alpha)\chi_1^2} \frac{\beta(\rho + \lambda^N)}{\mu^S - 1} \frac{\partial\omega}{\partial\mu^N} \right\} \geq 0 \\ \Leftrightarrow & -\frac{\alpha\lambda^N}{(1 - \alpha)\chi_1} + \frac{1}{\beta} - \frac{\alpha\beta(\rho + \lambda^N)(\rho + \lambda^N\mu^N)}{(1 - \alpha)(\mu^S - 1)\chi_1^2} \frac{\partial\omega}{\partial\mu^N} \geq 0 \\ \Leftrightarrow & \frac{1 - \alpha}{\alpha} \geq \frac{\beta^2(\rho + \lambda^N)(\rho + \lambda^N\mu^N)}{(\mu^S - 1)\chi_1^2} \frac{\partial\omega}{\partial\mu^N} + \frac{\beta\lambda^N}{\chi_1}, \end{aligned} \quad (\text{A.12})$$

where we have divided both sides of the third inequality to obtain the fourth inequality. Denote by Γ the expression in the RHS of the last inequality. Thus, when $(1 - \alpha)/\alpha > \Gamma$ (namely $(1 - \alpha)/\alpha$ is sufficiently large), or equivalently $\alpha < \bar{\alpha}$, a rise in μ^N increases Φ permanently, leading to a temporary higher rate of innovation λ^N according to (40); otherwise, when $(1 - \alpha)/\alpha < \Gamma$

(namely $(1 - \alpha)/\alpha$ is sufficiently small), implying $\alpha > \bar{\alpha}$, a rise in μ^N decreases Φ permanently, leading to a temporary lower rate of λ^N . This completes the proof for (i).

Appendix B : Alternative specification on R&D

To examine the robustness of our results in the baseline model, in this section we consider an alternative R&D specification that features fully endogenous growth in the long run. The main difference in this version of model is the instantaneous probability of innovative and adaptive R&D. Specifically, if an R&D entrepreneur employs an amount of Northern labor $L_{r,t}^N(j)$ to perform innovative R&D in industry j , then she succeeds in inventing the next higher quality product in this industry with an instantaneous probability such that

$$\lambda_t^N(j) = \frac{L_{r,t}^N(j)}{\beta L_t^N}. \quad (\text{B.1})$$

If the Southern affiliate of a Northern leader in industry j employs an amount of Southern labor $L_{r,t}^S(j)$ to conduct adaptive R&D, then the Northern firm succeeds in shifting the production to the Southern affiliate with an instantaneous probability such that

$$\lambda_t^S(j) = \frac{L_{r,t}^S(j)}{\gamma L_t^S}. \quad (\text{B.2})$$

The corresponding zero-expected-profit conditions for innovative R&D and adaptive R&D are, respectively, given by

$$v_t^N(j) = \beta w_t^N L_t^N, \quad (\text{B.3})$$

and

$$v_t^S(j) - v_t^N(j) = \gamma w_t^S L_t^S. \quad (\text{B.4})$$

In this setup, we now derive the Northern and Southern steady-state conditions and the steady-state relative wage condition. Using (B.1), the total amount of labor employed for innovative R&D is given by

$$L_{r,t}^N = \int_0^1 L_{r,t}^N(j) dj = \beta L_t^N \lambda^N. \quad (\text{B.5})$$

Thus, the Northern labor-market-clearing condition (in per capita terms) in (34) becomes

$$1 = \frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S} \frac{\bar{L}_{x,t}^N}{L_t^N} + \beta \lambda^N. \quad (\text{B.6})$$

Similarly, using (B.2), the amount of labor employed in adaptive R&D is given by

$$L_{r,t}^S = \int_{\theta^N} L_{r,t}^S(j) dj = \gamma L_t^S \lambda^S \left(\frac{\lambda^N}{\lambda^N + \lambda^S} \right), \quad (\text{B.7})$$

where (25) is applied. Then the Southern labor-market-clearing condition becomes

$$1 = \frac{\lambda^S}{\kappa\lambda^N + \lambda^S} \frac{\bar{L}_{x,t}^F}{L_t^S} + \gamma\lambda^S \left(\frac{\lambda^N}{\lambda^N + \lambda^S} \right). \quad (\text{B.8})$$

