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Abstract

This paper develops a product-cycle model with costly technology transfer, which requires resources from both the North and the South. In the basic model , we show that strengthening IPR protection induces a large technology transfer and narrows the North–South wage gap. However, we obtain an ambiguous result regarding the effect on economic growth, which depends crucially on the size of the transfer cost. Although strengthening IPR protection induces a high growth rate when the transfer cost is small, it can induce a low growth rate when the transfer cost is large. In the extended model, in order to examine what factors determine the transfer cost, we consider the situation where the Southern firms may misbehave and the Northern firms incur a cost to monitor them. We show that the degree of investor protection and the degree of morality in developing countries influence the size of the transfer cost, which affects economic growth.

keyword: R&D, product-cycle model, technology transfer, IPR protection

JEL classification: F12, F23, F43, O31, O34

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1 Introduction

Since a range of Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, which requires developing countries that are members of the World Trade Organization (WTO) to establish minimum standards of intellectual property right (IPR) protection, were signed in the Uruguay Round, many studies have analyzed the effects of strengthening IPR protection in developing countries. These studies typically construct a model consistent with the product cycle, as highlighted in Vernon (1966). New goods are invented and production takes place initially in high-wage developed countries. Subsequently, production shifts to low-wage developing countries, accompanied by technology transfer. Technology diffuses from developed countries to developing countries through many channels. Regardless of the channels, technology transfer involves substantial resource cost in both countries. For example, when technology transfer takes place through foreign direct investment (FDI), affiliates receiving technology will typically need to conduct R&D to absorb the technology and to modify it for the local market [1], and multinational firms will need to train workers in developing countries and to acquire knowledge about foreign customs and regulations. When technology transfer takes place through licensing, there is a negotiation cost incurred to establish an agreement. However, many theoretical papers ignore the cost of technology transfer. In particular, no study has considered that technology transfer involves a resource cost in both developed countries and developing countries. This paper, therefore, develops a product-cycle model with costly technology transfer, which requires resource use in both developed and developing countries.

We assume that there are two countries in the world, the North and the South. New goods are invented in the North, and inventors of the new good can earn a profit flow because they are protected by perfect IPR protection in the North. They have an incentive to transfer technology to the South in order to produce goods using Southern labor, whose wage is relative low. However they suffer from a one-off imitation risk and transfer cost. These trade-offs determine the amount of technology transfer in the equilibrium.

Then we analyze the effect of strengthening IPR protection. Strengthening IPR protection (decreasing imitation risk) induces a large technology transfer and narrows the North–South wage gap. Strengthening IPR protection reduces imitation risk, which decreases the disadvantage of transferring technology.

[1] Fors (1997) presented evidence that multinationals spend substantial amounts on R&D performed abroad.

Then, more inventors are willing to transfer technology, and more production shifts to the South, which induces increased demand for Southern labor. This reduces the North–South wage gap. These results are consistent with models in related studies in which technology diffuses through FDI or licensing. However, we obtain ambiguous results regarding the effect on economic growth. Although strengthening IPR protection induces a high growth rate when the transfer cost is small, strengthening IPR protection can induce a low growth rate when the transfer cost is large. Strengthening IPR protection induces a production shift to the South, which is accompanied by a technology transfer. On the one hand, more production takes place in the South, which makes Northern resources shift from production to R&D activities, which promotes economic growth. On the other hand, more technology transfer takes place, which requires Northern resources. The resources used in R&D will shift to the transfer activities, which impedes economic growth. If the former (latter) effect dominates the latter (former) effect, strengthening IPR protection promotes (harms) economic growth.

Then what factors determine the transfer cost, which plays a key role in our model? In the real world, it depends not only on the characteristics of the firms in the developed country such as the ability to conduct adaptive R&D and to accumulate knowledge, but also on the characteristics of the host countries such as the legal system, education level and morals of Southern workers. Specifically, entrepreneurs may misbehave and the Northern firms must monitor their behaviors so that they do not misbehave in countries with weaker investor protection or lower morality. Then we extend the basic model by introducing the framework of contract theory in order to examine how weaker investor protection or lower morality affect transfer cost and consequently economic growth.

We assume that for firms in developed countries to shift production to developing countries, it is necessary to cooperate with entrepreneurs in the developing countries, and that entrepreneurs have an incentive to enjoy private benefits by misbehaving. These private benefits depend on the degree of investor protection, the morals of workers in developing countries, and the monitoring by the firms transferring the technology. When the degree of investor protection and the morals of laborers are low, private benefits are high. However firms can reduce the private benefits of entrepreneurs by monitoring, which involves a resource cost. Although the characteristics of host countries are not so important when the degree of investor protection and the morals of laborers are sufficiently high, they have a crucial effect on the transfer cost when the degree of investor protection and the morals of laborers are low because firms must monitor entrepreneurs to ensure that they do not misbehave. The transfer cost is high if the degree of investor protection and the morals of laborers in the host country are low. In this situation, strengthening IPR protection impedes economic growth. This result implies that strengthening IPR protection does not promote R&D in all developed countries but rather depends on the characteristics of the host countries.

This paper develops a product-cycle model where the channel of technology transfer is FDI or licensing. Lai (1998), Yang and Maskus (2001), Glass and Wu (2007), Tanaka, Iwaisako and Futagami (2007), Dinopoulos and Segerstrom (2010), Branstetter and Saggi (2011), and Tanaka and Iwaisako (2014) constructed such a model. Most of these papers showed that strengthening IPR protection induces a large technology transfer, narrows the North–South wage gap and produces a high growth rate.[2] Our paper shows that the effect of strengthening IPR protection on the growth rate is ambiguous when we consider the role of costly transfer activities. Some papers have considered costly technology transfer. In the context of illegal imitation models, Grossman and Helpman (1991) and Mondal and Gupta (2007, 2009) assumed that illegal imitation as a channel of technology transfer is costly and requires Southern labor. In the context of licensing, Yang and Maskus (2001) and Tanaka, Iwaisako and Futagami (2007) assumed that firms incur negotiation cost to obtain licensing agreements, which is reduced by strengthening IPR protection. However, Yang and Maskus (2001) assumed that only Northern labor is needed for negotiation, while Tanaka, Iwaisako and Futagami (2007) assumed that only Southern labor is needed in negotiation. In the context of FDI models, Dinopoulos, and Segerstrom (2010) assumed that firms should conduct adoptive R&D to transfer technology, which requires only Southern labor. Our model generalizes these papers such that transfer activities require both Northern and Southern labor. Moreover we guarantee that comparative statistic of our generalized model is meaningful to show that the interior equilibrium is always saddle stable when transfer activity requires both Northern labor and Southern labor.

The rest of this paper is structured as follows. Section 2 describes the basic model and derives the equilibrium. Section 3 describes the extended model. Section 4 provides concluding comments.

[2] There is another category of product-cycle model in which technology transfer occurs through illegal imitation. Grossman and Helpman (1991), Helpman (1993), Arnold (2002), Mondal and Gupta (2007, 2009) and Akiyama and Furukawa (2009) constructed such a model. Most of these papers showed that strengthening IPR protection induces small technology transfers, widens the North–South wage gap and reduces the economic growth rate. Glass and Saggi (2002) and Parello (2008) developed hybrid models in which technology transfers occur through both FDI and illegal imitation.

2 Basic model

2.1 Setting

There are two countries in the world, the North and the South. Both country's populations are exogenous given M^N and M^S, respectively, and do not grow. They are linked by free international trade in differentiated goods. We consider the parameter values so that the wage rate of the North is higher than that of the South. Only the North has a research sector; therefore, new differentiated goods are invented only in the North. Inventors of the new goods are protected by perfect IPR protection in the North however are protected by imperfect IPR protection in the South. Northern firms can shift their production to the South and use the Southern labor. However they are exposed to the risk of being imitated due to the imperfect protection in the South.

2.1.1 Households

We construct an infinite representative agent model. Household members live forever and are endowed with one unit of labor, which is supplied inelastically. Each household maximizes its discounted utility:

$$U = \int_0^\infty \exp(-\rho t) \ln u(t) dt, \tag{1}$$

where ρ is the subjective discount rate and $u(t)$ is the instantaneous utility per person at time t, which is given by

$$u(t) = \left\{ \int_0^{n(t)} [x(z,t)]^{\frac{\varepsilon-1}{\varepsilon}} dz \right\}^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2}$$

where $x(z,t)$ is consumption of differentiated goods in industry z in period t, $\varepsilon > 1$ is the elasticity of substitution of differentiated goods, and $n(t)$ is the available variety of differentiated goods in period t, which increases through R&D activity. From (2), the demand function for the product in industry z in period t is given by

$$x(z,t) = \frac{p(z,t)^{-\varepsilon}}{\int_0^{n(t)} p(\nu,t)^{1-\varepsilon} d\nu} E(t), \tag{3}$$

where $p(z,t)$ is the price of differentiated goods in industry z in period t, and $E(t)$ is aggregate world consumption in period t. Given (3), intertemporal utility maximization yields

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho, \tag{4}$$

where $r(t)$ is the interest rate at time t.

