Patent Protection, Technological Change and Wage Inequality*

Shiyuan Pan[†] Tailong Li[‡] Ying Zhou[§] Heng-fu Zou[¶]

Abstract

We develop a directed-technological-change model to address the issue of the optimal patent system and investigate how the optimal patent system influences the direction of technological change and the inequality of wage, where patents are categorized as skill- and labor-complementary. The major results are: (i) Finite patent breadth maximizes the social welfare level; (ii) Optimal patent breadth increases with the amount of skilled (unskilled) workers; (iii) Optimal patent protection is skill-biased, because an increase in the amount of skilled workers increases the dynamic benefits of the protection for skill-complementary patents via the economy of scale of skill-complementary technology; (iv) Skill-biased patent protection skews inventions towards skills, thus increasing wage inequality; And, (v) international trade leads to strong protection for skill-complementary patents, hence increasing skill premia.

Keywords: Patent Breadth; Skill-Biased Patent Protection; Skill-Biased Technological Change; Wage Inequality; Growth

JEL Classification: O31; O34; J31

*We thank Angus C. Chu, Menghong Yang, Zhonglai Kou, Ziyin Zhuang and participants of the 1st Chinese Economics, Finance and Management Forum at Shenzhen University for helpful comments. All errors are ours.

[†]School of Economics and Center for Research of Private Economy, Zhejiang University, 38 Zheda Road, Hangzhou 310027, P.R.China. E-mail Address: shiyuanpan@zju.edu.cn.

[‡]School of Economics & Management, Zhejiang Sci-Tech University, West District, Xiasha Higher Education Zone, Hangzhou 310018, P.R. China. E-mail Address: m9845@163.com.

[§]School of Economics, Zhejiang University, 38 Zheda Road, Hangzhou 310027, P.R.China. E-mail Address: 21001046@zju.edu.cn.

[¶]Central University of Finance and Economics CEMA, 39 South College Road, Haidian District, Beijing 100081, P.R.China, Wuhan University IAS, Peking University and China Development Bank. E-mail Address: zouhengfu@gmail.com.

1 Facts[1]

Over the decades, global patent systems have gone through three significant changes: (1) Patent protection has been strengthened, in the sense that exclusive rights conferred by the patent have been reinforced; (2) Patent protection has become skill-biased, i.e., the protection for skill-complementary inventions is relatively strong;[2] (3) Patent systems are now harmonized worldwide.

1.1 Strengthening Patent Rights

At the end of the 1970s, patent protection in the United States was widely thought to be weak and ineffective. This situation was essentially reversed in the 1980s, in particular by the creation of Court of Appeals for the Federal Circuit (CAFC) in 1982, which was assigned patent litigation appeals from the federal district courts (Jaffe, 1999). The establishment of CAFC was viewed as one of the most important changes in the history of the U.S. patent system, and it has had a fundamental effect on the patent litigation that was followed.

The creation of CAFC strengthens patent rights by increasing the success rate of plaintiffs who appeal. For example, between 1953 and 1978, appeals courts upheld only 62 percent of district court decisions, but this percentage increased to 90 percent between 1982 and 1990. In addition, while appeals courts reversed 12 percent of district court verdicts that found patents to be invalid or not infringed between 1953 and 1980, that percentage increased to 28 percent between 1982 and 1990 (Koenig, 1980, Harmon, 1991). Furthermore, after CAFC was established, patentees were able to request a preliminary injunction preventing an infringing firm from using the patented invention during the period of the trial (Lanjouw and Lerner, 1998).

In 1977, the European Patent Office (EPO) was established by the European Patent Convention (EPC). This was a milestone in the history of patent protection in European countries. As a centralized patent office, EPO is in charge of patent application and grants on behalf of all contracting states. The fact that EPO introduced examination and opposition proceedings in the system, in contrast to the registration systems prevailing in most national Patent and Trademark Offices, significantly reinforced the rights of patent holders in Europe and precluded patents that would have been easily been overthrown in later courts (Martinez and Guellec, 2003).

[1] This section is based on Kortum and Lerner (1998), Jaffe (1999), Sakakibara and Branstetter (2001), Martinez and Guellec (2003), Merrill, Levin, and Myers (2004).

[2] We focus mainly on these two change phenomena as demonstrated in the United States, Europe and Japan.

One of the most important reforms to the Japanese patent law system was in 1988, when Japan changed from the single-claim system to the multi-claim system. The reform, one of the most significant in modern history, allowed patent applicants to define the coverage of an invention with multiple claims that, could be either independent of or dependent of other claims. Some patent experts argued that, after the reform, the scope of invention covered by a single patent application equaled or even exceeded that conferred by the U.S. and European patent systems. Therefore, this reform substantially reinforced patent rights in Japan (Sakakibara and Branstetter, 2001).

According to Lerner (2001), who has studied 150 years of policy shifts as demonstrated in 60 countries, policies aimed at strengthening patent protection worldwide dominated since 1850.[3] As Lerner explains, he examined the following five categories of patent policies were examined: (1) range of subjects, (2) duration of patent, (3) cost of patent, (4) limitation on patent, and, (5) measures of discrimination against foreign patentees.

1.2 Skill-Biased Patent Protection

Before 1980 there was serious doubt as to whether biotechnology, software and business methods could be patentability subject matter. Yet the number of patents for them has been continuously increasing since they entered the realm of patentability at the beginning of the 1980s in many developed countries. In Diamond v. Chakrabarty (1980) the U.S. Supreme Court confirmed the eligibility of patenting organisms with artificially engineered genetic characteristics.[4] In 2001, the United States Patent and Trademark Office (USPTO) exhibited clearly that gene compositions are patentable. Although there are some differences between the patent law in the United States and those in Europe and Japan, the general principles about patentability of biotechnology are fundamentally the same. After steady growth in the 1990s, in 2000 the number of biotechnology patent applications in OECD declined from about 11,500 to 8,700 in 2006. The average share of biotechnology patents in total patents, however, is about 6.5 percent, still a high figure (Van Beuzekom and Arundel, 2009).

Before 1980 computer programs were considered a mathematical algorithm and hence deemed unpatentable.[5] But in 1981, the US Supreme Court upheld the

[3] Moreover, relaxed limitations on antitrust and compulsory licensing also suggest strengthening patent protection.

[4] Diamond v. Chakrabarty, 447 U.S. 303, 100 S. Ct. 2204, 65 L. Ed. 3d 144, available at 1980 U.S. LEXIS 112, 206 U.S.P.Q. (BNA) 193 (1980). See Merrill, Levin, and Myers (2004) for further details.

[5] Although computer programs were unpatentable before 1980, there already existed few software patents.

patentability of computer software, Diamond v. Diehr,[6] because they produce a technical effect in a machine. Later kinds of software that affect physical processes were therefore also patentable. Table 1 reports that the number of software patents granted per year and the share of software patents in total patents in the United States have grown significantly, most notably, in 2002, when the share reached almost 15 percent.[7] In 1993 the Japanese Patent Office (JPO) verified that software inventions are patentable when they are concretely realized by using hardware resources. On the other hand, the patent for software in Europe has been rejected, as computer programs are explicitly excluded from patentability in Article 52 of the EPC. However, some decisions made by the EPO Technical Board of Appeal validated patents for computer programs in Europe if the inventions are claimed with reference to hardware, and if the inventive step makes a technical contribution to the state of the art (Martinez and Guellec, 2003).

The CAFC upheld the patentability of business methods, as well as that of software in a 1998 case, State Street Bank & Trust Co. v. Signature Financial Group.[8] This decision confirmed that business methods are patentable, and placed very few limits on the patentability of software and financial service products (Jaffe, 1999).[9] As a consequence, the number of business method patents has increased substantially during the last decade. Table 2 shows that the number of business method patents (USPTO Class 705) is 83 in 1988, 493 in 1998 and 1,692 in 2008, and that they account for 1.1 percent of all utility patents in 1988, 3.7 percent in 1998 and 10.4 percent in 2008. Despite the limits put on the patentability of business methods, the JPO started granting patents for them in 1997.[10] As in the case of software, business method patents are denied in European countries, due to Article 52 of the EPC. However, during the 1980s and early 1990s, the EPO awarded patents for most of the business method inventions to which USPTO already granted patents (Martinez and Guellec, 2003).

Clearly, most inventions of biotechnology, software and business methods are complementing to skills, although some of them are used by unskilled workers. Therefore,

---

[6] Diamond v. Diehr, 450 U.S. 175, 101 S. Ct. 1048, 67 L. Ed. 2d 155, available at 1981 U.S. LEXIS 73, 209 U.S.P.Q. (BNA) 1 (1981). See Merrill, Levin, and Myers (2004) for further details.

[7] This table is taken from Bessen and Hunt (2007).

[8] State St. Bank & Trust Co. v. Signature Fin. Group, 149 F.3d 1368, available at 1998 U.S. App. LEXIS 16869, 47 U.S.P.Q.2d (BNA) 1596 (Fed. Cir. 1998). See Merrill, Levin, and Myers (2004) for further details.

[9] Hall (2003) has found that thousands of business method patents have been granted at the USPTO between 1997 and 2001.

[10] For instance, JPO states that business methods are unpatentable when "the invention can be easily conceived through combining publicly known means and methods by those having common knowledge on the business field related to the patent application and technological knowledge on the computer technology" in its examination guidelines published in 2000.

the patentability of them suggests that patent protection is now more skill-biased than over past decades. In fact, the greater breadth of skill-complementary patents further demonstrates that patent protection is skill-biased. A famous example of broader claims in biotechnology is when Johns Hopkins University was assigned a patent that they claimed covered not only the My-10 antibody but also other antibodies that bind to CD34, although that patent only showed effects with respect to the My-10 antibody (Bar-Shalom, A. and R. Cook-Deegan, 2002).[11] Owing to 'function claims' in the field of software and business methods, that is, patents claiming 'problems' rather than 'solutions', any invention developed for that problem would infringe the patent (Martinez and Guellec, 2003). Therefore, the breadth of patent for software and business methods is substantially broad.

