Relative Backwardness and Policy Determinants of Technological Catching Up[1]

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Abstract

This paper theoretically and empirically analyzes the sources of the observed pattern that the levels and growth rates of technology are different across countries. The extended catching up model combined with the R&D based endogenous growth model shows that the steady state technology gap depends on both relative human capital investment and policy determinants conducive to technology adoption. Supporting the theoretical findings, the empirical analyses show that the technological catching up occurs, and that a strong scale effect is found. Finally, the estimated speeds of TFP catching up are around 2 percent.

Keywords: Relative Backwardness, Adoption Capacity, Endogenous Growth, Technological Catching Up, Speed of Technological Catching Up

JEL classification: F43, O47, O14

1 Introduction

The neoclassical and endogenous growth models in Solow (1956), Romer (1990), and Grossman and Helpman (1991) have emphasized the role of technology as one of the sources of per capita income growth rate. However, assuming that technology grows at a constant rate across countries, Barro (1991) and Mankiw, Romer, and Weil (1992) show the conditional convergence of real GDP per capita. Since the convergence in their models comes from the diminishing marginal product of capital, the role of the technological factor might be overlooked.

As Bernard and Jones (1996a,b), Klenow and Rodriguez (1997), and Hall and Jones (1999) show, there are important differences in technology across countries. Based on the catching up theory, which is consistent with the assumption of different technology levels across countries, this paper aims to find the sources of the observed pattern of technological catching up. The catching up theory can be formalized by combining the relative backwardness hypothesis and the adoption capacity.

The relative backwardness hypothesis introduced by Veblen (1915) and Gerschenkron (1952) states that laggard countries are able to exploit a backlog of existing technologies. Because adopting advanced technologies is easier and less costly than innovation, the backward countries attain a high productivity growth rate at the same time that advanced countries have fewer opportunities for high productivity growth. Thus, the technologically less advanced countries tend to grow faster than technologically leading countries.

It is assumed that the advanced technologies invented in a leading country are available to any other country even without any trade in commodities. A necessary condition, in order that the laggard countries might be able to take advantage of the available technology, is the well-developed capacity to adopt the superior technology. "Adoption capacity", or the capacity to adopt and implement advanced technologies, is determined by policy variables that are conducive to technology adoption. The catching up theory states that technological catching up is strongest in countries that are not only technologically backward but also in those countries that have policy determinants conducive to technology adoption.

The catching up theory, which is extended by including human capital as an input, is combined with R&D based endogenous growth models such as those of Romer (1990), Grossman and Helpmen (1991) and Jones (1995). It is shown that the steady state growth rate of technology is determined by population growth rate while the steady state relative backwardness depends on the adoption capacity, the productivity in the R&D sector, and the relative human capital stock. Unlike Parente and Presscott (1994) and Barro and Sala–i–Martin (1997), this paper formalizes the theoretical models of the catching up theory and implements empirical tests to support the theoretical predictions.

The empirical relevance of the catching up theory is investigated by using regression analyses. The empirical results support the formalized catching up theory by showing the significant role that policy determinants conducive to technological adoption play. The robust role of country size is also shown. Further, the speeds of technological catching up are estimated to be around 2 percent. In contrast to Barro (1991) and Mankiw, Romer, and Weil (1992), the empirical analyses propose to find the sources of the technological catching up rather than the growth rate of real GDP per capita under the assumption that the levels of technology are different across countries.

The remainder of this paper is organized as follows. In the next section a simple catching up theory is formalized. Section 3 develops a general equilibrium model by extending the simple catching up model and combining the extended catching up theory with R&D based endogenous growth models. In section 4, regression analyses are pursued to prove the empirical relevance of the catching up theory, and where the speeds of technological catching up and their standard errors are estimated. The policy implications of these models are then proposed in section 5.

2 Formalizing The Catching Up Theory

A simple model of technological catching up is formalized in this section. Section 3 extends this model by including the human capital as an input and then integrates it into R&D based endogenous growth models. A two country model without trade in commodities is assumed throughout this paper.