2.1.2 Production

There are three types of firms producing goods: Northern firms, Multinational firms and Imitation firms. Northern firms and Multinational firms supply goods monopolistically, and Imitation firms supply goods competitively. Northern firms hire one Northern laborer to produce one good. Multinational firms and Imitation firms hire one Southern laborer to produce one good. There are no fixed costs or transport costs. The instantaneous profits of Northern firms, Multinational firms and Imitation firms are expressed as $\pi^N(t) = x^N(t)\left(p^N(t) - w^N(t)\right)$, $\pi^M(t) = x^M(t)\left(p^M(t) - w^S(t)\right)$ and $\pi^I(t) = x^I(t)\left(p^I(t) - w^S(t)\right)$ respectively, where $x^N(t)$, $x^M(t)$ and $x^I(t)$ are the outputs and $p^N(t)$, $p^M(t)$ and $p^I(t)$ are the prices of Northern firms, Multinational firms and Imitation firms respectively, $w^N(t)$ is the wage rate of the North, and $w^S(t)$ is the wage rate of the South. As Northern firms and Multinational firms supply goods monopolistically, they choose the optimal price $p^N(t) = \frac{\varepsilon}{\varepsilon-1}w^N(t)$, $p^M(t) = \frac{\varepsilon}{\varepsilon-1}w^S(t)$ respectively. As Imitation firms supply goods competitively, the price of Imitation firms is $p^I(t) = w^S(t)$. Using (3), we obtain:

$$x^N(t) = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}}{n^N(t)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + n^M(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{1-\varepsilon} + n^I(t)\left(\omega(t)\right)^{1-\varepsilon}}\chi(t), \tag{5}$$

$$x^M(t) = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{-\varepsilon}}{n^N(t)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + n^M(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{1-\varepsilon} + n^I(t)\left(\omega(t)\right)^{1-\varepsilon}}\chi(t), \tag{6}$$

$$x^I(t) = \frac{\left(\omega(t)\right)^{-\varepsilon}}{n^N(t)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + n^M(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{1-\varepsilon} + n^I(t)\left(\omega(t)\right)^{1-\varepsilon}}\chi(t), \tag{7}$$

where $n^N(t)$, $n^M(t)$ and $n^I(t)$ are the available variety of differentiated goods produced by Northern firms, Multinational firms and Imitation firms respectively in period t, $\omega(t) \equiv \frac{w^S(t)}{w^N(t)}$ is the relative wage and $\chi(t) \equiv \frac{E(t)}{w^N(t)}$. Substituting (5) and (6) into the profit function, we obtain relative instantaneous profit as follows:

$$\frac{\pi^N(t)}{\pi^M(t)} = (\omega(t))^{\varepsilon-1}. \tag{8}$$

2.1.3 R&D activity

As inventors of new goods are protected by perfect IPR protection in the North, they can become Northern monopolistic firms and earn profit flow. Then new firms undertake R&D activity. We assume that a new firm must hire $\frac{1}{n(t)}$ units of Northern labor to invent a new product.[3] Then the return from the R&D activity is $v^N(t) - \frac{1}{n(t)}w^N(t)$, where $v^N(t)$ is the value of Northern firms in period t. Assuming free entry into each R&D race, we obtain:

$$v^N(t) = \frac{w^N(t)}{n(t)}. \tag{9}$$

Aggregating labor engaged in R&D yields the following dynamic equation of variety:

$$g(t) \equiv \frac{\dot{n}(t)}{n(t)} = H^R(t), \tag{10}$$

where $H^R(t)$ is aggregate labor engaged in R&D.

2.1.4 Technology transfer

Northern firms have an incentive to transfer technology to the South in order to produce goods using Southern labor, whose wage is relative low. Producing goods at low cost allows these firms to earn large profits, which is an advantage of technology transfer. However, they suffer from a one-off imitation risk and transfer cost, which are the disadvantages of technology transfer. As IPR protection in the South is imperfect, the Northern firms can lose their profit flow with probability δ because of imitation when

[3] We assume a simple setting in which the efficiency of R&D is unity, a spillover occurs from the aggregate available variable $n(t)$ and there is no uncertainty.

transferring their technology.[4] That is, Northern firms succeed in transferring technology and become Multinational firms with probability $1-\delta$, otherwise they lose profit flow, and goods are produced by the Imitation firms in their industry with probability δ. Then $\dot{n}^M(t) = (1-\delta)\dot{n}^S(t)$ and $\dot{n}^I(t) = \delta\dot{n}^S(t)$ are satisfied, where $n^S(t) \equiv n^M(t) + n^I(t)$ is the variety produced by Southern labor. We additively assume that transferring technology needs both Northern labor and Southern labor, and should satisfy the following CES restriction:[5]

$$n(t)\left[b\left(h^{FN}(t)\right)^{\frac{\eta-1}{\eta}} + (1-b)\left(h^{FS}(t)\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \geq f_F, \tag{11}$$

where $h^{FN}(t)$ is Northern labor engaged in technology transfer, $h^{FS}(t)$ is Southern labor engaged in technology transfer, $\eta \geq 0$ is the elasticity of substitution between Northern labor and Southern labor, $1/f_F$ is the efficiency of technology transfer, $b \in [0,1]$ is the degree of contribution of Northern labor. They choose optimal $h^{FN}(t)$ and $h^{FS}(t)$ to minimize transfer cost $c^F(t) \equiv w^N(t)h^{FN}(t) + w^S(t)h^{FS}(t)$ subject to (11). Then we obtain:

$$h^{FN}(t) = \frac{1}{n(t)}F^{FN}(\omega(t)), F^{FN}(\omega(t)) \equiv f_F\left[\frac{(\omega(t))^{\eta-1}(b)^{\eta-1}}{(\omega(t))^{\eta-1}(b)^{\eta} + (1-b)^{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{12}$$

$$h^{FS}(t) = \frac{1}{n(t)}F^{FS}(\omega(t)), F^{FS}(\omega(t)) \equiv f_F\left[\frac{(1-b)^{\eta-1}}{(\omega(t))^{\eta-1}(b)^{\eta} + (1-b)^{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{13}$$

$$c^F(t) = v^N(t)F^{FC}(\omega(t)), F^{FC}(\omega(t)) \equiv f_F\omega(t)\left[(\omega(t))^{\eta-1}(b)^{\eta} + (1-b)^{\eta}\right]^{-\frac{1}{\eta-1}}, \tag{14}$$

which are functions of relative wage rate ω. For the latter analysis, we check the properties of the above function. First, $\frac{dF^{FN}(\omega)}{df_F} > 0, \frac{dF^{FS}(\omega)}{df_F} > 0, \frac{dF^{FC}(\omega)}{df_F} > 0$ are satisfied, which means that low efficiency of technology transfer induces many Northern laborers and Southern laborers to engage in technology transfer and makes the technology transfer costly. Second, $\frac{dF^{FN}(\omega)}{d\omega} > 0, \frac{dF^{FS}(\omega)}{d\omega} < 0$ and

[4] Related studies assumed that Multinational firms suffer from Poisson imitation risk instead of a one-off imitation risk. Although these studies use settings that are more realistic than ours, both settings play a similar role in the model, and our setting makes analysis of the model easier. Then we adopt a one-off imitation risk.

[5] When the Northern firm transfers technology, on the one hand, they send their staff in order to provide the necessary knowledge, such as how to manage Southern workers, etc. Then Northern labor is required. On the other hand, Southern laborers must learn how to produce new goods, which requires time. Then Southern labor is required.

$\frac{dF^{FC}(\omega)}{d\omega} > 0$ are satisfied, which means that the high Southern wage, keeping the Northern wage constant, induces many Northern laborers and few Southern laborers to engage in technology transfer and incurs a large technology transfer cost. Third, $\frac{dF^{FC}(\omega)}{d\eta} < 0$ is satisfied, which means that the low elasticity of substitution between Northern labor and Southern labor induces a high transfer cost. Finally, F^{FC} is U-shaped with respect to the degree of contribution b.[6]

The expected gain from technology transfer is $\left((1-\delta)\,\phi v^{M}(t) - v^{N}(t)\right) - c^{F}(t)$ where $v^{M}(t)$ is the value of Multinational firms and $\phi \in [0,1]$ is the profit share of Northern firms. If the expected gain from technology transfer is strictly negative, Northern firms prefer not to transfer technology. If the expected gain from technology transfer is strictly positive, transfer takes place, and the demand for Southern labor increases. Then the North–South wage gap falls, which decreases the incentive to transfer. This mechanism continues until the expected gain reaches zero.[7] Therefore, when technology transfer takes place, using (14):

$$\frac{v^{N}(t)}{v^{M}(t)} = \frac{(1-\delta)\,\phi}{F^{FC}(\omega(t)) + 1} \tag{15}$$

is satisfied. Our assumption about the technological transfer cost is a generalization of that in related studies. When $f_F = 0$ and $\phi = 1$, our model reflects the economy of Lai (1998). When $f_F > 0$ and $b = 1$, our model reflects the economy of Yang and Maskus (2001). When $f_F > 0$ and $b = 0$ and we interpret ϕ as the profit share of Southern licensed firms, our model reflects the economy of Tanaka, Iwaisako and Futagami (2007). When $f_F > 0$, $b = 0$ and $\phi = 1$, our model reflects the economy of Dinopoulos and Segerstrom (2010).