1.3 Harmonization of Patent Systems Worldwide

The Paris Convention is commonly remembered as the first step to international harmonization of patent protection. And the establishment of the World Intellectual Property Organization (WIPO) in 1967 made a further step towards the global protection of patents, as did the WIPO's administration of the Patent Cooperation Treaty (PCT) from 1970. However, since there were no effective measures for settling disputes, the PCT was partly unenforceable, and large differences in patent policies across countries were common until the mid-1990s.

During the 1980s and early 1990s, patent protection in some developing countries proved inadequate. For instance, biotechnology, software and business methods were widely considered unpatentable, and most importantly, procedures and resources for the enforcement of patent laws were often inadequate at protecting patent holders under even the existing weak standards of patent protection (Maskus, 2000). After most developed countries expressed dissatisfaction with this situation, the improvement of intellectual property rights (IPRs) protection became one of the highest priorities at the Uruguay Round of trade talks. As a result of the Uruguay Round, the scope of the WTO was expanded to include an agreement on Trade-Related Intellectual Property Rights (TRIPs).

A major turning point in the global protection of intellectual property (patent protection) was the enforcement of an agreement on TRIPs in 1995. TRIPs brings intellectual property rights into the realm of the WTO dispute resolution procedures, hence it is the first comprehensive and enforceable global pact set of rules covering IPRs (Maskus, 2000). All WTO member countries have signed on to TRIPs and are

[11] For further details see Bar-Shalom, A. and R. Cook-Deegan (2002), Merrill, Levin, and Myers (2004).

obligated to implement the most rudimentary rules for IPRs protection based on the U.S. and EU practices. Moreover, when additional countries join the WTO, they must meet the minimum standard required by TRIPs. Therefore, the implementation of the agreement on TRIPs has significantly increased harmonization of IPRs protection worldwide.[12]

It is notable that pressure from the United States and the European Union played a critical role in the international harmonization of IPRs protection (e.g., Maskus, 2000, Grossman and Lai, 2004).[13] Widely publicized American negotiations and threats in the 1980s and 1990s resulted in stronger IPRs legislation in South Korea, Argentina, Brazil, Thailand, Taiwan, and China. Similarly, European Union negotiations and assistance advanced IPRs protection in Egypt and Turkey (Maskus, 2000).

These facts must be interpreted with caution. Nevertheless, they suggest that we should be aware of the changes in global patent systems over the past few decades. In this paper, we propose a unified theory to answer the following questions: (1) Is infinite patent breadth optimal in a directed-technological-change economy? (2) Why does the protection for patents, in particular skill-complementary patents, increase? (2) How does free trade affect the changes in patent systems? (3) What is the impact of skill-biased patent protection on wage inequality? (4) How does the international harmonization of patent systems place an impact on skill premia?

The paper proceeds as follows. In the next section, we review the literature. In Section 3, building on Acemoglu (1998, 2007, 2009) and the literature on an optimal patent system, we present the basic model to explore the effect of patent protection on the direction of technological change and wage inequality. In Section 4, we extend the basic model to investigate the impact of international trade on skill-biased patent protection and skill premia. Conclusions are found in Section 5.

2 Literature Review

Endogenous-growth literature has viewed invention as the engine of economic growth (Romer, 1990, Grossman and Helpman, 1991, Aghion and Howitt, 1992).[14] Ever since Schumpeter (1942), we have known that it is necessary to provide inventors with some form of market power to give them incentives to invent in the first place.

---

[12] Since TRIPs only sets out minimum standards with which countries must comply, it does not aim at complete harmonization.

[13] Maskus (2000) has also pointed out that business interests are another important reason why some developing countries, in particular advanced developing countries, increases IPRs protection.

[14] This literature is comprehensively reviewed by Romer (1994), etc.

Consequently, two branches of literature have been devoted to the topic of optimal patent protection, namely, that of the patent system that best solves the trade-off between providing enough incentives to invent ex ante and minimizing dead-weight losses ex post. One branch of literature has studied optimal patent protection in a partial equilibrium model (see, for example, Nordhaus, 1969, Scherer, 1972, Gilbert and Shapiro, 1990, Klemperer, 1990, Gallini, 1992). Another branch of literature has looked at the optimal patent system within a framework of general equilibrium (e.g., Judd, 1985, Goh and Oliver, 2002, Kwan and Lai, 2003, Iwaisako and Futagami, 2003, Horii and Iwaisako, 2007, Futagami and Iwaisako, 2007, Chu, 2009, 2010).

Recently, several models have been developed to address the issue of directed technological change, in which technology is complementary to skilled or unskilled workers (Acemoglu, 1998, 2002a, 2003, 2007, Thoenig and Verdier, 2003). We would like to combine the literature on the optimal patent system and the one on directed technological change in this paper. Consequently, we construct an endogenous growth model to study the optimal patent system in the directed-technological-change economy and how the optimal patent system impacts the direction of technological change and wage inequality, in which patents are classified as skill- and labor-complementary. The first main results are: (1) Optimal patent breadth is finite, and increases with the quantity of skilled workers;[15] (2) Optimal patent protection is skill-biased. The basic idea is that the more skilled workers, the greater the economy of scale of skill-complementary technology, and thus the more the dynamic benefits of protection for skill-complementary patent; (3) Skill-biased patent protection induces technological change towards skills, thus increasing wage inequality. Therefore, based on the evidence of an increased supply of skills over the past decades, the model provides an interpretation for the following interesting questions: Why does the protection for patents, in particular skill-complementary patents, increase? What is the impact of skill-biased patent protection on wage inequality?

We show first that, in an open economy, international trade will induce skill-biased patent protection, because opening trade increases the relative price of the skill-intensive good, therefore increasing the relative dynamic benefits of protection for skill-complementary patents. Hence, the model can explain how globalization influences the recent changes in patent systems worldwide. Then, in the tradition of Acemoglu (2003), Neary (2002) and Theonig and Verdier (2003), we illustrate that increased international trade could be a major cause of the increase in wage inequality because it induces skill-biased technological change. The mechanism, however, is

[15] A number of studies have documented that the relative supply of skills have increased over the past decades (see, for example, Acemoglu, 2002b, and references therein).

different. In Acemoglu's paper, the main mechanism is that trade in final goods increases the relative price of the skill-intensive good, thus encouraging technological change towards skilled workers and increasing skill premia. Neary (2002), Thoenig and Verdier (2003) show that free trade causes knowledge diffusion and increases the possibilities of imitation, hence encouraging firms to adopt defensive innovation strategies to reinforce non-replication measures. This strategy leads to an increase in the relative demand for skills, hence raising skill premia. The main mechanism in this paper is that skill-biased patent protection and the market size effect induce technological change towards skilled workers,[16] thus increasing wage inequality.

The paper is related to Deardorff (1992), Maskus (2000), Yang and Maskus (2001), Grossman and Lai (2004), among others. Deardorff (1992), Grossman and Lai (2004) have argued that while the welfare of developed countries certainly rises with harmonization of patent systems worldwide, that of developing countries may fall, and may well fall by more than the increase in the welfare of the developed countries. Maskus (2000) has stressed that in the short-term, global patent protection decreases the welfare of developing countries, but it would benefit all countries in the long-run. Yang and Maskus (2001) have pointed out that strong intellectual property rights in the South promotes innovation in the North and technology transfer. In this paper, we give attention to the effect of the harmonization of patent systems on wage inequality in developing countries. It is shown that stronger protection of skill-complementary patents, as forced by the U.S. and European countries after globalization, could be a major cause of the increase in wage inequality in developing countries,[17] since it encourages skill bias of technology.

The related literature also includes Cozzi and Galli (2009) and Adams (2008). Cozzi and Galli (2009) have stated that a strengthening of intellectual property rights will lead to an increase in wage inequality. They focus on a closed-economy quality-ladder model, whereas we consider a model with skill-biased technological change. Adams (2008) have reported that strengthening intellectual property rights and openness are positively correlated with income inequality in developing countries.

[16] The market size effect encourages the development of technologies that have a larger market. Actually, Acemoglu (2002a) has shown that there are three forces determining the direction of technological change: the price effect, the market size effect and the effect of innovation possibilities frontier. See Acemolgu's paper for details.

[17] Many papers have shown that skill premia increase after globalization in many developing countries (see, for example, Wood, 1997, Hason and Harrison, 1999, Attanasio et al., 2004).

3 The Model

We now develop a simple model to explore why the optimal patent protection is skill-biased and how the skill-biased patent protection affects the degree of skill bias of technology and wage inequality, in which patents are categorized as skill- and labor-complementary.

3.1 The Environment

Consider an economy populated with H skilled workers and L unskilled workers, who supply one unit labor inelastically.[18] Representative consumers are with constant relative risk aversion (CRRA) preference. These consumers maximize intertemproral utility[19]

$$\int_0^\infty \frac{C(t)^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt, \tag{1}$$

where $C(t)$ is consumption at time t, θ is the coefficient of relative risk aversion (or intertemporal elasticity of substitution) and ρ is the subjective discount rate. We drop the time index as long as this causes no confusion.

The budget constraint of the consumer is:

$$C + I + R \leq Y = \left[(Y_l)^{\frac{\epsilon-1}{\epsilon}} + (Y_h)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{2}$$

where I is investment, and R is total R&D expenditure. The production function in (2) implies that output aggregate is defined over a constant elasticity of substitution (CES) aggregate of a labor-intensive good, Y_l, and a skill-intensive good, Y_h. Parameter $\epsilon \in [0, \infty)$ is the elasticity of substitution between the two goods. When $\epsilon = \infty$, the two goods are perfect substitutes, and the function is linear. When $\epsilon = 1$, the function is Cobb-Douglas. And when $\epsilon = 0$, there is no substitution between the two goods, and the production function is Leontieff.

Following Acemoglu (1998, 2002, 2009), the labor-intensive good is produced from unskilled workers and different types of labor-complementary machines or intermediates, while the skill-intensive good is produced from skilled workers and a set of differentiated skill-complementary machines. The key assumption is that none of these machines are used by both types of workers. Specifically, the production functions of the skill-intensive and the labor-intensive good are as follows[20]:

[18] Endogenous skill acquisition will not change our qualitative results.