2.1 The Relative Backwardness and the Adoption Capacity

The relative backwardness hypothesis states that the greater the relative backwardness, the faster the rate will be at which countries can catch up with the technology level of the leading country through the adoption of advanced technologies invented in advanced countries. This implies that the countries having the same degree of relative backwardness at the initial time period should grow at the same rate. This hypothesis alone does not seem to be realistic. Even if several countries have the same initial technology level, some can grow faster than others. This fact is shown by the rapid growth in East Asian countries and the slow growth in several Latin American countries, even if they had almost the same level of real GDP per worker in the 1960s. Thus, highly backward countries cannot automatically catch up with the technological level of the advanced countries. This implies that a high degree of backlog is not a sufficient but only a necessary condition for catching up.

In order for any technology adoption to be operational, a laggard country must have a well-developed adoption capacity. This implies that even if two different laggard countries have the same degree of relative backwardness, the actual technological catching up will depend on their respective adoption capacity, which is, in turn, determined by policy factors. Economic policies such as the distortion of the foreign exchange markets, financial development index, etc. affect this adoption capacity. The other factors such as income distribution, openness and human capital are also included as explanatory variables.

In combining the relative backwardness and adoption capacity, the catching up theory implies that a country′s potential for growth is strong. However, it does not imply that a country is relatively backward in all respects, rather that it is technically backward but has policies conducive to technology adoption.

This process of adopting and implementing advanced technologies is described by many papers using different terminologies. These are "social capability" (Abramovitz, 1986), "monopoly barriers" (Parent and Prescott, 1994), "imitation costs" (Barro and Sala–i–Martin, 1997), and "social infrastructure" (Hall and Jones, 1999). This paper uses the more neutral "adoption capacity" that is approximated by policy determinants conducive to technology adoption because the empirical analyses include policy variables as an approximation of adoption capacity.

2.2 A Simple Model of Technological Catching Up

Assume that the technological leader has a higher level of technology than that of the laggard countries at the initial time, and that all innovations occur only in the leading country, and can be adopted by the laggard countries.

Assuming that the technology frontier expands at a constant growth rate, g_N:

$$\frac{\dot{A}_N}{A_N} = g_N \tag{1}$$

where A_N is the level of technology in a leading country N.[1]

[1] Here and in subsequent notations, $\dot{x}$ denotes the time derivative of the variable x.

The advanced technologies innovated in the leading country are available to any country world wide even without a trade in commodities. So a unique R&D project in the leading country contributes to the understanding of the scientific principles in all countries. However, the implementation of diffused advanced technologies depends on the characteristics of each country. Two steps are considered in this simple model: the degree of the diffusion of the advanced technologies, and the degree of implementation of the diffused technologies.

First, assume that the technology level of the laggard country, A_S, overlaps with the level of A_N; in other words, A_S is a subset of A_N. Thus, the level of new technologies available to the backward countries is $A_N - A_S$. Then assume that the degree of technology diffusion is related to the ratio of this available level to the existing technology level of the laggard countries with an exponential scale factor.[2] This is shown as G_S^η where $\frac{A_N - A_S}{A_S} \equiv G_S - 1$, and $G_S \equiv \frac{A_N}{A_S}$, which implies the relative backwardness hypothesis.

Second, the degree of implementation of the diffused technologies depends on the adoption capacity, Θ_S, of the laggard countries that is different across countries. As discussed above, Θ_S depends on policies conducive to the technology adoption.

Combining the degree of technology diffusion with the degree of implementation of diffused technologies, the technology adoption function of the laggard country, S, is given as:

$$\frac{\dot{A}_S(t)}{A_S(t)} = \Theta_S \left(\frac{A_N(t)}{A_S(t)} \right)^\eta \equiv \Theta_S G_S^\eta(t) \tag{2}$$

In order to assure a positive effect of the technology gap, $\eta > 0$ is assumed.[3]

[2] In the next section, the level of technology is defined as the number of intermediate goods used in production. Thus, the technology gap represents the difference in the number of intermediate goods of two countries.

[3] Eaton and Kortum (1996) suggest the technology diffusion process under stochastic model.

Equation (2) formalizes the catching up theory that the realized effect of technology adoption depends on relative backwardness as well as on the adoption capacity. The rate of technical progress in the laggard country is positively related to the level of adoption capacity as well as to the degree of relative backwardness.