2.1.5 Labor market

Northern laborers are engaged in the production of Northern firms, R&D activity and technological transfer. Northern labor supply is exogenously given. The labor market clearing condition in the North is:

$$x^{N}(t)\,n^{N}(t) + H^{R}(t) + \dot{n}^{S}(t)\,h^{FN}(t) = M^{N}. \tag{16}$$

[6] A high (low) b induces many Northern (Southern) laborers to engage in technology transfer. An increase in b means an increase (decrease) in the efficiency of Northern (Southern) labor. Thus when few (many) Northern laborers are engaged in technology transfer, an increase in b induces an increase (decrease) in the transfer cost.

[7] We only focus on the case in which production takes place in both the North and South.

Southern laborers are engaged in the production of Multinational firms and Imitation firms, and technological transfer. Southern labor supply is exogenously given. The labor market clearing condition in the South is:

$$x^{M}(t)\,n^{M}(t)+x^{I}(t)\,n^{I}(t)+\dot{n}^{S}(t)\,h^{FS}(t)=M^{S}. \tag{17}$$

2.1.6 Asset market

When both stock of existing Northern firms and stock of existing Multinational firms are held, the return on these stocks is equal, which is also equal in the return on riskless asset. The no-arbitrage condition satisfies:

$$r(t)=\frac{\pi^{N}(t)+\dot{v}^{N}(t)}{v^{N}(t)}=\frac{\pi^{M}(t)+\dot{v}^{M}(t)}{v^{M}(t)}, \tag{18}$$

where $r(t)$ is the return on riskless asset at time t.

3 Equilibrium

3.1 Transition Dynamics

From (10), (12), (13), (16) and (17), the differential equation of the ratio of goods produced by Southern labor to all produced goods $\zeta(t)\equiv\frac{n^{S}(t)}{n(t)}$ is as follows:

$$\dot{\zeta}(t)=\frac{1+\zeta(t)\,F^{FN}(\omega(t))}{F^{FS}(\omega(t))}\left[M^{S}-X^{S}(\omega(t),\zeta(t),\psi(t))\,\chi(t)\right]-\zeta(t)\left[M^{N}-X^{N}(\omega(t),\zeta(t),\psi(t))\,\chi(t)\right]. \tag{19}$$

, where $\psi\equiv\frac{n^{I}}{n^{S}}$, $X^{N}(\omega(t),\zeta(t),\psi(t))\equiv\frac{n^{N}(t)x^{N}(t)}{\chi(t)}=\frac{(1-\zeta(t))\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}}{(1-\zeta(t))\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi(t))\zeta(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{1-\varepsilon}+\psi(t)\zeta(t)(\omega(t))^{1-\varepsilon}}$ and $X^{S}(\omega(t),\zeta(t),\psi(t))\equiv\frac{x^{M}(t)n^{M}(t)+x^{I}(t)n^{I}(t)}{\chi(t)}=\frac{(1-\psi(t))\zeta(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{-\varepsilon}+\psi(t)\zeta(t)(\omega(t))^{-\varepsilon}}{(1-\zeta(t))\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi(t))\zeta(t)\left(\frac{\varepsilon}{\varepsilon-1}\omega(t)\right)^{1-\varepsilon}+\psi(t)\zeta(t)(\omega(t))^{1-\varepsilon}}$.[8] [9] We can confirm that $\frac{\partial X^{N}(\omega,\zeta,\psi)}{\partial\omega}>0$, $\frac{\partial X^{N}(\omega,\zeta,\psi)}{\partial\zeta}<0$, $\frac{\partial X^{N}(\omega,\zeta,\psi)}{\partial\psi}<0$, $\frac{\partial X^{S}(\omega,\zeta,\psi)}{\partial\omega}<0$, $\frac{\partial X^{S}(\omega,\zeta,\psi)}{\partial\zeta}>0$

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[8] Differentiating $\zeta(t)=\frac{n^{S}(t)}{n(t)}$, and substitutes (17) yields $\frac{\dot{\zeta}(t)}{\zeta(t)}=\frac{\dot{n}^{S}(t)}{n^{S}(t)}-\frac{\dot{n}(t)}{n(t)}=\frac{1}{\zeta(t)F^{FS}(\omega(t))}\left[M^{S}-X^{S}(t)\,\chi(t)\right]-g(t)$. From (10), (12), (13), (16) and (17), $g(t)=-\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}\left[M^{S}-X^{S}(t)\,\chi(t)\right]+M^{N}-X^{N}(t)\,\chi(t)$ is satisfied. Combining these two equation yields (19).

[9] This differentiated equation holds when $f_{F}>0$ and $b\in[0,1)$ are satisfied.

and $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial \psi} > 0$ are satisfied.[10]

From $\psi(t) = \frac{n^I(t)}{n^S(t)}$, (17) and $\dot{n}^I(t) = \delta \dot{n}^S(t)$,

$$\dot{\psi}(t) = \left[\frac{M^S - X^S(\omega(t), \zeta(t), \psi(t)) \chi(t)}{F^{FS}(\omega(t)) \zeta(t)} \right] [\delta - \psi(t)]. \tag{20}$$

is satisfied.[11]

From (4) (10), (12), (13), (16), (17) and (18),

$$\frac{\dot{\chi}(t)}{\chi(t)} = \frac{(1-\zeta(t))(\varepsilon-1)+1}{(1-\zeta(t))(\varepsilon-1)} X^N(\omega(t), \zeta(t), \psi(t)) \chi(t) - M^N + \frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))} \left[M^S - X^S(\omega(t), \zeta(t), \psi(t)) \chi(t) \right] - \rho. \tag{21}$$

is satisfied.[12]

From (8), (9), (15) and (18),

$$\dot{\omega}(t) = \frac{X^N(\omega(t), \zeta(t), \psi(t)) \chi(t)}{(1-\zeta(t))(\varepsilon-1) \frac{\partial F^{FC}(\omega(t))}{\partial \omega(t)}} \left[-(1-\delta)(\omega(t))^{1-\varepsilon} + F^{FC}(\omega(t)) + 1 \right]. \tag{22}$$

is satisfied.[13] [14] Then this economy's dynamics are described by (19), (20), (21) and (22) in $(\zeta, \psi, \chi, \omega)$ space.[15]

3.2 BGP equilivrium

In the following, we focus on the balanced growth path (BGP) equilibrium where g, ζ, ψ, χ and ω are constants. First we describe the equilibrium North–South relative wage. From (22) and $\dot{\omega}(t) = 0$, we

[10]We confirm this in the appendix A1.

[11]Differentiating $\psi(t) = \frac{n^I(t)}{n^S(t)}$ yields $\frac{\dot{\psi}(t)}{\psi(t)} = \frac{\dot{n}^I(t)}{n^I(t)} - \frac{\dot{n}^S(t)}{n^S(t)} = \delta \frac{\dot{n}^S(t)}{n^S(t)} \frac{n^S(t)}{n^I(t)} - \frac{\dot{n}^S(t)}{n^S(t)} = \frac{\dot{n}^S(t)}{n^S(t)} \left[\frac{\delta}{\psi(t)} - 1 \right]$. From (17), $\frac{\dot{n}^S(t)}{n^S(t)} = \frac{M^S - X^S(\omega(t),\zeta(t),\psi(t))\chi(t)}{F^{FS}(\omega(t))\zeta(t)}$ is satisfied. Combining these two equation yields (20).

[12]Differentiating $\chi(t) = \frac{E(t)}{w^N(t)}$, and substitutes (4) and (18) yields $\frac{\dot{\chi}(t)}{\chi(t)} = \frac{\dot{E}(t)}{E(t)} - \frac{\dot{w}^N(t)}{w^N(t)} = r(t) - \rho - \frac{\dot{v}^N(t)}{v^N(t)} - \frac{\dot{n}(t)}{n(t)} = \frac{\pi^N(t)}{v^N(t)} - \rho - g(t)$. From (10), (12), (13), (16) and (17), $g(t) = -\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))} \left[M^S - X^S(t) \chi(t) \right] + M^N - X^N(t) \chi(t)$ is satisfied. Combining these two equation yields (21).

[13]From (15), $\frac{\dot{v}^N(t)}{v^N(t)} - \frac{\dot{v}^M(t)}{v^M(t)} = -\frac{\frac{\partial F^{FC}(\omega(t))}{\partial \omega(t)} \dot{\omega}(t)}{F^{FC}(\omega(t))+1}$ is satisfied. From (9) and $\pi^N(t) = \frac{1}{\varepsilon-1} x^N(t) w^N(t)$, $\frac{\pi^N(t)}{v^N(t)} = \frac{X^N(t)\chi(t)}{(1-\zeta(t))(\varepsilon-1)}$ is satisfied. From (8), (18) and $\frac{\pi^N(t)}{v^N(t)} = \frac{X^N(t)\chi(t)}{(1-\zeta(t))(\varepsilon-1)}$, $\frac{\dot{v}^N(t)}{v^N(t)} - \frac{\dot{v}^M(t)}{v^M(t)} = \frac{\pi^M(t)}{v^M(t)} - \frac{\pi^N(t)}{v^N(t)} = \frac{X^N(t)\chi(t)}{\left(F^{FC}(\omega(t))+1\right)(1-\zeta(t))(\varepsilon-1)} \left[(1-\delta)(\omega(t))^{1-\varepsilon} - F^{FC}(\omega(t)) - 1 \right]$ is satisfied. Combining above equations yields (22).