[19] In this paper, we assume $0 < \theta < 1$, because only in the this circumstance, an increase protection for patent has the dynamic benefit and static cost as pointed out in Section 2.

[20] The main results are not altered when we assume that $Y_h = \frac{\Phi}{1-\alpha} \int_0^{A_h} k_h(i)^{1-\alpha} di \cdot (ZH)^\alpha$ and $Y_l =$

$$Y_h = \frac{1}{1-\alpha} \int_0^{A_h} k_h(i)^{1-\alpha} \, di \cdot (ZH)^{\alpha}, \tag{3}$$

and

$$Y_l = \frac{1}{1-\alpha} \int_0^{A_l} k_l(i)^{1-\alpha} \, di \cdot L^{\alpha}, \tag{4}$$

where $\alpha \in (0,1)$, A_z is the number of machines complementary to z, $k_z(i)$ is the quantity of machines of variety i together with workers of skill level z, $z = h$ or l. Indexes h and l denote skilled and unskilled workers, respectively. $Z > 1$ measures the relative productivity of skilled workers. Consequently, ZH represents the effective amount of skilled workers. The production functions in (3) and (4) exhibit constant returns to scale in input factors: the double of labor and the quantity of all intermediate goods doubles output. However, the production possibilities set of the economy will exhibit increasing returns to scale because technological knowledge, A_z, are endogenized.

Technological progress takes the form of the increase in A_z over time. Using μ units of the final good, a firm can develop a new variety of either type of machine. Therefore, the accumulation equation of technological knowledge is given by[21]

$$\dot{A}_z = \frac{X_z}{\mu}, \tag{5}$$

where X_z denotes total output devoted to improving the technology complementary to $z = h$ or l. Equation (5) implies that with a total expenditure of X, there will be X/μ new varieties invented. For convenience, we assume the marginal cost for the production of any machine is constant and equal to one unit of the final good.

A firm that invents a machine obtains the protection granted by patent. As do Goh and Oliver (2002), we assume that the life of a patent is infinite and we focus on the issue of patent breadth. Following Gilbert and Shapiro (1990), Diwan and Rodrik (1991), Iwaisako and Futagami (2003), we define patent breadth as the ability of the patentee to raise the prices for the patented goods over the lifetime of patent. Strong protection granted by the patent increases the number of substitute products that infringe on the patent or raises the costs of imitation, thus allowing the patentee to raise prices. In particular, the prices charged by firms producing the goods that embody inventions are given by

---

$\frac{\Psi}{1-\alpha} \int_0^{A_l} k_l(i)^{1-\alpha} \, di \cdot L^{\alpha}$, where $\Phi \neq \Phi$.

[21] Assumption $\dot{A}_z = \frac{X_z}{\mu_z}$ where $\mu_h \neq \mu_l$ will not change our main results.

$$\chi_z(i) = \chi_z = 1 + \beta_z, \ z = h \text{ or } l, \tag{6}$$

where β_z is the measure of patent breadth. The bigger the β_z, the greater the patent breadth. Using some algebra, we know that the monopoly price maximizing the profits of patent products is $\frac{1}{1-\alpha}$. Therefore, $\beta_z \leq \frac{\alpha}{1-\alpha}$, and patent breadth is infinite as equality holds.

3.2 Equilibrium

Taking advantage of (3), (4) and (6), we obtain the quantity of machines complementary to skilled and unskilled workers:

$$k_h(i) = \left[p_h / (1 + \beta_h)\right]^{1/\alpha} \cdot ZH, \tag{7}$$

and

$$k_l(i) = \left[p_l / (1 + \beta_l)\right]^{1/\alpha} \cdot L, \tag{8}$$

where p_h and p_l are the prices of the skill-intensive and the labor-intensive good, respectively. We normalize the price of consumption aggregate as one. Therefore, the monopoly profits of any intermediate good used by skilled and unskilled workers at time τ are:

$$\pi_h(\tau) = \beta_h \left[p_h / (1 + \beta_h)\right]^{1/\alpha} \cdot ZH, \tag{9}$$

and

$$\pi_l(\tau) = \beta_l \left[p_l / (1 + \beta_l)\right]^{1/\alpha} \cdot L. \tag{10}$$

It is simple to show that when $\beta_z < \frac{\alpha}{1-\alpha}$, $\frac{\partial \pi_z(\tau)}{\partial \beta_z} > 0$ and when $\beta_z = \frac{\alpha}{1-\alpha}$, $\frac{\partial \pi_z(\tau)}{\partial \beta_z} = 0$. This implies that the monopoly profits of a new variety of machines increase with patent breadth, and maximum extent of patent breadth makes the profits highest.

Plugging (7) and (8) into (3) and (4) respectively, we obtain

$$Y_h = \frac{1}{1-\alpha} \left[p_h / (1 + \beta_h)\right]^{(1-\alpha)/\alpha} \cdot A_h ZH \text{ and } Y_l = \frac{1}{1-\alpha} \left[p_l / (1 + \beta_l)\right]^{(1-\alpha)/\alpha} \cdot A_l L. \tag{11}$$

The market for the skill-intensive and the labor-intensive good is competitive, thus using (2) and (11), we find that the relative price of the two goods is

$$p = \frac{p_h}{p_l} = \left(\frac{1+\beta_h}{1+\beta_l}\right)^{\frac{1-\alpha}{1+\alpha(\epsilon-1)}} \left(\frac{A_h}{A_l} \cdot \frac{ZH}{L}\right)^{-\frac{\alpha}{1+\alpha(\epsilon-1)}} . \tag{12}$$

This shows that when either the technology is highly skill-biased (high A_h/A_l) or the relative supply of skilled workers is great (high H/L), the relative supply of the skill-intensive good is large and the relative price is low. The relatively strong protection for the skill-complementary patent (high β_h/β_l) leads to a decrease in the relative demand for machines complementing skills, thus declining the relative supply of the skill-intensive good and increasing the relative price.

Free-entry in the R&D business implies that the cost of invention, μ, should be equal to the present value of profits of any intermediate good, V_z. That is,

$$\mu = \int_t^{\infty} e^{-\int_t^{\tau} r(s)ds} \pi_z(\tau) d\tau = V_z, \tag{13}$$

where r is the rental price of capital. It suggests that in the equilibrium the flow profits from selling labor- and skill-complementary machines should be equal, i.e., $\pi_h = \pi_l$. Therefore, inspection of (9) and (10) results in

$$\frac{p_h}{p_l} = \frac{1+\beta_h}{1+\beta_l} \left(\frac{\beta_h}{\beta_l} \cdot \frac{ZH}{L}\right)^{-\alpha} . \tag{14}$$

Intuitively, the bigger the amount of skilled workers, the larger the market for skill-complementary machines, thus the lower the relative price of the skill-intensive good to ensure $\pi_h = \pi_l$. Moreover, it is clear that $\frac{\partial\left[(1+\beta_z)\beta_z^{-\alpha}\right]}{\partial \beta_z} \leq 0$. This implies that the stronger the protection for the skill-complementary patent, the larger the profits of new invention complementing skills, thus the relative price of the skill-intensive good has to be lower to make the flow profits of labor- and skill- complementary machines equal.

Combining (12) and (14), we obtain

$$\frac{A_h}{A_l} = \left(\frac{1+\beta_h}{1+\beta_l}\right)^{-\epsilon} \left(\frac{\beta_h}{\beta_l}\right)^{1+\alpha(\epsilon-1)} \left(\frac{ZH}{L}\right)^{\alpha(\epsilon-1)} . \tag{15}$$

By (2), (11) and (12), we know that the elasticity of substitution between skilled and unskilled workers is $1 + \alpha(\epsilon - 1)$. Thus, (15) shows that the relative degree of skill bias of technology, A_h/A_l, is determined by the relative factor supply and the elasticity of substitution between the two factors, skilled and unskilled workers. When $\epsilon > 1$, i.e., when the two factors are gross substitutes, technological change is towards skilled workers; while $\epsilon < 1$, i.e., when the two factors are gross complements, technological change is unskilled-biased (skill-replacing).[22] Almost all estimates show an elasticity of substitution between skilled and unskilled workers greater than 1, most likely greater than 1.4, and perhaps as large as 2, that is, $1 \leq 1 + \alpha(\epsilon - 1) \leq 2$ (see, for example, Freeman, 1986, Acemoglu, 2002b). Hence, we take ϵ to be greater than 1 in the rest of the paper. In addition, using some algebra, we find that $\frac{\partial (1+\beta_z)^{-\epsilon}(\beta_z)^{1+\alpha(\epsilon-1)}}{\partial \beta_z} > 0$ as $\beta_z \leq \frac{\alpha}{1-\alpha}$. Therefore, the degree of skill bias of technology, A_h/A_l, rises with the breadth of the skill-complementary patent. Strong protection for the skill-complementary patent results in an increase in the profits selling skill-complementary machines, thus inducing skill-biased technological change.

Inspection of the production function in (2) yields

$$\left(p_l^{1-\epsilon} + p_h^{1-\epsilon}\right)^{\frac{1}{1-\epsilon}} = 1 \tag{16}$$

Using (14) and (16), we find the price indices to be

$$p_h = \left[1 + \left(\frac{1+\beta_h}{1+\beta_l}\right)^{\epsilon-1} \left(\frac{\beta_h Z H}{\beta_l L}\right)^{\alpha(1-\epsilon)}\right]^{-\frac{1}{1-\epsilon}} \text{ and } p_l = \left[1 + \left(\frac{1+\beta_h}{1+\beta_l}\right)^{1-\epsilon} \left(\frac{\beta_h Z H}{\beta_l L}\right)^{-\alpha(1-\epsilon)}\right]^{-\frac{1}{1-\epsilon}}. \tag{17}$$

Therefore, the price of the skill-intensive good is lower (and the price of the labor-intensive good is higher) when the relative supply of skilled workers is larger or the relative protection for the skill-complementary patent is stronger.