Since relative backwardness is defined as the technology gap between the leading and laggard countries, $G_S(t)$, then using (1) and (2) the time path of the technology gap is:[4]

$$\dot{G}_S(t) = G_S(t)\left[g_N - \Theta_S G_S^{\eta}(t)\right]. \tag{3}$$

$g = g_N = g_S$ because the steady state growth rates of technology for the two countries are the same, where g_N and g_S are the steady state growth rates of technology of the leading and laggard countries, respectively. Using (3) and Θ_S, since this is constant in the steady state, the steady state level of the technology gap for a laggard country i is:

$$G_S^* = \left(\frac{g_N}{\Theta_S^*}\right)^{\frac{1}{\eta}} \tag{4}$$

where Θ_S^* is the steady state value of adoption capacity.

The result implies that the higher adoption capacity of the laggard country causes the technology gap to decrease in the steady state. Equations (3) and (4) result in the following three remarks.

Remark 1 *(*Convergence*) Suppose that the laggard countries have different levels of adoption capacities. They converge to their own steady state values of relative backwardness,* $\left(\frac{g_N}{\Theta_S^*}\right)^{\frac{1}{\eta}}$*, depending on their respective adoption capacities.*

Remark 2 *(*Technological Catching Up and Underdevelopment*) Suppose that the laggard countries have the same initial levels of technology gap*

[4] The degree of relative backwardness and the technology gap are used interchangeably throughout this paper.

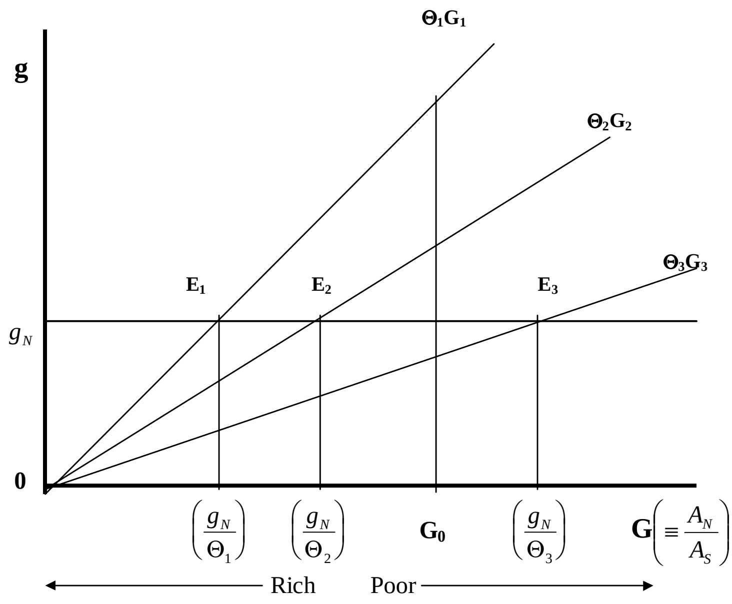

Figure 1: A Simple Catching Up Model

but different levels of adoption capacity. For a constant level of adoption capacity, Θ_S, countries' growth rates along the transition path and steady state levels of technology gap, G_S, will be ranked by Θ_S.

Remark 3 *(*Economic Policy Implication*) If a country caught in an underdeveloped position can increase its adoption capacity through economic policies, then this country might move from underdeveloped to the catching up position. Conversely, if a country in the catching up process has a decrease in the level of adoption capacity due to policy failure, then this country might move from the catching up to the underdeveloped position.*

For example, in Figure 1 (with $\eta = 1$), E_1, E_2, and E_3 are the steady state values of the technology gap. Assuming that G_0 is the initial technology gap, the countries, with the adoption capacities Θ_1 and Θ_2, are in the catching up position, and the other country with Θ_3 is in an underdeveloped position since the technology gap in E_3 is wider than G_0. If this country can increase its adoption capacity from Θ_3 to Θ_1 or Θ_2, it can move from the underdeveloped to the catching up position.

What happens if two laggard countries start from different technology gaps? If their adoption capacities are the same, then the country that is more highly backward will grow faster. However, in reality, these levels are not the same. Even if one country is highly backward, it cannot grow rapidly without the support of its adoption capacity. This means that the country cannot realize and implement advanced technologies sufficiently because of its limited capacity to do so.