[14]This differential equation holds when $f_F > 0$ is satisfied. When $f_F = 0$, $\frac{X^N(\omega(t),\zeta(t),\psi(t))\chi(t)}{(1-\zeta(t))(\varepsilon-1)} \left[(1-\delta) \phi(\omega(t))^{1-\varepsilon} - 1 \right] = 0$ is satisfied insted of (22).

[15]The interior equilibrium is saddle stable as shown in appendix A2.

obtain:

$$\left(\omega^*\right)^{\varepsilon-1}\left[F^{FC}\left(\omega^*\right)+1\right]=(1-\delta)\,\phi. \tag{23}$$

The North–South relative wage $\omega=\frac{w^S}{w^N}$ is determined by this equation. The relative wage is an increasing function of ε, η, ϕ and a decreasing function of δ and f_F, which means that enhancing the transfer incentive increases the relative wage. [16]

Lemma 3.1. *Strengthening IPR protection (decreasing δ) and decreasing transferring cost (decreasing f_F) narrow the North–South wage gap.*

This lemma is consistent with the results of related studies such as Lai (1998), Tanaka, Iwaisako and Futagami (2007), Dinopoulos and Segerstrom (2010), Branstetter and Saggi (2011) and Tanaka and Iwaisako (2014).

We can also describe equilibrium value of the ratio of goods produced by Imitation firm to goods produced by Southern labor ψ easily. From (20) and $\dot{\psi}(t)=0$, we obtain:

$$\psi^*=\delta. \tag{24}$$

Next we describe the equilibrium value of the growth rate g and production ratio ζ. As $\dot{\zeta}\left(t\right)=0$ is satisfied on the BGP equilibrium, we obtain:

$$\left(\frac{\dot{n}^S}{n}\right)=\zeta g. \tag{25}$$

As $\dot{\chi}\left(t\right)=0$ is satisfied on the BGP equilibrium, from (4), (9) and (18),

$$X^N\left(\omega^*,\zeta,\psi^*\right)\chi^*=\left(\rho+g\right)\left(1-\zeta\right)\left(\varepsilon-1\right). \tag{26}$$

is satisfied. [17]

[16] As the high elasticity of substitution of differentiated good ε leads to a low price and high output (labor demand), the incentive to hire lower wage labor is high. A high elasticity of substitution of the labor-hiring transfer activity η and a high efficiency of technology transfer result in a low transfer cost, which enhances the transfer incentive. Low imitation risk and a high share of profit of Northern firms lead to a high expected return of technology transfer, which increases the transfer incentive. As $F^{FC}\left(\omega\right)$ is inverse U-shaped with respect to the degree of contribution b, the relative wage is U-shaped with respect to b.

[17] From (4) and (18), $\dot{\chi}\left(t\right)=0$ yields $\frac{\dot{\chi}(t)}{\chi(t)}=\frac{\dot{E}(t)}{E(t)}-\frac{\dot{w}^N(t)}{w^N(t)}=r\left(t\right)-\rho-\frac{\dot{v}^N(t)}{v^N(t)}-\frac{\dot{n}(t)}{n(t)}=\frac{\pi^N(t)}{v^N(t)}-\rho-g\left(t\right)=0$. From (9)

Substituting (10), (12), (25) and (26) into (16) yields,

$$g = \frac{M^N - (1-\zeta)(\varepsilon - 1)\rho}{\zeta F^{FN}(\omega^*) + 1 + (1-\zeta)(\varepsilon-1)}. \tag{27}$$

This equation depicts a two-dimensional N-curve whose vertical axis measures the growth rate g and horizontal axis measures the production ratio ζ respectively. A rising ζ induces two effects on the N-curve. The first effect is through $\frac{d(1-\zeta)(\varepsilon-1)}{d\zeta} < 0$. This effect means that increasing the ratio of goods produced by Southern labor decreases the ratio of goods produced by Northern labor, which increases labor engaged in R&D and g. The second effect is through $\frac{d\zeta F^{FN}(\omega^*)}{d\zeta} > 0$. This effect means that increasing the ratio of goods produced by Southern labor increases technology transfer, which increases labor engaged in the transfer, which then decreases labor engaged in R&D and g. Therefore, the slope of the N-curve is ambiguous. If F^{FN} is small (large), this slope is positive (negative) because the second effect is weak (strong).

Substituting (13), (25) and (26) into (17) yields,

$$g = \frac{M^S - \frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}(1-\zeta)(\varepsilon-1)\rho}{\zeta F^{FS}(\omega^*) + \frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}(1-\zeta)(\varepsilon-1)}. \tag{28}$$

This equation depicts an S-curve. Increasing ζ decreases g in the S-curve because $\frac{d}{d\zeta}\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}(1-\zeta)(\varepsilon-1) > 0$ and $\frac{d}{d\zeta}\zeta F^{FS}(\omega^*) > 0$ are satisfied. The S-curve is always downward sloping.

Then we can analyze the effect of strengthening IPR protection (decreasing imitation probability δ). First we consider the special case that $F^{FN} = 0$ $(b = 0)$ is satisfied. In this case, the N-curve is upward sloping, which is depicted in Figure 1. On one hand, strengthening IPR protection has no effect on the N-curve. On the other hand, this effect shifts the S-curve counter-clockwise from the solid line to the broken line, and the equilibrium shifts to point B from point A.[18] Then the ratio of goods produced by Southern labor ζ and growth rate g increase, which is consistent with models in related studies in which technology diffuses through FDI or licensing. When F^{FN} is sufficiently small, we get same result.

---

and $\pi^N(t) = \frac{1}{\varepsilon-1}x^N(t)w^N(t)$, $\frac{\pi^N}{v^N} = \frac{X^N}{(1-\zeta)(\varepsilon-1)}$ is satisfied. Combining these two equations yields (26).

[18]Since $\frac{\partial X^N(\omega,\zeta,\psi)}{\partial\omega} > 0$, $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial\omega} < 0$, $\frac{d\omega^*}{d\delta} < 0$, $\frac{\partial X^N(\omega,\zeta,\psi)}{\partial\psi} < 0$, $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial\psi} > 0$ and $\frac{d\psi^*}{d\delta} > 0$ are satisfied, we get $\frac{d}{d\delta}\left(\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}\right) = \underbrace{\frac{\partial}{\partial\omega^*}\left(\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}\right)}_{-}\underbrace{\frac{d\omega^*}{d\delta}}_{-} + \underbrace{\frac{\partial}{\partial\psi^*}\left(\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}\right)}_{+}\underbrace{\frac{d\psi^*}{d\delta}}_{+} > 0$. Since $\frac{\partial F^{FS}(\omega^*)}{\partial\omega^*} < 0$ is satisfied, we get $\frac{dF^{FS}(\omega^*)}{d\delta} = \underbrace{\frac{\partial F^{FS}(\omega^*)}{\partial\omega^*}}_{-}\underbrace{\frac{d\omega^*}{d\delta}}_{-} > 0$. Therefore decreasing δ shifts S-curve counter-clockwise.

Lemma 3.2. *When few Northern labor is needed for technology transfer (with small F^{FN}), strengthening IPR protection (decreasing δ) increase the ratio of goods produced in South ζ and growth rate g.*

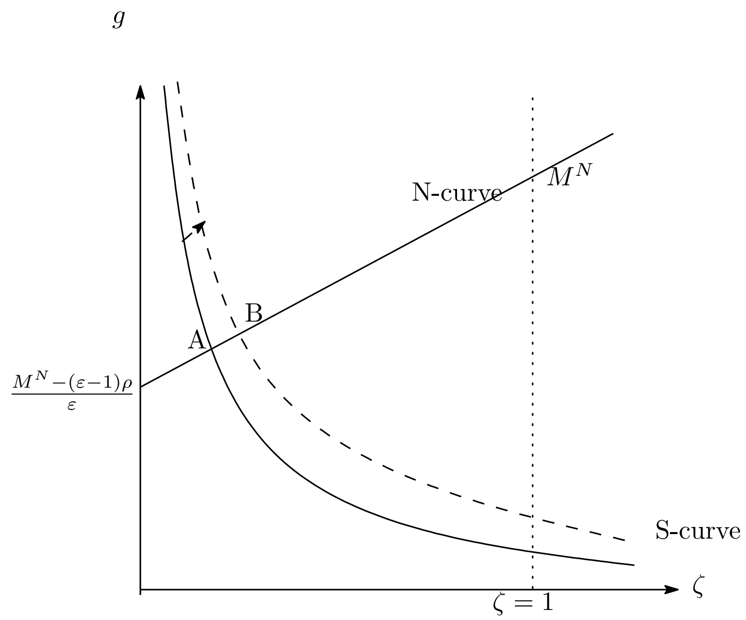

Figure 1. The effect of strengthening IPR protection when few Northern labor is needed for technology transfer.

However, when F^{FN} is large, this result changes. In this case, the N-curve is downward sloping, which is depicted in Figure 2.[19] On one hand, strengthening IPR protection shifts N-curve clockwise from the solid line to the broken line.[20] On the other hand, these effects shift the S-curve counter-clockwise from the solid line to the broken line. Then the equilibrium shifts to point B from point A. Therefore the ratio of goods produced by Southern labor ζ increases, however, growth rate g decreases.