Maximization of utility function in (1), subject to a standard budget constraint, yields the usual formula for the growth rate of consumption:

$$\frac{\dot{C}}{C} = \frac{1}{\theta}(r - \rho), \tag{18}$$

It says that either the intertemporal elasticity of substitution is bigger or the discount rate is smaller, the growth rate of consumption is higher.

Combining (9), (10), (13), (17) and (18), we obtain the equilibrium economic growth rate:[23]

[22] When the elasticity of substitution is equal to 1, technological change is never biased towards skilled or unskilled workers.

[23] The growth rate expression suggests that the parameters must be assumed to be such that $g \geq 0$. Otherwise, the constraint that A_z cannot be decreasing would be violated, and the free-entry condition for R&D would not hold with equality. Therefore, the measure of patent breadth, β_h and β_l, will not be zero.

$$g = \frac{1}{\theta}\left\{\frac{\left[(1+\beta_h)^{1-\epsilon}(\beta_h ZH)^{\alpha(\epsilon-1)} + (1+\beta_l)^{1-\epsilon}(\beta_l L)^{\alpha(\epsilon-1)}\right]^{\frac{1}{\alpha(\epsilon-1)}}}{\mu} - \rho\right\}. \tag{19}$$

Obviously, $\frac{\partial g}{\partial \beta_z} \geq 0$, that is, strong patent protection increases the growth rate. This denotes the dynamic benefits of the patent system. Intuitively, great patent breadth raises the profits of invention, thus inducing resources devoted to inventing technology and a high growth rate. When there is a bigger amount of skilled (unskilled) workers, the market for machines complementing skilled (unskilled) workers is larger, hence the profits of invention are higher. Therefore, the growth rate increases with the quantity of skilled and unskilled workers, i.e., $\frac{\partial g}{\partial H} > 0$ and $\frac{\partial g}{\partial L} > 0$.

Now let us briefly investigate the stability of the equilibrium. For given patent breadth, according to Acemoglu and Zilibotti (2001), we know that off the balanced growth path, there will only be one type of innovation. That is, if $V_h/V_l > 1$, only skill-complementary innovation is taken place, and if $V_h/V_l < 1$, innovators only undertake labor-complementary R&D. Clearly, when A_h/A_l is lower than in (15), $V_h/V_l > 1$, and vice versa when A_h/A_l is too high. As a consequence, the transitional dynamics of the economy are stable.[24]

3.3 Optimal Patent System

Since the utility function is continuous on $\beta_z \in \left[0, \frac{\alpha}{1-\alpha}\right]$, there exists β_z^* maximizing social welfare.[25] Output growth maximization, however, may not be equivalent to welfare maximization. Therefore, infinite patent breadth, which maximizes the output growth rate, is not optimal. Intuitively, when patent breadth is infinite, the benefit of increasing patent protection is zero (i.e., $\left.\frac{\partial g}{\partial \beta_z}\right|_{\beta_z = \frac{\alpha}{1-\alpha}} = 0$), but the cost is bigger than zero because of monopoly pricing. Hence, we state the following proposition

Proposition 1 *The patent breadth that maximizes social welfare is finite, i.e.,* $\beta_z^* < \frac{\alpha}{1-\alpha}$.

Proof. See the Appendix. ■

[24] See Acemoglu and Zilibotti (2001) for a formal and detail proof.

[25] Maybe β_z^* is unique. However, the analysis is substantially complicated. Fortunately, the following results are independent of whether β_z^* is singleton or not. Indeed, when β_z^* is not unique, it is reasonable to choose β_z^* that maximizes the growth rate as the optimal patent breadth. Moreover, it is easy to know that $\frac{\partial U(\beta_h, \beta_l)}{\partial \beta_z} > 0$ at β_z which satisfies $g(\beta_h, \beta_l) = 0$. Therefore, optimal β_z is interior solution, i.e., $\frac{\partial U(\beta_h, \beta_l)}{\partial \beta_z} = 0$.

Propositions 1 shows that finite patent breadth maximizes the social welfare level. This result is similar to the results of many existing studies. For instance, Gilbert and Shapiro (1990) have argued that narrow patent is optimal because broad patent is costly for society in that it gives excessive monopoly power to the patent holder.

In recent decades, the relative quantity of skilled workers has increased sharply in most developed countries. To the best of our knowledge, there is no previous paper investigating the impact of an increased supply of skills on the optimal patent system.

Proposition 2 *The more the quantity of (unskilled) skilled workers, the greater the breadth of patent, that is,* $\frac{\partial(\beta_z)^*}{\partial ZH} > 0$ *and* $\frac{\partial(\beta_z)^*}{\partial L} > 0$*. Moreover, if the effective amount of skilled workers is bigger (smaller) than the amount of unskilled workers, the optimal breadth of the skill-complementary patent is broader (narrower) than that of the labor-complementary patent, and if the effective amount of skilled workers is equal to the amount of unskilled workers, the optimal breadth of the two types of patents is same. That is, when* $ZH > L$*,* $\beta_h^* > \beta_l^*$*; while* $ZH = L$*,* $\beta_h^* = \beta_l^*$*; when* $ZH < L$*,* $\beta_h^* < \beta_l^*$*.*[26]

Proof. See the Appendix. ■

The intuition is straightforward. The more the supply of skilled workers, the greater the economy of scale of knowledge complementing skilled workers, thus the broader the breadth of the skill-complementary patent. That is, $\frac{\partial(\beta_h)^*}{\partial H} > 0$. Moreover, the relative price of the labor-intensive good rises with the amount of skilled workers, thus the economy of scale of knowledge complementing unskilled workers becomes large. As a consequence, the protection for labor-complementary patent strengthens, namely, $\frac{\partial(\beta_l)^*}{\partial H} > 0$. By symmetry, $\frac{\partial(\beta_z)^*}{\partial L} > 0$.

During recent decades, the supply of unskilled and skilled workers has increased in developed countries, hence proposition 2 can provide an interpretation for why protection for patents has been strengthened in developed countries. Moreover, it is reasonable that before the 1980s the amount of the effective skilled workers is much smaller than that of unskilled workers. Over past decades, the supply of skilled workers has increased more than that of unskilled workers in developed countries. If the amount of the effective skilled workers is greater than that of unskilled workers after the 1980s, then this proposition predicts protection for skill-complementary patent strengthens. Indeed, even if the amount of the effective skilled workers is still smaller

[26] When we take into account of the other differences in the production of the skill-intensive and the labor-intensive good, even though $ZH < L$, $\beta_h^* > \beta_l^*$ may hold. For example, if the production technology of the skill-intensive good is assumed to be $Y_h = \frac{\phi}{1-\alpha} \int_0^{A_h} k_h(i)^{1-\alpha} di \cdot (ZH)^\alpha$ where $\phi > 1$, then $\phi^{1/\alpha} ZH > L$, $\beta_h^* > \beta_l^*$.

than that of unskilled workers, the former is much close to the latter.[27] In this circumstance, we can say protection for skill-complementary patent increases relatively more. Thus this proposition can provide an explanation for why protection for skill-complementary patent has risen substantially. Since there are less skilled workers in developing countries, one implication of the proposition is that strengthening global patent protection, with help from the United States and Europe, may decrease the social welfare level of many developing countries.[28]

Proposition 2 implies that, theoretically, it is optimal to have different patent protection for different type of innovation. For instance, it will be beneficial to strengthen protection for labor-complementary patent in developing countries, whereas it will be better off to increase protection for skill-complementary patent in developed countries. Consequently, it may be time to consider whether or not patent rules that are neutral to technologies in the real world are the best.

Taking advantage of (15) and proposition 2, we know that there are two mechanisms causing skill-biased technological change, one standard, i.e., the large relative amount of skilled workers induces skill-biased technological change via the market size effect, another new, that is, it encourages technological change towards skills through the effect of skill-biased patent protection.

As an important consequence of proposition 2, the patent protection is skill-biased. Precisely, it is easy to see that, in any line segment of $ZH = L$, $\frac{\partial(\beta_h)^*}{\partial ZH} > \frac{\partial(\beta_l)^*}{\partial ZH} > 0$ and $\frac{\partial(\beta_l)^*}{\partial L} > \frac{\partial(\beta_h)^*}{\partial L} > 0$, respectively. This implies, at least in a neighborhood of the segment, there is a skill-biased patent protection, that is, for $ZH > L$, $ZH' > L'$ and $\frac{ZH'}{L'} > \frac{ZH}{L}$, $\frac{(\beta'_h)^*}{(\beta'_l)^*} > \frac{\beta_h^*}{\beta_l^*}$, and for $ZH < L$, $ZH' < L'$ and $\frac{ZH'}{L'} < \frac{ZH}{L}$, $\frac{(\beta'_h)^*}{(\beta'_l)^*} < \frac{\beta_h^*}{\beta_l^*}$. Hence, we'd like to claim that a relative increasing of skill workers will lead to a relatively stronger protection towards skill-complementary patent. In the following analysis, when we address the issue of the direction of patent protection, we will restrict our attention to the case where ZH and L are close.

3.4 Discussion

As vast quantities of empirical papers have documented over past decades, there has been an increase in wage inequality in most developed and developing countries.

[27] In recent years, the share of skilled workers in labor force is over 20 percent in OECD countries. Furthermore, when L is sufficiently large, an increase in L increases β_l^* little, because optimal breadth is finite. As a result, for a small $\frac{ZH}{L}$, an increase in $\frac{ZH}{L}$ may lead to $\frac{\beta_h^*}{\beta_l^*}$ increase.

[28] The patent breadth determined in the decentralized equilibrium may be narrower than the social optimal patent breadth. Therefore, strengthening gobal patent protection may increase the social welfare level of middle-income countries.

The standard explanation for this pattern is that technological change has been skill-biased over this period. We argue here that skill-biased patent protection could be another major cause.