Substituting (15) and (42) into (B.3) and making use of symmetry yield the steady-state innovative R&D condition such that

$$\left(\mu^N - 1 \right) \frac{\bar{L}_{x,t}^N}{L_t^N} = \beta(\rho + \lambda^N). \quad (\text{B.9})$$

Moreover, substituting (15), (16), (42), and (43) into (B.4) yields the steady-state adaptive R&D condition such that

$$\left(\mu^S - 1 \right) \frac{\bar{L}_{x,t}^F}{L_t^S} - \left(\mu^N - 1 \right) \frac{\bar{L}_{x,t}^N}{L_t^S} = \gamma \left(\rho + \lambda^N \right). \quad (\text{B.10})$$

Combining (B.6) with (B.9) yields the Northern steady-state condition such that

$$1 = \beta\lambda^N \left[\frac{\kappa(\rho + \lambda^N)}{(\kappa\lambda^N + \lambda^S)(\mu^N - 1)} + 1 \right], \quad (\text{B.11})$$

and combining (B.8) with (B.10) yields the Southern steady-state condition such that

$$1 = \lambda^S \left\{ \frac{(\rho + \lambda^N)[\gamma + \beta\omega(1 - \alpha)/\alpha]}{(\mu^S - 1)(\kappa\lambda^N + \lambda^S)} + \frac{\gamma\lambda^N}{\lambda^N + \lambda^S} \right\}, \quad (\text{B.12})$$

where we have applied $L_t^N/L_t^S = (1 - \alpha)/\alpha$. Using (B.9), (B.10) and (53), we obtain the steady-state wage condition such that

$$\frac{\gamma}{\beta\omega^\sigma} + \frac{(1 - \alpha)\omega^{1-\sigma}}{\alpha} = \delta^{\sigma-1} \left(\frac{\mu^N}{\mu^S} \right)^\sigma \frac{(\mu^S - 1)(1 - \alpha)}{\alpha(\mu^N - 1)}, \quad (\text{B.13})$$

which is an implicit function that determines the steady-state equilibrium value of the relative wage $\omega(\mu^N, \mu^S)$. (B.13) also implies that ω is increasing in μ^N whereas it is decreasing in μ^S , which yields the same result as in Proposition 1 under the setting of semi-endogenous growth.³⁹

Next, we derive the steady-state rate of economic growth. Equation (12) shows that the labor demand for an average-quality product produced by a Northern leader is $\bar{L}_{x,t}^N = Q_t Y_t (\mu^N w_t^N)^{-\sigma}$. Equation (39) implies that the growth rate of quality index is $\dot{Q}_t/Q_t = (\kappa - 1)\lambda_t^N$. It can be shown that $\dot{Y}_t/Y_t = \dot{C}_t/C_t = \dot{c}_t^N/c_t^N + g_L$ by using (5) and $\dot{c}_t^N/c_t^N = \dot{w}_t^N/w_t^N = g$ by using (2). Combining these conditions yields $g = (\kappa - 1)\lambda^N/(\sigma - 1)$, where the Northern innovation arrival rate λ^N is implicitly determined by (B.11) - (B.13).

As for social welfare, the steady-state welfare function of the Northern household is identical

³⁹Following the proof in the Appendix A.3, it is easy to show the same result for the effects of patent breadth on the relative wage by differentiating (B.13) with respect to μ^N and μ^S .

to (48). By analogous derivations in Lemma 2, we can show that

$$a_0^N = \frac{v_0^N}{L_0^N} = \beta w_0^N, \quad (\text{B.14})$$

and

$$a_0^S = \frac{v_0^S - v_0^N}{L_0^S} = \gamma w_0^S. \quad (\text{B.15})$$

Thus, the balanced-growth level of consumption per capita for both countries now are, respectively,

$$c_0^N = w_0^N [1 + \beta(\rho - g_L)] = \omega w_0^S [1 + \beta(\rho - g_L)], \quad (\text{B.16})$$

and

$$c_0^S = w_0^S [1 + \gamma(\rho - g_L)], \quad (\text{B.17})$$

where w_0^S , which is similarly derived as (52), is given by

$$w_0^S = Q_0^{\frac{1}{\sigma-1}} \left[\left(\mu^N \omega \right)^{1-\sigma} \left(\frac{\kappa \lambda^N}{\kappa \lambda^N + \lambda^S} \right) + \left(\frac{\mu^S}{\delta} \right)^{1-\sigma} \left(\frac{\lambda^S}{\kappa \lambda^N + \lambda^S} \right) \right]^{\frac{1}{\sigma-1}}. \quad (\text{B.18})$$

where initial Q_0 is normalized to unity.