Proposition 3.1. *When many Northern labor is needed for technology transfer (with large F^{FN}), strengthening IPR protection (decreasing δ) induces a large technology transfer, and the ratio of goods produced by Southern labor ζ increases. However, the growth rate, g, decreases.*

[19]In Figure 2, the intersection of two curves is on the left to the $\zeta = 1$ line. However, there is a possibility that the intersection of two curves is on the right to the $\zeta = 1$. In this case extreme point equilibrium, all production takes place in the South, is realized. To ensure interior point equilibrium, $\frac{M^N}{F^{FN}(\omega^*)+1} > \frac{M^S\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \left[(1-\delta)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \delta(\omega^*)^{-\varepsilon}\right](\varepsilon-1)\rho}{F^{FS}(\omega^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} + \left[(1-\delta)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \delta(\omega^*)^{-\varepsilon}\right](\varepsilon-1)}$ should be satisfied. That is, $F^{FN}(\omega^*)$ should not be large relative to $F^{FS}(\omega^*)$ to get interior point equilibrium.

[20]Note that $\frac{dF^{FN}(\omega^*)}{d\delta} = \underbrace{\frac{\partial F^{FN}(\omega^*)}{\partial \omega^*}}_{+} \underbrace{\frac{d\omega^*}{d\delta}}_{-} < 0$ is satisfied.

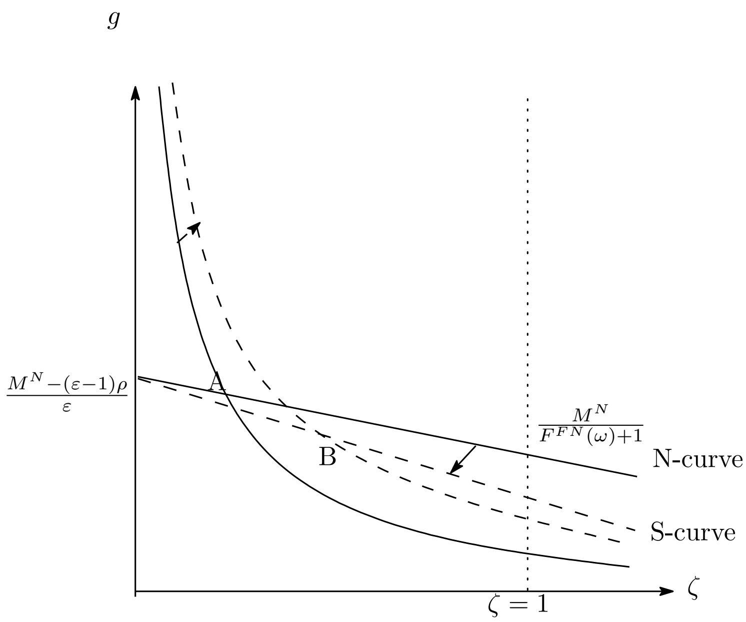

Figure 2. The effect of strengthening IPR protection when many Northern labor is needed for technology transfer.

Finally we examine the effect of an improvement of technology transfer efficiency (decreasing f_F). When $F^{FN} = 0$ ($b = 0$) is satisfied, an improvement of technology transfer efficiency has no effect on the N-curve, however, shifts the S-curve counter-clockwise from the solid line to the broken line, and the equilibrium shifts to point B from point A as shown in Figure 1. Then the ratio of goods produced by Southern labor ζ and growth rate g increase.[21] When $F^{FN} > 0$ ($b > 0$), this effect is ambiguous. However we can confirm that an improvement of technology transfer efficiency induces high growth rate if N-curve is positive and $\frac{d\zeta F^{FN}(\omega^*)}{df_F} = \underbrace{\frac{\partial \zeta F^{FN}(\omega^*)}{\partial \omega^*}}_{+} \underbrace{\frac{d\omega^*}{df_F}}_{-} + \underbrace{\frac{\partial \zeta F^{FN}(\omega^*)}{\partial f_F}}_{+} \geq 0$ is satisfied. This is depicted in Figure 3.[22]

[21]Since $\frac{dF^{FS}(\omega^*)}{df_F} = \underbrace{\frac{\partial F^{FS}(\omega^*)}{\partial \omega^*}}_{-} \underbrace{\frac{d\omega^*}{df_F}}_{-} + \underbrace{\frac{\partial F^{FS}(\omega^*)}{\partial f_F}}_{+} > 0$ is satisfied, a decreasing f_F shifts S-curve counter-clockwise.

[22]If $\frac{d\zeta F^{FN}(\omega^*)}{df_F} \geq 0$ is satisfied, N-curve shifts counter-clockwise.

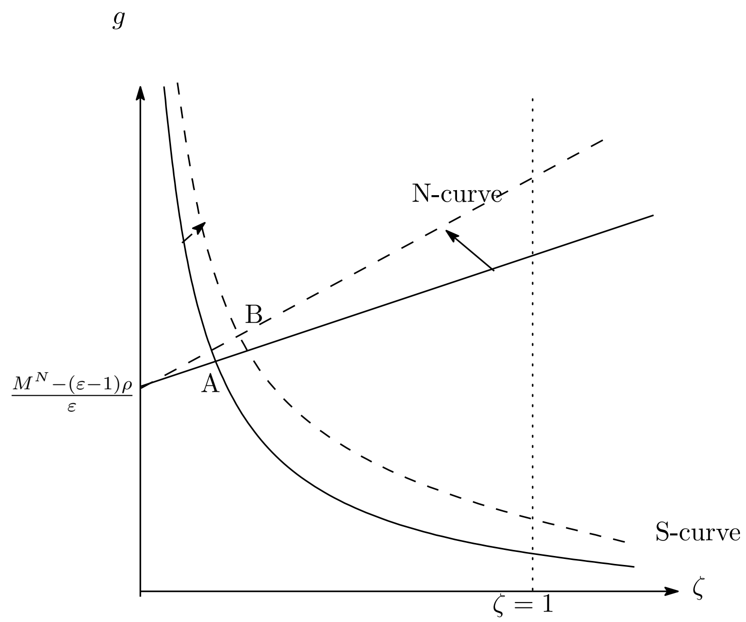

Figure 3. The effect of an improvement of technology transfer efficiency when few Northern labor is needed for technology transfer.

4 Extended model

In the previous section, we showed that the effect of strengthening IPR protection on the growth rate depends crucially on the transfer cost, which is a function of the efficiency of technology transfer f_F. This parameter summarizes many factors such as the experience of Northern firms, the degree of globalization, the environments of host countries, etc. In this section, we focus on the characteristics of the host countries. Then we introduce a moral hazard framework following Holmstrom and Tirole (1997) and Antras, Desai and Foley (2009). In this setting, when Northern firms transfer their technology to the South, they need to cooperate with Southern entrepreneurs, who have no profitable opportunity except for cooperation with Northern firms. However, they cannot fully control Southern entrepreneurs; therefore, they have to contract with Southern entrepreneurs. After technology is transferred, Southern entrepreneurs choose to behave or to misbehave. When Southern entrepreneurs choose to behave, the transfer succeeds with probability $p^H(1-\delta)$, and Southern entrepreneurs enjoy no private benefits. When Southern entrepreneurs choose to misbehave, the transfer succeeds with probability $p^L(1-\delta)$, and the Southern entrepreneurs enjoy private benefits.[23] For simplicity, we assume that $p^H = 1$ and $p^L = 0$.[24] Following

[23]Private benefits are interpreted as perquisites for the Southern entrepreneurs associated with leaking technology, diverting funds, doing careless work, making less effort, etc.

[24]This assumption enables us to focus only on the case in which Northern firms ensure that Southern entrepreneurs do not misbehave; then, Southern entrepreneurs do not choose to misbehave in equilibrium.

Antras, Desai and Foley (2009), we also assume that the private benefits of Southern entrepreneurs are proportional to the value of Multinational firms and are influenced by the investor protection in the South and the monitoring by Northern firms. If the investor protection is strong, it is difficult for Southern entrepreneurs to misbehave and enjoy private benefits. Even if the investor protection is not sufficiently strong, Northern firms can reduce the private benefits of Southern entrepreneurs by monitoring, which needs Northern labor. Severe monitoring by Northern firms also makes it difficult to obtain private benefits. Then, following Antras, Desai and Foley (2009), we specify the private benefits of Southern entrepreneurs as $(1-\mu)(1-\delta)v^M(t)C\left(h^{FN}(t)\right)$, where μ is the degree of investor protection or morality in the host country, and $C\left(h^{FN}(t)\right)$ is the monitoring function, which satisfies $\frac{dC\left(h^{FN}(t)\right)}{h^{FN}} < 0$. For simplicity, we specify the monitoring function as $C\left(h^{FN}(t)\right) = \frac{1}{a^M n(t) h^{FN}(t)}$, where $n(t)$ is a spillover and a^M is the efficiency of monitoring.