Now let us first address the problem of wage inequality in developed countries. Inspection of (11) yields the ratio of wages paid for skilled workers to the ones paid for unskilled workers

$$\frac{w_h}{w_l} = \left(\frac{p_h}{p_l}\right)^{1/\alpha} \cdot \left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(1-\alpha)/\alpha} \frac{A_h Z}{A_l}. \tag{20}$$

It suggests that skill premia are greater when either the relative price of the skill-intensive good is higher or the technology is more skill-biased. Equation (20) also says that when the impact of skill-biased patent protection on the direction of technological change is not considered, great protection for skill-complementary patent reduces the demand for machines used by skilled workers, due to the high price, and thus the marginal product of skilled workers (or wages) declines.

Combining (12), (15) and (20), we get the ratio of wages paid for skilled workers to the ones paid for unskilled workers:

$$\frac{w_h}{w_l} = \underbrace{Z\left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(\epsilon-1)}\left(\frac{\beta_h}{\beta_l}\right)^{\alpha(\epsilon-1)}}_{\substack{\text{effect of skill-biased} \\ \text{patent protection}}} \cdot \underbrace{\left(\frac{ZH}{L}\right)^{\alpha(\epsilon-1)-1}}_{\substack{\text{effect of skill-biased} \\ \text{technological change}}}. \tag{21}$$

When β_z and $\frac{\beta_h}{\beta_l}$ increase, $\left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(\epsilon-1)}\left(\frac{\beta_h}{\beta_l}\right)^{\alpha(\epsilon-1)}$ becomes larger. As pointed out in the above analysis, β_z and $\frac{\beta_h}{\beta_l}$ are likely to have increased over past decades. As a consequence, $\left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(\epsilon-1)}\left(\frac{\beta_h}{\beta_l}\right)^{\alpha(\epsilon-1)}$ has enlarged over past decades. In this circumstance, we state

Proposition 3 *When $\alpha(\epsilon-1)-1>0$, skill-biased patent protection and technological change lead to an increase in skill premia in developed countries.*

The United States and Europe have been dissatisfied with the situation of weak IPRs protection in many developing countries. Hence, they have tried to force developing countries to increase the protection for patents, in particular for skill-complementary patents after globalization. We will show that this will lead to an increase in wage inequality in developing countries and then discuss the problem further in the context of an open economy.

Let us assume $ZH^N > L^N$ in developed countries and $ZH^S < L^S$ in developing countries.[29] By proposition 2, we know that in the autarkic economy $\beta_h^S < \beta_l^S$. Therefore, (21) implies that skill premia in developing countries in autarky are

$$\frac{w_h^S}{w_l^S} < Z\left(\frac{ZH^S}{L^S}\right)^{\alpha(\epsilon-1)-1}. \tag{22}$$

Now if patent protection is harmonized all over the world and under pressures of the developed countries the developing countries are forced to enforce the patent protection, $\left(\beta_h^N, \beta_l^N\right)$, then by (21), we obtain[30]

$$\frac{\left(w_h^S\right)'}{\left(w_l^S\right)'} > Z\left(\frac{ZH^S}{L^S}\right)^{\alpha(\epsilon-1)-1} \tag{23}$$

Comparing (22) and (23), we obtain the following proposition

Proposition 4 *Harmonization of global patent protection increases wage inequality in developing countries.*

Intuitively, stronger protection of skill-complementary patents forced by the U.S. and European countries induces skill-biased technological change, thus increasing skill premia in developing countries.

4 International Trade, Skill-Biased Patent Protection and Wage Inequality

We now explore the impact of international trade on the patent system and on wage inequality. For this purpose, we consider a world economy consisting of two countries, one a developed country and another a developing country. What distinguishes the two countries is the abundance of skills. For simplicity, suppose that $ZH^N > L^N$ and $ZH^S < L^S$, i.e., the developed country is more abundant in skills.[31]

Producers in the developing country adopt machines invented in the developed country. However, because these machines may not be appropriate to its need, the

[29] As a matter of fact, if $\frac{\beta_h^N}{\beta_l^N} > \frac{\beta_h^S}{\beta_l^S}$, the main results remain unchanged.

[30] The main results still apply to the case where the patent protection in the developing country is $\left(\phi\beta_h^N, \psi\beta_l^N\right)$, where $\phi < 1$, $\psi < 1$, $\phi\beta_h^N > \beta_h^S$, $\psi\beta_l^N > \beta_l^S$ and $\phi\beta_h^N > \psi\beta_l^N$.

[31] The value of the skill-intensive good is larger than that of the labor-intensive good in many developed countries, while the former is smaller than the latter in many developing countries. As a consequence, the assumption may be reasonable.

productivity in the developing country is proportional to the productivity in the developed country. More formally, following Acemoglu (2003) we assume

$$A_z^S = \lambda A_z^N, \tag{24}$$

where $\lambda \leq 1$.[32] Furthermore, suppose that the developing country is forced to upgrade its patent system to implement the most rudimentary rules for IPRs protection based on the U.S. and EU practices under their pressures. Therefore, the monopoly profits of skill-complementary machines and the ones of labor-complementary machines invented in the developed country at time τ in the open economy are:

$$\pi_h^o(\tau) = \frac{\beta_h^o}{(1+\beta_h^o)^{1/\alpha}} (p_h^o)^{1/\alpha} \left(ZH^N + vZH^S\right), \tag{25}$$

and

$$\pi_l^o(\tau) = \frac{\beta_l^o}{(1+\beta_l^o)^{1/\alpha}} (p_l^o)^{1/\alpha} \left(L^N + vL^S\right), \tag{26}$$

where o represents the open economy, and $0 < \nu \leq 1$ captures the fact that R&D firms in the developed country can only seize the proportion of revenues generated by machine sales in the developing country.[33] For simplicity, we assume $\lambda = v$.[34]

In the balanced growth path (BGP), the flow profits from selling labor- and skill-complementary machines should be equal, i.e., $\pi_h^o(\tau) = \pi_l^o(\tau)$. It implies that

$$\frac{p_h^o}{p_l^o} = \frac{1+\beta_h^o}{1+\beta_l^o}\left(\frac{\beta_h^o}{\beta_l^o}\cdot\frac{ZH^N + \lambda ZH^S}{L^N + \lambda L^S}\right)^{-\alpha}. \tag{27}$$

Taking advantage of (16) and (27), we obtain the price indices to be

$$p_h^o = \left[1 + \left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{\epsilon-1}\left(\frac{\beta_h^o}{\beta_l^o}\cdot\frac{ZH^N + \lambda ZH^S}{L^N + \lambda L^S}\right)^{\alpha(1-\epsilon)}\right]^{-\frac{1}{1-\epsilon}}, \tag{28}$$

and

[32] If the cost of innovation is higher in the developing country than in the developed country, then when international trade is considered, the former is likely to adopt machines from the latter, because the latter has comparative advantage in innovation.

[33] Although developing countries are forced to upgrade patent protection, the degree of patent protection in developing countries may still be lower than that in developed countries.

[34] Usually, λ and v are not equated. When they are small, however, we can take them to be equal in the following analysis.

$$p_l^o = \left[1 + \left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{1-\epsilon} \left(\frac{\beta_h^o}{\beta_l^o} \cdot \frac{ZH^N + \lambda ZH^S}{L^N + \lambda L^S}\right)^{-\alpha(1-\epsilon)}\right]^{-\frac{1}{1-\epsilon}}. \quad (29)$$

Since $H^N/L^N > H^S/L^S$, $\frac{ZH^N+\lambda ZH^S}{L^N+\lambda L^S} < H^N/L^N$. Equations (28) and (29) suggest that, all other things being equal, the price of the skill-intensive good increases, while the one of the labor-intensive good decreases after opening-up, i.e., $p_h^o > p_h^N$ and $p_l^o < p_l^N$.[35] The intuition that we use is straightforward. The relative profitability of invention complementing skills declines after opening-up, due to the relatively smaller quantity of skill-complementary machines used in the developing country. Therefore, the price of the skill-intensive good goes up to make $\pi_h^o(\tau) = \pi_l^o(\tau)$ equal.

Using some algebra, we obtain the world economic growth rate in BGP:

$$g^o = \frac{1}{\theta}\left\{\frac{\left[(1+\beta_h^o)^{1-\epsilon}\left(\beta_h^o\left(ZH^N+\lambda ZH^S\right)\right)^{\alpha(\epsilon-1)} + (1+\beta_l^o)^{1-\epsilon}\left(\beta_l^o\left(L^N+\lambda L^S\right)\right)^{\alpha(\epsilon-1)}\right]^{\frac{1}{\alpha(\epsilon-1)}}}{\mu} - \rho\right\}. \quad (30)$$

Since international trade strengthens patent protection for machines invented in the developed country, their profits increase. Therefore, more resources are devoted to inventing machines in the developed country. This implies the increase in the world growth rate.

Comparing (19) and (30), we find that $\frac{\partial g^o}{\partial \beta_z^o} > \frac{\partial g}{\partial \beta_z}$, namely, opening-up increases dynamic benefits of patent protection in the developed country. Hence, free trade will result in greater protection for patents. Summarizing the foregoing analysis and using proposition 2, we state

Proposition 5 *International trade leads to an increase in optimal patent protection, namely,* $(\beta_z^o)^* > \beta_z^*$.

We omit the straightforward proof of the proposition, and center our attention on an extended application of the skill-biased patent protection arguments below proposition 2. If we replace the increments λZH^S and λL^S by $\lambda_1 ZH^S$ and $\lambda_2 L^S$, respectively, then, for $\lambda_1 > \lambda_2$ and $\frac{ZH^N+\lambda_1 ZH^S}{L^N+\lambda_2 L^S} > \frac{ZH^N}{L^N}$, the trade will impact the relative strength of patent protection by causing $\frac{(\beta_h^o)^*}{(\beta_l^o)^*} > \frac{\beta_h^*}{\beta_l^*}$. Therefore, free trade may encourage skill-biased patent protection.[36]

[35] Clealy, $p_h^o < p_h^S$ and $p_l^o > p_l^S$.

[36] Since the developed country exports the skill-intensive good and imports labor-intensive good, it will strengthen the protection for skill-complementary patent to gain benefits from trade. In this sense, globalization results in skill-biased patent protection.