Given its complexity, this extended model is hereafter solved numerically. The benchmark parameter values are given by the same set of values in the main text: $\{\rho, \sigma, \alpha, \mu^N, \mu^S, \kappa, z\} = \{0.05, 2.9, 0.829, 1.3, 1.25, 2.609, 1.656\}$. For the remaining parameters $\{\delta, \gamma, \beta\}$, we set δ to 0.0516 to ensure that Assumptions 1 and 2 hold, and calibrate β and γ by using equations (B.11), (B.12) and (B.13), with the following moments: the innovation arrival rate (i.e., 12%), the growth rate of labor force (i.e., 0.5%)⁴⁰ and the relative wage between China and the US (i.e., 20.101). The calibrated parameter values are reported in Table 7. Given these parameter values, the equilibrium value of λ^S is 6.285%.

Table 7: Calibrated parameter values in the fully endogenous growth model

ρ	σ	α	μ^N	μ^S	δ	κ	z	β	γ
0.05	2.9	0.829	1.3	1.25	0.0516	2.609	1.656	2.1190	0.0074

Given these calibrated parameter values, we consider the same experiments as in the baseline model by raising the levels of patent breadth in China and the US (i.e., μ^S and μ^N) by 1% (percent change), respectively. The results are reported in Table 8. We find that a permanent increase of 1% in patent breadth μ^S in China decreases the wage gap ω by 1.043% (percent change), and increases the innovation arrival rate λ^N by 1.446% (percent change), the international technology transfer rate λ^S by 7.638% (percent change), and the growth rate of consumption g by 0.147% (percentage point). These changes are similar to those in the semi-endogenous growth model except that the Northern wage rate is depressed slightly by 0.330%. Moreover, the effects of a

⁴⁰ According to <http://wdi.worldbank.org/tables>, Table 2.2, Labor Force Structure, the growth rate of labor force in the US during 2007-2016 is 0.5%.

rise in μ^S on both Southern and Northern welfare are similar to the counterparts in the semi-endogenous growth model: a 1% increase in μ^S leads to a welfare gain (in terms of equivalent variation in consumption) of 3.983% in China and 2.935% in the US, respectively. Therefore, strengthening patent protection in China in the fully endogenous growth model also benefits both countries in terms of welfare, and the benefit to China continues to be more significant than to the US.

Table 8: Simulation under the alternative model

	$\Delta\lambda^N$	$\Delta\lambda^S$	$\Delta\omega$	Δg	$\Delta \ln \omega_0^N$	$\Delta \ln \omega_0^S$	$\Delta \ln U_0^N$	$\Delta \ln U_0^S$
$\Delta\mu^S$	1.446%	7.638%	-1.043%	0.147%	-0.330%	0.718%	2.935%	3.983%
$\Delta\mu^N$	4.944%	-0.130%	0.716%	0.502%	-0.736%	-1.450%	10.429%	9.715%

Finally, as in the semi-endogenous growth model, the effects of strengthening patent protection in the US still lead to similar results on the innovation rate, the rate of international technology transfer, and the relative wage in the fully endogenous growth model. Specifically, a permanent increase of 1% in patent breadth μ^N in the US raises the relative wage ω by 0.716% (percent change), the innovation arrival rate λ^N by 4.944% (percent change), and the growth rate of consumption g by 0.502% (percentage point), but it stifles the international technology transfer rate λ^S by 0.130% (percent change). In addition, the rise in μ^N leads to a welfare gain of 10.429% and 9.715% in the US and China, respectively. Strengthening patent protection in the US continues to benefit more itself than China. Analogous to the benchmark case, in this extended case both countries still benefit much more from the strengthening of Northern patent protection.