Then Northern firms choose the volume of employment engaged in technology transfer $h^{FN}(t)$, $h^{FS}(t)$ and the share of the transfer cost κ such that they maximize the transfer gain and Southern entrepreneurs choose to behave. This optimal contract is given as follows:

$$
\begin{aligned}
\max_{h^{FN}(t),h^{FS}(t),\kappa} \quad & (1-\delta)\phi v^M(t) - \kappa c^F(t) \\
s.t. \quad & c^F(t) = w^N h^{FN}(t) + w^S h^{FS}(t) \\
& n(t)\left[b\left(h^{FN}(t)\right)^{\frac{\eta-1}{\eta}} + (1-b)\left(h^{FS}(t)\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \geq f_F \\
& (1-\delta)(1-\phi)v^M(t) - (1-\kappa)c^F(t) \geq 0 \\
& (1-\delta)(1-\phi)v^M(t) - (1-\kappa)c^F(t) \geq (1-\mu)(1-\delta)v^M(t)\frac{1}{a^M n(t) h^{FN}(t)} - (1-\kappa)c^F(t)
\end{aligned}
\tag{29}
$$

The objective function is the transfer gain of Northern firms, which is the same as in the previous section except for the presence of κ.[25] The first constraint is definition of cost function on technology transfer. The second constraint is a resource constraint on technology transfer, which was used in the previous section. The third constraint is the participation constraint of Southern entrepreneurs, given that they have no other option for earning a profit. Southern entrepreneurs gain an exogenous $(1-\phi)$ share of profit and pay an endogenous κ share of cost. This constraint says that the expected gain of

[25] In this section, we allow the share of transfer cost κ to be selected to obtain a simple solution for the optimal contract. In our model, ϕ is exogenously given, which is an endogenous variable in Antras, Desai and Foley (2009). They analyzed how the share of profit and the share of cost are affected by the Southern investor protection. They showed that both are high in the low protection case, and vice versa. Although their setting is more realistic, our setting is rich enough to analyze the effect of Southern investor protection and the level of IPR protection on the growth rate.

Southern entrepreneurs must be nonnegative. The final constraint is an incentive compatibility constraint of Southern entrepreneurs. The left-hand-side of this inequality is the benefit of Southern entrepreneurs when they choose to behave, and the right-hand-side is the benefit of Southern entrepreneurs when they choose to misbehave. This inequality must hold so that Southern entrepreneurs choose not to misbehave.

The first constraint is always binding because excess investment leads to a high transfer cost, which reduces the transfer gain. The second constraint is also always binding in our setting because the Northern firm has an incentive that continues to decrease κ if this inequality is strictly positive. Then $\kappa = 1-(1-\delta)(1-\phi)\frac{v^M(t)}{c^F(t)}$ is satisfied. The third constraint is not binding when μ is high enough, which yields $h^{FN}(t) = \frac{1}{n(t)} F^{FN}(\omega(t))$, $h^{FS}(t) = \frac{1}{n(t)} F^{FS}(\omega(t))$ and $c^F(t) = v^N(t) F^{FC}(\omega(t))$. These results are the same as in the previous section. However, when μ is low, the third constraint is binding, which yields:

$$h^{FN}(t) = \frac{1}{n(t)} \hat{F}^{FN}, \hat{F}^{FN} \equiv \frac{1}{a^M} \frac{1-\mu}{1-\phi}, \tag{30}$$

$$h^{FS}(t) = \frac{1}{n(t)} \hat{F}^{FS}, \hat{F}^{FS} \equiv \left[\left(\frac{1}{1-b}\right) (f_F)^{\frac{1-\eta}{\eta}} - \left(\frac{b}{1-b}\right) \left(\frac{1}{a^M} \frac{1-\mu}{1-\phi}\right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{31}$$

$$c^F(t) = v^N(t) \hat{F}^{FC}(\omega(t)), \hat{F}^{FC}(\omega(t)) \equiv \left\{ \frac{1-\mu}{1-\phi^N} + \omega(t) \left[\left(\frac{1}{1-b}\right) (f_F)^{\frac{1-\eta}{\eta}} - \left(\frac{b}{1-b}\right) \left(\frac{1-\mu}{1-\phi^N}\right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \right\}, \tag{32}$$

where $\hat{F}^{FN} > F^{FN}(\omega(t))$, $\frac{d\hat{F}^{FN}}{d\mu} > 0$, $\hat{F}^{FC}(\omega(t)) > F^{FC}(\omega(t))$ and $\frac{d\hat{F}^{FC}(\omega(t))}{d\mu} > 0$ are satisfied. Therefore, when Southern investor protection is weak, more Northern laborers must be engaged in technology transfer than the optimal hiring level that the third constraint is not binding in order for the Southern entrepreneur not to misbehave, and therefore the cost of transfer is also higher than the optimal level. We can easily verify that relaxing Southern investor protection (decreasing μ) induces increasing $h^{FN}(t)$ and $c^F(t)$. The other setting, except for the cost of transfer, is the same as in the previous section, which gives us the following equations:

$$(\omega^*)^{\varepsilon-1}\left[\hat{F}^{FC}(\omega^*)+1\right]=(1-\delta)\,\phi, \tag{33}$$

$$g=\frac{M^N-(1-\zeta)(\varepsilon-1)\rho}{\zeta\hat{F}^{FN}+1+(1-\zeta)(\varepsilon-1)}, \tag{34}$$

$$g=\frac{M^S-\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}(1-\zeta)(\varepsilon-1)\rho}{\zeta\hat{F}^{FS}+\frac{X^S(\omega^*,\zeta,\psi^*)}{X^N(\omega^*,\zeta,\psi^*)}(1-\zeta)(\varepsilon-1)}, \tag{35}$$

instead of (23), (27) and (28). These equations and (24) determine the equilibrium value of ω, ζ, ψ and g. As discussed in the previous section, strengthening IPR protection reduces the growth rate when $\hat{F}^{FN}(\omega)$ is high. Then we get following proposition.

Proposition 4.1. *Strengthening IPR protection (decreasing δ) induces a low growth rate when Southern investor protection and the level of morality in the host country are weak.*

5 Conclusion

We developed a product-cycle model with costly technology transfer that requires resources from the North and South. We showed that whether strengthening IPR protection enhances growth or impedes growth depends heavily on the size of the transfer cost. This result is not obtained in related studies using a product-cycle model where the channel of technology transfer is FDI or licensing, because they do not take into account the resource cost of technology transfer in both countries. If only Southern labor is used in the transfer, shifts in production to the South always increase R&D activity in the North. If only Northern labor is used in the transfer, the extreme point equilibrium can be realized when the efficiency of transfer is low. By reason of the above, our generalization of technology transfer is meaningful. Moreover, we showed that the interior equilibrium is always saddle stable, which ensures comparative statics meaningful.

In the extended model, we introduced a contract theory framework, which is usually analyzed in a partial equilibrium model. Our general equilibrium model identified the effect of investor protection and the level of morality in developing countries on the growth rate through the labor market; weaker investor protection raises the monitoring cost, which wastes labor resource in the North and thus impedes R&D activities. This effect cannot be caught in partial equilibrium models.

We showed that characteristics of developing countries affect transfer cost. However, another factor affecting transfer cost is possible. Analyzing the various aspects of the transfer cost may yield interesting interactions between strengthening IPR protection and economic growth. This is an important direction for future research.

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6 Appendix

6.1 A1

In this appendix, we confirm the differential calculus of $X^N(\omega,\zeta,\psi) = \frac{(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}}{(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}}$ and $X^S(\omega,\zeta,\psi) = \frac{(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi\zeta(\omega)^{-\varepsilon}}{(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}}$. As $\varepsilon > 1$, $\omega < 1$ are satisfied, we can easily show $\frac{\partial X^N(\omega,\zeta,\psi)}{\partial\omega} = \frac{(\varepsilon-1)(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}\left[(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi\zeta(\omega)^{-\varepsilon}\right]}{\left[(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}\right]^2} > 0$, $\frac{\partial X^N(\omega,\zeta,\psi)}{\partial\zeta} = \frac{-\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi(\omega)^{1-\varepsilon}\right]}{\left[(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}\right]}$ 0, $\frac{X^N(\varepsilon,\zeta,\psi)}{\partial\psi} = -\frac{(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}\zeta\left[-\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+(\omega)^{1-\varepsilon}\right]}{\left[(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}\right]^2} < 0$ and $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial\zeta} = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi(\omega)^{-\varepsilon}\right]}{\left[(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{1-\varepsilon}+\psi\zeta(\omega)^{1-\varepsilon}\right]}$ 0. Since we can easily confirm $\frac{1}{X^S(\omega,\zeta,\psi)} = (\omega)^{\varepsilon}\frac{(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi\zeta} + \omega\frac{(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+\psi}{(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi}$ is increasing function of ω, $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial\omega} < 0$ is satisfied. Since $\frac{\partial}{\partial\psi}\frac{(\omega)^{\varepsilon}(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi\zeta} = \frac{(\omega)^{\varepsilon}\zeta(1-\zeta)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}\left[-\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon-1}+(\omega)^{-\varepsilon-1}\right]}{\left[(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi\zeta\right]^2} > 0$ and $\frac{\partial}{\partial\psi}\left(\omega\frac{(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+\psi}{(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi}\right) = \frac{\omega\left[-\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}+1\right](1-\psi)\zeta\left[\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}-\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}\right]}{\left[(1-\psi)\zeta\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\psi\zeta\right]^2} > 0$ are satisfied, $\frac{1}{X^S(\omega,\zeta,\psi)}$ is increasing function of ψ. Then $\frac{\partial X^S(\omega,\zeta,\psi)}{\partial\psi} < 0$ is satisfied.