Now we address the problem of wage inequality in the open economy. After trade openness all consumers in the world face the same relative price and will have the same relative consumption of the skill-intensive good and the labor-intensive good. Hence, using (24), we obtain the relative price of the skill-intensive good in the open economy

$$\frac{p_h^o}{p_l^o} = \left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{\frac{1-\alpha}{1+\alpha(\epsilon-1)}} \left(\frac{A_h}{A_l} \cdot \frac{ZH^N + \lambda ZH^S}{L^N + \lambda L^S}\right)^{-\frac{\alpha}{1+\alpha(\epsilon-1)}}. \tag{31}$$

Combining (27) and (31), we obtain

$$\frac{A_h^o}{A_l^o} = \underbrace{\left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{-\epsilon} \left(\frac{\beta_h^o}{\beta_l^o}\right)^{1+\alpha(\epsilon-1)}}_{\text{effect of skill-biased patent protection}} \cdot \underbrace{\left(\frac{ZH^N + \lambda ZH^S}{L^N + \lambda L^S}\right)^{\alpha(\epsilon-1)}}_{\text{market size effect}}. \tag{32}$$

On the one hand, open trade encourages skill-biased patent protection, thus inducing invention complementary to skills. On the other hand, trade openness declines the relative strength of the market size effect (i.e., $\frac{ZH^N+\lambda ZH^S}{L^N+\lambda L^S} < \frac{ZH^N}{L^N}$), thus inducing skill-replacing technological change. Therefore, whether free trade induces skill-biased technological change depends on the relative strengths of the two effects.

Inspecting (12), (31) and (32), we get that $\frac{(w_h^N)^o}{(w_l^N)^o} = Z\left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{-(\epsilon-1)} \left(\frac{\beta_h^o}{\beta_l^o}\right)^{\alpha(\epsilon-1)} \cdot \left(\frac{ZH^N+\lambda ZH^S}{L^N+\lambda L^S}\right)^{\alpha(\epsilon-1)-1}$. When $\lambda \to 0$, $\frac{(w_h^N)^o}{(w_l^N)^o} > \frac{w_h^N}{w_l^N} = Z\left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(\epsilon-1)} \left(\frac{\beta_h}{\beta_l}\right)^{\alpha(\epsilon-1)} \left(\frac{ZH^N}{L^N}\right)^{\alpha(\epsilon-1)-1}$. As a result, by the continuity, we know that there exists $\widehat{\lambda} > 0$ such that if $\lambda \leq \widehat{\lambda}$,

$$\frac{(w_h^N)^o}{(w_l^N)^o} > \frac{w_h^N}{w_l^N}. \tag{33}$$

The intuition is straightforward. When $\lambda \leq \widehat{\lambda}$, free trade encourages skill-biased patent protection, thus inducing inventions complementary to skills and an increase in wage inequality. In addition, international trade results in an increase in the relative price of the skill-intensive good, and therefore skill premia increase. Summarizing the foregoing analysis, we state

Proposition 6 *There exists $\widehat{\lambda} > 0$, such that if $\lambda \leq \widehat{\lambda}$, skill premia in the developed country increase.*

Using $A_z^S = \lambda A_z^N$ and some algebra, we obtain

$$\begin{aligned}\frac{\left(w_h^S\right)^o}{\left(w_l^S\right)^o} &= Z\left(\frac{1+\beta_h^o}{1+\beta_l^o}\right)^{-(\epsilon-1)}\left(\frac{\beta_h^o}{\beta_l^o}\right)^{\alpha(\epsilon-1)}\left(\frac{ZH^N+\lambda ZH^S}{L^N+\lambda L^S}\right)^{\alpha(\epsilon-1)-1} \\ &> Z\left(\frac{1+\beta_h}{1+\beta_l}\right)^{-(\epsilon-1)}\left(\frac{\beta_h}{\beta_l}\right)^{\alpha(\epsilon-1)}\left(\frac{ZH^S}{L^S}\right)^{\alpha(\epsilon-1)-1} \qquad (34)\end{aligned}$$

By proposition 5 and (34), it is obvious that when $\alpha(\epsilon-1)-1>0$, free trade leads to an increase in wage inequality in the developing country, i.e., $\frac{\left(w_h^S\right)^o}{\left(w_l^S\right)^o} > \frac{w_h^S}{w_l^S}$. Therefore, we state the following proposition:

Proposition 7 *When $\alpha(\epsilon-1)-1>0$, international trade increases skill premia in the developing country.*

Intuitively, free trade encourages skill-biased patent protection, thus stimulating inventions complementary to skills and an increase in wage inequality in the developing country.

5 Conclusion

In this paper, a simple model has been constructed to explore the optimal patent system in the directed-technological-change economy and the impact of the optimal patent system on the direction of technological change and wage inequality, in which patent is categorized as skill- and labor-complementary. We show that: (1) Optimal patent breadth is finite, and rises with the quantity of skilled workers; (2) An increase in the amount of skilled workers increases the protection for the skill-complementary patent, i.e., optimal patent protection is skill-biased; (3) Skill-biased patent protection increases wage inequality by encouraging skill-biased technological change; (4) Free trade leads to a strong protection for patents, especially for skill-complementary patents, thus increasing skill premia.

The United States and Europe are dissatisfied with the inadequate protection of IPRs in developing countries, hence they strongly encourage many developing countries to enforce skill-biased patent systems. We show that greater protection for skill-complementary patents, implemented under pressures from the United States and Europe countries after globalization could be a major cause of the increase in wage inequality in developing countries, since it encourages skill-biased technological change.

However, it must be stressed that we relied on the strong assumption of infinite patent life to obtain unambiguous results. The obvious next issue on the research agenda is to check the robustness of our results to departures from the assumption.

References

[1] Acemoglu, Daron, 1998, "Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality", *Quarterly Journal of Economics*, 113, pp. 1055-1090.

[2] Acemoglu, Daron and Fabrizio Zilibotti, 2001, "Productivity Differences", *Quarterly Journal of Economics*, 116, pp. 563-606.

[3] Acemoglu, Daron, 2002a, "Directed Technical Change", *Review of Economic Studies*, 69, pp. 781-809.

[4] Acemoglu, Daron, 2002b, "Technical Change, Inequality, and the Labor Market", *Journal of Economic Literature*, 40, pp. 7-72.

[5] Acemoglu, Daron, 2003, "Patterns of Skill Premia", *Review of Economic Studies*, 70, pp. 199-230.

[6] Acemoglu, Daron, 2007, "Equilibrium Bias of Technology", *Econometrica*, 75, pp. 1371-1409.

[7] Adams, S., 2008, "Globalization and Income Inequality: Implications for Intellectual Property Rights", *Journal of Policy Modeling*, 30, pp. 725-735.

[8] Aghion, Philippe and Peter Howitt, 1992, "A Model of Growth through Creative Destruction", *Econometrica*, 60, pp. 321-351.

[9] Attanasio, O., P. Goldberg, and N. Pavcnik, 2004, "Trade Reforms and Wage Inequality in Columbia", *Journal of Development Economic*, 74, pp. 331-366.

[10] Bar-Shalom, A. and R. Cook-Deegan, 2002, "Patents and Innovation in Cancer Therapeutics: Lessons from CellPro", *Millbank Quarterly*, 80, pp. 637-676.

[11] Bessen, James and Rober Hunt, 2007, "An Empirical Look at Software Patents", *Journal of Economics & Management*, 16, pp. 157-189.

[12] Chu, Angus C., 2009, "Effects of Blocking Patents on R&D: A Quantitative DGE Analysis", *Journal of Economic Growth*, 14, pp. 55-78.

[13] Chu, Angus C., "Effects of Patent Length on R&D: A Quantitative DGE Analysis", *Journal of Economics*, 2010, 99, pp. 117-140.

[14] Cozzi, G., and S. Galli, 2009, "Upstream Innovation Protection: Common Law Evolution and the Dynamics of Wage Inequality", University of Glasgow Working Papers No. 2009-20.

[15] Deardorff, Alan, 1992, "Welfare Effects of Global Patent Protection", *Economica*, 59, pp. 35-51.

[16] Diwan, I., and D. Rodrik, 1991, "Patents, Appropriate Technology, and North-South Trade", *Journal of International Economics*, 30, pp. 27-47.

[17] Freeman, Richard, 1986, "Demand For Education", in Orley Ashenfelter and Richard Layard, eds., *Handbook of Labor Economics*, 1, North Holland: El Sevier Publishing Company.

[18] Futagami, K. and T. Iwaisako, 2007, "Dynamic Aanalysis of Patent Policy in An Endogenous Growth Model", *Journal of Economic Theory*, 132, pp. 306-334.

[19] Gallini, Nancy T., 1992, "Patent Policy and Costly Imitation", *RAND Journal of Economics*, 23, pp. 52-63.

[20] Gilbert, Richard and Carl Shapiro, 1990, "Optimal Patent Length and Breadth", *RAND Journal of Economics*, 21, pp. 106-112.

[21] Goh, Ai-Ting and Jacques Oliver, 2002, "Optimal Patent Protection in a Two-Sector Economy", *International Economic Review,* 43, pp. 1191-1214.

[22] Grossman, Gene M. and Elhanan Helpman, *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press, 1991.

[23] Grossman, Gene M. and Edwin Lai, 2004, "International Protection of Intellectual Property", *American Economic Review*, 94, pp.1635-1653.

[24] Hall, B., 2003, "Business Method Patents, Innovation and Policy", NBER Working Paper No. 9717.

[25] Harmon, R., *Patents and the Federal Circuit*, Washington: Bureau of National Affairs, 1991.

[26] Harrison, Ann and Gordon Hanson, 1999, "Who Gains from Trade Reform? Some Remaining Puzzles", *Journal of Development Economics*, 59, pp. 125-154.

[27] Horii, Ryo and T. Iwaisako, 2007, "Economic Growth with Imperfect Protection of Intellectual Property Rights", *Journal of Economics*, 90, pp. 45-85.