6.2 A2

In this appendix, we confirm the interior BGP equilibrium is saddle stable. Linearizing (19), (20), (21) and (22) around the BGP equilibrium, we obtains:

$$\begin{pmatrix} \dot{\zeta}(t) \\ \dot{\psi}(t) \\ \dot{\chi}(t) \\ \dot{\omega}(t) \end{pmatrix} = \begin{pmatrix} q_{11} & q_{12} & q_{13} & q_{14} \\ 0 & q_{22} & 0 & 0 \\ q_{31} & q_{32} & q_{33} & q_{34} \\ 0 & 0 & 0 & q_{44} \end{pmatrix} \begin{pmatrix} \zeta^* - \zeta(t) \\ \psi^* - \psi(t) \\ \chi^* - \chi(t) \\ \omega^* - \omega(t) \end{pmatrix}, \tag{36}$$

where $q_{11} = -\frac{1}{\zeta^* F^{FS}(\omega^*)}\left[M^S - X^{S*}\chi^*\right] - \frac{1+\zeta^* F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\zeta^*} + \zeta^*\chi^*\frac{\partial X^{N*}}{\partial\zeta^*} < 0$, $q_{12} = -\frac{1+\zeta^* F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\psi^*} + \zeta^*\chi^*\frac{\partial X^{N*}}{\partial\psi^*} < 0$, $q_{13} = -\frac{1+\zeta(t)F^{FN}(\omega(t))}{F^{FS}(\omega(t))}X^{S*} + \zeta^* X^{N*}$, $q_{14} = \left[\zeta^*\frac{\partial F^{FN}(\omega^*)}{\partial\omega^*} - \frac{1+\zeta^* F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\frac{\partial F^{FS}(\omega^*)}{\partial\omega^*}\right]\frac{M^S - X^{S*}\chi^*}{F^{FS}(\omega^*)} - \frac{1+\zeta^* F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\omega^*} + \zeta^*\chi^*\frac{\partial X^{N*}}{\partial\omega^*} > 0$, $q_{22} = -\frac{M^S - X^{S*}\chi^*}{F^{FS}(\omega^*)\zeta^*} = -g^* < 0$, $q_{31} = \chi^*\frac{\partial}{\partial\zeta^*}\left[\frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)}\right] + \chi^*\frac{\partial X^{N*}}{\partial\zeta^*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\zeta^*} < 0$, $q_{32} = \chi^*\frac{\partial}{\partial\psi^*}\left[\frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)}\right] + \chi^*\frac{\partial X^{N*}}{\partial\psi^*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\psi^*} < 0$, $q_{33} = \frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)} + X^{N*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*}$, $q_{34} = \left[\frac{\partial F^{FN}(\omega^*)}{\partial\omega^*} - \frac{\partial F^{FS}(\omega^*)}{\partial\omega^*}\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\right]\frac{M^S - X^{S*}\chi^*}{F^{FS}(\omega^*)} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\chi^*\frac{\partial X^{S*}}{\partial\omega^*} + \frac{(1-\zeta^*)(\varepsilon-1)+1}{(1-\zeta^*)(\varepsilon-1)}\chi^*\frac{\partial X^{N*}}{\partial\omega^*} > 0$ and $q_{44} = \frac{X^{N*}\chi^*}{(1-\zeta^*)(\varepsilon-1)\frac{\partial F^{FC}(\omega^*)}{\partial\omega^*}}\left[(\varepsilon-1)(1-\delta)(\omega^*)^{-\varepsilon} + \frac{\partial F^{FC}(\omega^*)}{\partial\omega^*}\right] > 0$ are satisfied. We obtain characteristic equation of this matrix as $(q_{22}-\lambda)(q_{44}-\lambda)\left[\lambda^2 - (q_{11}+q_{33})\lambda + q_{11}q_{33} - q_{13}q_{31}\right] = 0$. Since $q_{22} < 0$ and $q_{44} > 0$ are satisfied, showing $q_{11}q_{33} - q_{13}q_{31} < 0$ guarantees two positive eigen-values and two negative eigen-values, which means that BGP equilibrium is saddle stable. Then we examine $\dot{\zeta}(t) = 0$ and $\dot{\chi}(t) = 0$ where ω^* and ψ^* satisfy (23) and (24) respectively. Since signs of q_{13} and q_{33} are ambiguous, we need to show $q_{11}q_{33} - q_{13}q_{31} = -q_{13}q_{33}\left(\left(-\frac{q_{11}}{q_{13}}\right) - \left(-\frac{q_{31}}{q_{33}}\right)\right) < 0$ with all possible combination of q_{13} and q_{33} satisfying $\zeta^* \geq 0$ and $\chi^* \geq 0$.

First we consider the case of $q_{13} > 0$ and $q_{33} > 0$. Since $q_{11}q_{33} - q_{13}q_{31} = -\underbrace{q_{13}}_{+}\underbrace{q_{33}}_{+}\left(\left(-\frac{q_{11}}{q_{13}}\right) - \left(-\frac{q_{31}}{q_{33}}\right)\right)$

is satisfied, showing that the slope of $\dot{\zeta}(t) = 0$ curve is greater than the sope of $\dot{\chi}(t) = 0$ curve ,$\left(\left(-\frac{q_{11}}{q_{13}}\right) - \left(-\frac{q_{31}}{q_{33}}\right)\right) > 0$, ensures $q_{11}q_{33} - q_{13}q_{31} < 0$. [26] Since $q_{33} = \frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)} + X^{N*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} = \frac{\rho + M^N - \frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S}{\chi^*}$ is satisfied, $\zeta^* < \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} + \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi(\omega^*)^{-\varepsilon}\right]}$ and $\rho + M^N - \frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S > 0$ should be satisfied. [27] Then $\dot{\chi}(t) = 0$ curve, $\chi = \frac{\rho + M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S}{\frac{1}{(1-\zeta)(\varepsilon-1)}X^N(\omega^*,\zeta,\psi^*) - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^S(\omega^*,\zeta,\psi^*)}$, is $\rho + M^N - \frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S > 0$ when $\zeta = 0$ and $+\infty$ when $\zeta = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} + \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]}$. Since $q_{13} = \zeta^* X^{N*} - \zeta^* \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} - X^{S*} = \frac{\zeta^*\left[M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right] - \frac{M^S}{F^{FS}(\omega^*)}}{\chi^*}$ is satisfied, $0 < \zeta^* < \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} + \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]}$ and $\zeta^* > \frac{\frac{M^S}{F^{FS}(\omega^*)}}{M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S} > 0$ should be satisfied. [28] Then $\dot{\zeta}(t) = 0$ curve, $\chi = \frac{\zeta\left[M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right] - \frac{1}{F^{FS}(\omega^*)}M^S}{\zeta\left[X^N(\omega^*,\zeta,\psi^*) - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^S(\omega^*,\zeta,\psi^*) - \frac{1}{F^{FS}(\omega^*)}\frac{X^S(\omega^*,\zeta,\psi^*)}{\zeta}\right]}$, is $-\infty$ when $\zeta = 0$, 0 when $\zeta = \frac{\frac{M^S}{F^{FS}(\omega^*)}}{M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S}$ and $+\infty$ when $\zeta = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} + \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]}$. Therefore the dynamics is described in (χ,ζ) space as depicted in Figure 4. Since we can confirm that the slope of $\dot{\zeta}(t) = 0$ curve is greater than the sope of $\dot{\chi}(t) = 0$ curve ,$\left(\left(-\frac{q_{11}}{q_{13}}\right) - \left(-\frac{q_{31}}{q_{33}}\right)\right) > 0$, $q_{11}q_{33} - q_{13}q_{31} = -\underbrace{q_{13}}_{+}\underbrace{q_{33}}_{+}\underbrace{\left(\left(-\frac{q_{11}}{q_{13}}\right) - \left(-\frac{q_{31}}{q_{33}}\right)\right)}_{+} < 0$ is satisfied.

[26] From (36), the slope of $\dot{\zeta}(t) = 0$ curve and $\dot{\chi}(t) = 0$ curve are given by $-\frac{q_{11}}{q_{13}}$ and $-\frac{q_{31}}{q_{33}}$ respectively.

[27] Since $\frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)} + X^{N*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} = \frac{\left[\frac{(1-\zeta^*)(\varepsilon-1)+1}{(\varepsilon-1)}\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*\zeta^*(\omega^*)^{-\varepsilon}\right]\right]}{(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + (1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{1-\varepsilon} + \psi^*\zeta^*(\omega^*)^{1-\varepsilon}}$ and $(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + (1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{1-\varepsilon} + \psi^*\zeta^*(\omega^*)^{1-\varepsilon} > 0$ are satisfied with $\zeta \geq 0$, $\frac{(1-\zeta^*)(\varepsilon-1)+1}{(\varepsilon-1)}\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*\zeta^*(\omega^*)^{-\varepsilon}\right] > 0$ is satisfied.

[28] Since $\zeta^* X^{N*} - \zeta^*\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} - X^{S*} = \frac{\zeta^*\left[(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \frac{\zeta^* F^{FN}(\omega^*) + F^{FS}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right]\right]}{(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + (1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{1-\varepsilon} + \psi^*\zeta^*(\omega^*)^{1-\varepsilon}}$ and $(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon} + (1-\psi^*)\zeta^*\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{1-\varepsilon} + \psi^*\zeta^*(\omega^*)^{1-\varepsilon} > 0$ are satisfied with $\zeta \geq 0$, $(1-\zeta^*)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} - \frac{\zeta^* F^{FN}(\omega^*) + F^{FS}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon} + \psi^*(\omega^*)^{-\varepsilon}\right] > 0$ is satisfied when $\zeta^* > 0$. From $\frac{\zeta^*\left[M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right] - \frac{M^S}{F^{FS}(\omega^*)}}{\chi^*} > 0$, $\frac{\frac{M^S}{F^{FS}(\omega^*)}}{M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S}$ should be positive with $\zeta^* \geq 0$ and $\chi^* \geq 0$.

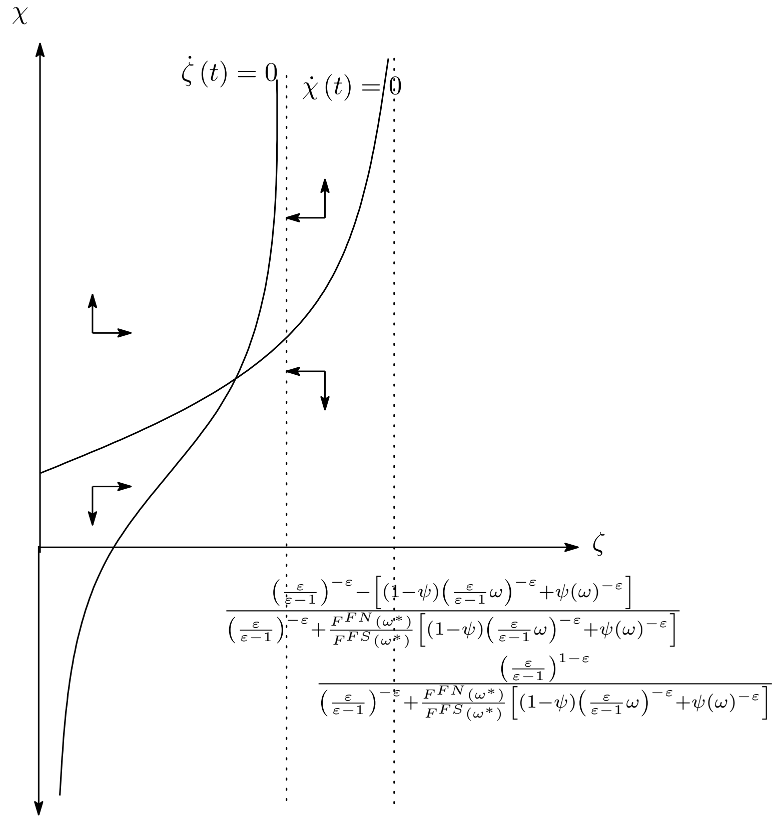

Figure 4. Dynamics in (χ, ζ) space (the case of $q_{13} > 0$ and $q_{33} > 0$).

Second we consider the case of $q_{13} < 0$ and $q_{33} < 0$. Since $q_{11}q_{33}-q_{13}q_{31} = -\underbrace{q_{13}}_{-}\underbrace{q_{33}}_{-}\left(\left(-\frac{q_{11}}{q_{13}}\right)-\left(-\frac{q_{31}}{q_{33}}\right)\right)$ is satisfied, showing that the slope of $\dot{\zeta}(t) = 0$ curve is greater than the sope of $\dot{\chi}(t) = 0$ curve ,$\left(\left(-\frac{q_{11}}{q_{13}}\right)-\left(-\frac{q_{31}}{q_{33}}\right)\right) > 0$, ensures $q_{11}q_{33} - q_{13}q_{31} < 0$. Since $q_{33} = \frac{X^{N*}}{(1-\zeta^*)(\varepsilon-1)} + X^{N*} - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} = \frac{\rho+M^N-\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S}{\chi^*}$ is satisfied, $\zeta^* > \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi(\omega^*)^{-\varepsilon}\right]}$ and $\rho+M^N-\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S < 0$ should be satisfied. Then $\dot{\chi}(t) = 0$ curve is $+\infty$ when $\zeta = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{1-\varepsilon}}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi^*(\omega^*)^{-\varepsilon}\right]}$ and 0 when $\zeta = +\infty$. Since $q_{13} = \zeta^* X^{N*} - \zeta^* \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}X^{S*} - X^{S*} = \frac{\zeta^*\left[M^N-\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right]-\frac{M^S}{F^{FS}(\omega^*)}}{\chi^*}$ is satisfied, $\zeta^* > \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}-\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi^*(\omega^*)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi^*(\omega^*)^{-\varepsilon}\right]}$ and $\zeta^* > \frac{\frac{M^S}{F^{FS}(\omega^*)}}{M^N-\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S}$ should be satisfied. [29] Then $\dot{\zeta}(t) = 0$ curve is $+\infty$ when $\zeta^* = \frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}-\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi^*(\omega^*)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi^*)\left(\frac{\varepsilon}{\varepsilon-1}\omega^*\right)^{-\varepsilon}+\psi^*(\omega^*)^{-\varepsilon}\right]}$ and has positive value when $\zeta = +\infty$. Therefore the dynamics is described in (χ, ζ) space as depicted in Figure 5. [30] Since we can confirm that the negative slope of $\dot{\zeta}(t) = 0$ curve is smaller than the negative slope of $\dot{\chi}(t) = 0$

[29]Note that from $q_{33} < 0$, $M^N - \frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S$ should be negative.

[30]This figure is depicted the case that $\frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}-\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi(\omega)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi(\omega)^{-\varepsilon}\right]} > 0$ is satisfied. Of course, it is possible that $\frac{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}-\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi(\omega)^{-\varepsilon}\right]}{\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon}+\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}\left[(1-\psi)\left(\frac{\varepsilon}{\varepsilon-1}\omega\right)^{-\varepsilon}+\psi(\omega)^{-\varepsilon}\right]} < 0$ is satisfied. Inthis case $\dot{\zeta}(t) = 0$ curve is $+\infty$ when $\zeta = 0$.

curve, $\left(\left(-\frac{q_{11}}{q_{13}}\right)-\left(-\frac{q_{31}}{q_{33}}\right)\right)>0$, $q_{11}q_{33}-q_{13}q_{31}=-\underbrace{q_{13}}_{-}\underbrace{q_{33}}_{-}\underbrace{\left(\left(-\frac{q_{11}}{q_{13}}\right)-\left(-\frac{q_{31}}{q_{33}}\right)\right)}_{+}<0$ is satisfied.

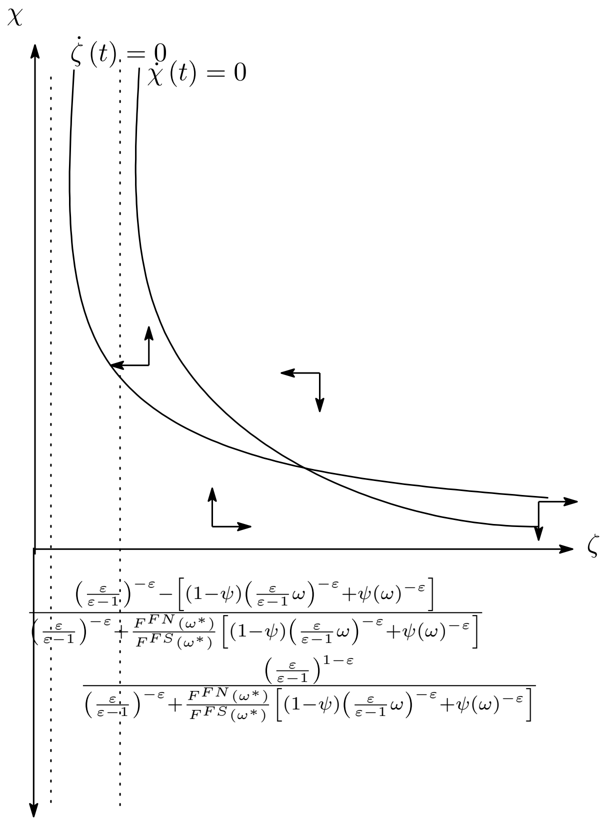

Figure 5. Dynamics in (χ,ζ) space (the case of $q_{13}<0$ and $q_{33}<0$).

Third we consider the case of $q_{13}<0$ and $q_{33}>0$. In this case, we can easily confirm $\underbrace{q_{11}}_{-}\underbrace{q_{33}}_{+}-\underbrace{q_{13}}_{-}\underbrace{q_{31}}_{-}<0$.

Finally we consider the case of $q_{13}>0$ and $q_{33}<0$. On one hand, $q_{33}=\frac{\rho+M^N-\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S}{\chi^*}<0$ should be satisfied. On the other hand $q_{13}=\frac{\zeta^*\left[M^N-\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right]-\frac{M^S}{F^{FS}(\omega^*)}}{\chi^*}>0$ should be satisfied. However, $\zeta^*\left[M^N-\frac{F^{FN}(\omega^*)}{F^{FS}(\omega^*)}M^S\right]-\frac{M^S}{F^{FS}(\omega^*)}$ cannnot be positive with $\zeta^*>0$ under $\rho+M^N-\frac{F^{FN}(\omega(t))}{F^{FS}(\omega(t))}M^S<0$. Therefore the case of $q_{13}>0$ and $q_{33}<0$ does not occur in the equilibrium.

With above discussion we confirmed that $q_{11}q_{33}-q_{13}q_{31}=-q_{13}q_{33}\left(\left(-\frac{q_{11}}{q_{13}}\right)-\left(-\frac{q_{31}}{q_{33}}\right)\right)<0$ is satisfied with all possible combination of q_{13} and q_{33}. Then BGP equilibrium is saddle stable.