[28] Iwaisako, T. and K. Futagami, 2003, "Patent Policy in an Endogenous Growth Model", *Journal of Economics*, 78, pp. 239-258.

[29] Jaffe, A., 1999, "The US Patent System in Transition: Policy Innovation and the Innovation Process", NBER Working Paper 7280.

[30] Judd, Kenneth L., 1985, "On the performance of Patents", *Econometrica*, 53, pp. 567-585.

[31] Klemperer, Paul, 1990, "How Broad Should the Scope of Patent Protection Be?", *RAND Journal of Economics*, 21, pp. 113-130.

[32] Koenig, Gloria, *Patent Invalidity: A Statistical and Substantive Analysis*, New York: Clark Boardman, 1980.

[33] Kortum, Samuel and Josh Lerner, 1998, "Stronger Protection or Technological Revolution: What Is Behind the Recent Surge in Patenting?", *Carnegie-Rochester Conference Series on Public Policy*, 48, pp. 247-304.

[34] Kwan, Y., and Edwin Lai, 2003, "Intellectual Property Rights Protection and Endogenous Economic Growth", *Journal of Economic Dynamics and Control*, 27, pp. 853-873.

[35] Lanjouw, Jean and Josh Lerner, 1998, "The Enforcement of Intellectual Property Rights: A Survey of the Empirical Literature", *Annales d'Economie et de Statistique*, July, No. 49/50, pp. 223-246..

[36] Lerner, J., 2002, "150 Years of Patent Protection", NBER Working Paper No. 7477.

[37] Marrtinez C. and Guellec D., 2004, "Overview of Recent Changes and Comparison of Patent Regimes in the United States, Japan and Europe", Chapter 7 in *Patents, Innovation and Economic Performance*, OECD Conference Proceedings, Paris: OECD.

[38] Maskus, K.E., *Intellectual property rights in the global economy*, Washington: Institute for International Economics, 2000.

[39] Merrill, Stephen, Richard Levin and Mark Myers (ed.), *A Patent System for the 21st Century*, Washington: The National Academies Press, 2004.

[40] Neary, P., 2002, "Foreign Competition and Wage Inequality", *Review of International Economics*, 10, pp. 680-693.

[41] Nordhaus, W. D., *Invention, Growth, and Welfare; A Theoretical Treatment of Technological Change*, Cambridge: MIT Press, 1969.

[42] Romer, Paul M., 1990, "Endogenous Technological Change", *Journal of Political Economy*, 98, pp. s71-s102.

[43] Romer, Paul M., 1994, "The Origins of Endogenous Growth", *Journal of Economic Perspectives*, 8, pp. 3-22.

[44] Sakakibara, M. and L. Branstetter, 2001, "Do Stronger Patents Induce More Innovation? Evidence from the 1988 Japanese Patent Law Reforms", *RAND Journal of Economics*, 32, pp. 77-100.

[45] Scherer, F. M., 1972, "Nordhaus' Theory of Optimal Patent Life: A Geometric Reinterpretation", *American Economic Review*, 62, pp. 422-427

[46] Schumpeter, Joseph, *Capitalism, Socialism and Democracy,* New York: Harper, 1942.

[47] Van Beuzekom, B. and A. Arundel, *OECD Biotechnology Statistics 2009*, Paris: OECD, 2009.

[48] Wood, A., 1997, "Openness and Wage Inequality in Developing Countries: The Latin American Challenge to East Asia Conventional Wisdom", *World Bank Economic Review,* 11, pp. 33-57.

[49] Yang, Guifang and K. E. Maskus, 2001, "Intellectual Property Rights, Licensing, and Innovation in an Endogenous Product Cycle Model", *Journal of International Economics*, 53, pp. 169-187.

Table 1: Number of Software Patents

	Patents Issued			Successful Patent Applications	
	Software Patents	Total Utility Patents	Software/ Total (%)	Software Patents	Total Utility Patents
1976	765	70,226	1.1	853	65,804
1977	884	65,269	1.4	1,094	65,978
1978	897	66,102	1.4	1,170	65,601
1979	795	48,854	1.6	1,439	65,726
1980	1,080	61,819	1.7	1,633	66,491
1981	1,275	65,771	1.9	1,821	63,910
1982	1,402	57,888	2.4	2,233	65,009
1983	1,443	56,860	2.5	2,297	61,563
1984	1,939	67,200	2.9	2,641	67,071
1985	2,453	71,661	3.4	2,924	71,442
1986	2,657	70,860	3.7	3,482	75,088
1987	3,530	82,952	4.3	4,055	81,458
1988	3,495	77,924	4.5	4,841	90,134
1989	4,974	95,537	5.2	5,755	96,077
1990	4,704	90,364	5.2	6,471	99,254
1991	5,347	96,513	5.5	7,091	100,016
1992	5,862	97,444	6.0	8,149	103,307
1993	6,756	98,342	6.9	9,459	106,848
1994	8,031	101,676	7.9	12,251	120,380
1995	9,000	101,419	8.9	16,617	137,661
1996	11,359	109,645	10.4	17,085	131,450
1997	12,262	111,983	10.9	13,087	114,881
1998	19,355	147,519	13.1		
1999	20,385	153,486	13.3		
2000	21,065	157,595	13.4		
2001	23,406	166,158	14.1		
2002	24,981	167,438	14,9		

Source: Bessen and Hunt (2007)

Table 2: Number of Business Method Patents

	Patents Issued		
	Business Method Patents	Total Utility Patents	Business Method / Total (%)
1988	83	78,333	1.1
1989	128	96,011	1.4
1990	100	90,877	1.4
1991	95	96,918	1.6
1992	89	97,921	1.7
1993	164	98,815	1.9
1994	171	102,109	2.4
1995	119	101,855	2.5
1996	155	110,032	2.9
1997	247	112,338	3.4
1998	493	147,876	3.7
1999	719	153,984	4.3
2000	729	158,119	4.5
2001	480	166,584	5.2
2002	451	167,833	5.2
2003	431	169,475	5.5
2004	312	164,607	6.0
2005	775	144,070	6.9
2006	1,260	174,316	7.9
2007	1168	157,812	8.9
2008	1,692	158,424	10.4

Source: USPTO, http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cbcby.pdf.

Appendix: Proof of Propositions

Proof of Proposition 1: As in most of literature, we assume the economy is in its BGP at time 0. Obviously, (15) suggests that

$$A_h(0) = \frac{\beta_h(1+\beta_l)\Omega_l}{\beta_l(1+\beta_h)\Omega_h} A_l(0), \tag{A1}$$

where $\Omega_h = (1+\beta_h)^{\epsilon-1}(\beta_h ZH)^{\alpha(1-\epsilon)}$ and $\Omega_l = (1+\beta_l)^{\epsilon-1}(\beta_l L)^{\alpha(1-\epsilon)}$. In order to investigate whether the optimal patent protection β_z^* is finite or not, we have to compute the utility of a representative agent in the equilibrium. From (1), the discounted sum of utility could be written as, for $0 < \theta < 1$,

$$U(\beta_h, \beta_l) = \frac{C(0)^{1-\theta}}{(1-\theta)[\rho-(1-\theta)g]} - \frac{1}{\rho(1-\theta)}, \tag{A2}$$

where

$$C(0) = p_h Y_h(0) + p_l Y_l(0) - A_h(0)k_h(0) - A_l(0)k_l(0) - \mu g A_h(0) - \mu g A_l(0) \tag{A3}$$

denotes the agent's consumption. Since the amount of initial total capital, $A_h(0)k_h(0)+A_l(0)k_l(0)$, should be taken as given, thus

$$\frac{\partial\left(A_h(0)k_h(0)+A_l(0)k_l(0)\right)}{\partial\,\beta_z} = 0. \tag{A4}$$

From (19), the infinite patent breadth $\beta_z = \frac{\alpha}{1-\alpha}$ maximizes the growth rate, explicitly,

$$\left.\frac{\partial g}{\partial \beta_z}\right|_{\beta_z^* = \frac{\alpha}{1-\alpha}} = 0. \tag{A5}$$

In fact,

$$\left.\frac{\partial \Omega_z}{\partial \beta_z}\right|_{\beta_z^* = \frac{\alpha}{1-\alpha}} = 0, \tag{A6}$$

and from (17),

$$\left.\frac{\partial\, p_z}{\partial \beta_z}\right|_{\beta_z^* = \frac{\alpha}{1-\alpha}} = 0. \tag{A7}$$

By (11) and (A1), direct computation on (A3) gives

$$\begin{aligned} C(0) &= \frac{\beta_h(1+\beta_h)^{-\frac{1}{\alpha}}(1+\beta_l)}{(1-\alpha)\beta_l X_h} p_h^{\frac{1}{\alpha}} \Omega_l Z H A_l(0) + \frac{(1+\beta_l)^{1-\frac{1}{\alpha}}}{1-\alpha} p_l^{\frac{1}{\alpha}} L A_l(0) \\ &\quad -[A_h(0)k_h(0) + A_l(0)k_l(0)] - \mu g \left(\frac{\beta_h(1+\beta_l)\Omega_l}{\beta_l(1+\beta_h)\Omega_h} + 1 \right) A_l(0), \end{aligned}$$

where we take $A_l(0)$ be given. Then, we deduce from (A4)—(A7) and the fact $\frac{\partial\,[\beta_h(1+\beta_h)^{-\frac{1}{\alpha}}]}{\partial\,\beta_h}|_{\beta_z=\frac{\alpha}{1-\alpha}} = 0$ that

$$\left.\frac{\partial\,C(0)}{\partial\beta_z}\right|_{\beta_z^*=\frac{\alpha}{1-\alpha}} = -\mu g \frac{(1+\beta_l)}{(1+\beta_h)^2 \beta_l \Phi_h} \Omega_l A_l(0)\Big|_{\beta_z^*=\frac{\alpha}{1-\alpha}} < 0.$$

As the partial derivative of $U(\beta_h, \beta_l)$ is

$$\frac{\partial\,U}{\partial\,\beta_z} = \frac{C(0)^{-\theta}}{\rho-(1-\theta)g}\left(\frac{\partial\,C(0)}{\partial\,\beta_z} + \frac{C(0)}{\rho-(1-\theta)g}\frac{\partial\,g}{\partial\,\beta_z}\right), \tag{A8}$$

we conclude from above that $\left.\frac{\partial\,U}{\partial\,\beta_h}\right|_{\beta_z^*=\frac{\alpha}{1-\alpha}} < 0$. Similarly, $\left.\frac{\partial\,U}{\partial\,\beta_L}\right|_{\beta_z^*=\frac{\alpha}{1-\alpha}} < 0$. Therefore, $\beta_z^* < \frac{\alpha}{1-\alpha}$ holds, that is, the patent breadth maximizing social welfare is finite.

Proof of Proposition 2: The economy is assumed to be in its BGP. By (A3), when $A_l(0)$ is fixed, we consider the utility $U(\beta_z)$ as a function with parametric variables H and L, and rewrite it as $U(\beta_z; H, L)$. Let $\beta_z^*(\xi)$ be the finite optimal patent breadth in the economy with ξH skilled workers and ξL unskilled workers. For the simplicity, denote $\beta_z^*(1)$ by β_z^*.

For fixed $A_z(0)$ and β_z, $C(0)$ increases as a function of ξ. Otherwise, we can find a sufficient large ξ such that $C(0;\xi) < 0$, which is impossible. Since the more the workers are, the higher the growth rate g is, we obtain, for $\xi > 1$,

$$\frac{C(0;\xi)}{\rho-(1-\theta)g(\xi)} > \frac{C(0)}{\rho-(1-\theta)g}.$$

In addition,

$$\left.\frac{\partial\,C(0;\xi)}{\partial\,\beta_z}\right|_{\beta_z^*} = \xi \left.\frac{\partial\,C(0)}{\partial\,\beta_z}\right|_{\beta_z^*}, \quad \left.\frac{\partial\,g(\xi)}{\partial\,\beta_z}\right|_{\beta_z^*} = \xi \left.\frac{\partial\,g}{\partial\,\beta_z}\right|_{\beta_z^*}.$$

Therefore, we get from (A8) that

$$\frac{\partial\,U}{\partial\,\beta_z}(\beta_z^*; \xi H, \xi L) > 0.$$

It says that $\beta_z^*(\xi) > \beta_z^*$. Hence, we can claim here that $\frac{\partial \beta_h^*}{\partial ZH} > 0$ (i.e., $\frac{\partial \beta_l^*}{\partial L} > 0$) or $\frac{\partial \beta_h^*}{\partial L} > 0$ (i.e., $\frac{\partial \beta_l^*}{\partial ZH} > 0$) hold. If the claim is false, we will have both $\frac{\partial \beta_h^*}{\partial ZH} \leq 0$ (i.e, $\frac{\partial \beta_l^*}{\partial L} < 0$) and $\frac{\partial \beta_h^*}{\partial L} \leq 0$ (i.e., $\frac{\partial \beta_l^*}{\partial ZH} < 0$), and then create a contradiction to $\beta_z^*(\xi) > \beta_z^*$.

From (A8), at β_z^*, we have

$$\frac{\partial C(0)}{\partial \beta_h} / \frac{\partial g}{\partial \beta_h} = -\frac{C(0)}{\rho - (1-\theta)g} = \frac{\partial C(0)}{\partial \beta_l} / \frac{\partial g}{\partial \beta_l}, \tag{A9}$$

and the following long identity

$$\begin{aligned} & -\frac{(1+\beta_l)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_h)}{(1+\beta_h)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_l)} \\ = \quad & \frac{(1+\beta_h)^{-\epsilon}\beta_h^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)(ZH)^{\alpha(\epsilon-1)}}{(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_l)L^{\alpha(\epsilon-1)}} \\ & -\frac{(\mu\theta g+\mu\rho)^{1+\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)}{(1-\alpha)\mu g\beta_h(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}}. \end{aligned} \tag{A10}$$

After a simple algebra, we know that when H is enlarged and β_z is given, the right hand of the identity becomes greater than the left hand of the identity. Consequently, $\frac{\partial \beta_l^*}{\partial ZH} > 0$. In addition, when $ZH = L$, (A10) implies

$$\frac{(\mu\theta g+\mu\rho)^{1+\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)}{(1-\alpha)\mu g\beta_h(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}} = 2 \tag{A11}$$

Equation (A11) together with $\frac{\partial \beta_l^*}{\partial ZH} > 0$ suggests that $\frac{(\mu\theta g+\mu\rho)^{1+\alpha(\epsilon-1)}}{\mu g}$ is an increasing function of g. Therefore, when L increases and β_z is given, the right hand of (A10) becomes smaller than the left hand. It is followed that $\frac{\partial \beta_h^*}{\partial L} > 0$. Using symmetry, we get $\frac{\partial \beta_z^*}{\partial ZH} > 0$ and $\frac{\partial \beta_z^*}{\partial L} > 0$.

In order to prove the rest of proposition 2, we now first prove when $ZH = L$, $\frac{\partial \beta_h^*}{\partial ZH} > \frac{\partial \beta_l^*}{\partial ZH} > 0$. Due to symmetry, when $ZH = L$, we have $\beta_h^* = \beta_l^*$. Suppose that $\overline{ZH} = (1+\zeta)\,ZH$ and $\overline{L} = (1-\varsigma)\,ZH$ where $\zeta \to 0^+$, $\varsigma \to 0^+$ and $(1+\zeta)^{\alpha(\epsilon-1)} + (1-\varsigma)^{\alpha(\epsilon-1)} = 2$, and that patent protection remains unchanged. Then, the growth rate remains the same. Hence, when $A_l(0)$ is unchanged, $p_l Y_l(0) - A_l(0)\,k_l(0) - gA_l(0)\,\mu = \frac{\beta_l^*+\alpha}{1+\beta_l^*}\; p_l Y_l(0) - gA_l(0)\,\mu$ remains invariant. Some calculation yields that $\frac{p_h Y_h(0) - A_h(0) k_h(0) - gA_h(0)\mu}{p_l Y_l(0) - A_l(0) k_l(0) - gA_l(0)\mu} = \frac{A_h(0)}{A_l(0)}$. Therefore, (A3) says that when $\overline{ZH} = (1+\zeta)\,ZH$ and $\overline{L} = (1-\varsigma)\,ZH$, if $\beta_z = \beta_z^*$, then $C(0)$ goes up. This means that in order to increase utility, patent protection should be adjusted to increase the growth rate. Using (A11), we know that when $\alpha(\epsilon-1) = 1$, $\frac{\partial \beta_z^*}{\partial ZH} \neq \frac{\partial \beta_z^*}{\partial L}$. Thus, some algebra implies that for $\alpha(\epsilon-1) >$

0, $\beta_h^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) > \beta_h^*\left(ZH,ZH\right)$ and $\beta_l^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) < \beta_l^*\left(ZH,ZH\right)$ hold, or $\beta_h^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) < \beta_h^*\left(ZH,ZH\right)$ and $\beta_l^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) > \beta_l^*\left(ZH,ZH\right)$ are satisfied. Suppose the latter two inequalities hold. Then, $\beta_h^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right)+$ $\beta_l^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) > \beta_h^*\left(ZH,ZH\right)+\beta_l^*\left(ZH,ZH\right)$ must be satisfied to increase the growth rate. Since $\frac{\partial\beta_h^*}{\partial ZH}=\frac{\partial\beta_l^*}{\partial L}$ and $\frac{\partial\beta_h^*}{\partial L}=\frac{\partial\beta_l^*}{\partial ZH}$ when $ZH=L$, this inequality cannot hold. Thus, inequalities $\beta_h^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) > \beta_h^*\left(ZH,ZH\right)$ and $\beta_l^*\left((1+\zeta)\,ZH,(1-\varsigma)\,ZH\right) <$ $\beta_l^*\left(ZH,ZH\right)$ should be satisfied. It is followed that when $ZH=L$, $\frac{\partial\beta_h^*}{\partial ZH} > \frac{\partial\beta_l^*}{\partial ZH} > 0$.

Suppose when $ZH>L$, $\beta_h^*<\beta_l^*$. Then, there exists $\widetilde{ZH}>L$ such that $\beta_h^*=\beta_l^*$. By symmetry, the following two equations should be satisfied

$$
\begin{aligned}
& -\frac{(1+\beta_l)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_h)}{(1+\beta_h)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_l)} \\
= \; & \frac{(1+\beta_h)^{-\epsilon}\beta_h^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)(\widetilde{ZH})^{\alpha(\epsilon-1)}}{(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_l)L^{\alpha(\epsilon-1)}} \\
& -\frac{(\mu\theta g+\mu\rho)^{1+\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)}{(1-\alpha)\mu g\beta_h(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}}.
\end{aligned} \tag{A12}
$$

and

$$
\begin{aligned}
& -\frac{(1+\beta_l)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_h)}{(1+\beta_h)(1+\alpha(\epsilon-1)-(1-\alpha)(\epsilon-1)\beta_l)} \\
= \; & \frac{(1+\beta_h)^{-\epsilon}\beta_h^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)L^{\alpha(\epsilon-1)}}{(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_l)(\widetilde{ZH})^{\alpha(\epsilon-1)}} \\
& -\frac{(\mu\theta g+\mu\rho)^{1+\alpha(\epsilon-1)}(1-\frac{1-\alpha}{\alpha}\beta_h)}{(1-\alpha)\mu g\beta_h(1+\beta_l)^{-\epsilon}\beta_l^{\alpha(\epsilon-1)}}.
\end{aligned} \tag{A13}
$$

Clearly, when (A12) and (A13) cannot hold simultaneously. Therefore, we get a contradiction to the case $\beta_h^*=\beta_l^*$ when $\widetilde{ZH}>L$. As a result, when $ZH>L$, $\beta_h^*>\beta_l^*$; when $ZH<L$, $\beta_h^*<\beta_l^*$.