3 A General Equilibrium Model

The simple catching up model operates under the assumptions that the technological progress of the leading country is given exogenously, and that the technology adoption process of the laggard countries does not need any resources. In this section, the simple model is extended by assuming that the innovation and adoption processes need a resource.

All technological change is assumed to take the form of increases in the range of intermediate inputs used in production. While new products are produced through the investment of resources in the leading countries, they are available to all laggard countries. Since the laggard countries have different capacities for the adoption and implementation of new technologies, it is assumed that the real effect of diffused technologies will depend on the catching up theory previously discussed. As in the simple model, it is assumed here that there is no trade in commodities.

The extended catching up model is combined with a R&D based endogenous growth model as in those in Romer (1990), Grossman and Helpman (1991), and Jones (1995). The growth rate of technology and the level of technology gap in the steady state are then derived.

3.1 Producer Behavior

3.1.1 The final goods sector

Assume that the production of final goods $Y(t)$ uses human capital $H_Y(t)$ and a collection of intermediate capital inputs $x_j(t)$ at any point in time for two countries – the technological leader (N) and the technological laggard (S).[5]

$$Y(t) = H(t)_Y^{1-\alpha} \int_0^{A(t)} x_j(t)^\alpha dj \tag{5}$$

where $A(t)$ is the variety of available intermediate capital inputs, and α is a parameter between zero and one. While the production of final output can employ any capital goods indexed by $[0, \infty)$, only the available goods, $[0, A(t)]$, at time t are used. The technology in (5) can be accessed by all agents in each country, and production occurs under a perfectly competitive market. The total stock of durables is related to capital stock as follows,

$$K(t) = \int_0^{A(t)} x_j(t)dj = A(t)x(t). \tag{6}$$

It is assumed that the number of workers, L, is homogenous within a country, and that each unit of labor has been trained with S_h years of schooling. S_h is determined by the constant fraction of time individuals spend in accumulating skills:

$$H_Y(t)\ (\equiv hL_Y(t)) = e^{\omega S_h} L_Y(t) \tag{7}$$

where h stands for human capital per worker and L_Y is the labor force employed in final goods production. The exponential formulation is motivated by the Mincer wage equation in empirical labor literature.[6] It is straightforward to show that the parameter ω can be interpreted as the return to

[5] Subscript $i = N$ and S is omitted without loss of generality .

[6] See Halls and Jones (1999) for details.

schooling. Note that $\omega = 0$ is a standard production function with unskilled labor.

Normalizing the price of final output to 1, the demand for intermediate input j demanded by a firm that manufactures Y units of the final goods is:

$$p_j(t) = \alpha H_Y^{1-\alpha}(t) x_j^{\alpha-1}(t), \qquad j \in [0, A(t)] \tag{8}$$

where $p_j(t)$ is the price of jth brand at time t.

The wage rate for human capital is:

$$w_Y(t) = (1-\alpha)\frac{Y(t)}{H_Y(t)}. \tag{9}$$

3.1.2 The Intermediate Goods Sector

Assume that the intermediate goods sector is composed of an infinite number of firms on the interval $[0, A(t)]$, and has purchased a design from the R&D sector. All differentiated intermediate products are manufactured subject to a common constant returns to scale under a monopolistic competitive market structure at any moment of time. A firm that has purchased a design can then effortlessly transform each unit of capital into a unit of the intermediate input. It is assumed that capital is rented at rate r. A unique supplier of jth variety who faces the demand function (8) maximizes operating profits at time t.

$$\max_{x_j(t)} \pi_j(t) = p_j(t)x_j(t) - r_j(t)x_j(t) \quad j \in [0, A(t)] \tag{10}$$

Once a firm in either region has mastered the technology for some products, the goods can be manufactured with one unit of capital goods per unit of output.

A firm in the leading country that is uniquely able to produce some innovative goods faces competition only from other horizontally differentiated brands. Such a monopoly firm sees the downward sloping demand function in (8) and maximizes profits by setting its price at a fixed markup over unit cost, given as:

$$p_N(t) = \frac{r_N(t)}{\alpha}. \tag{11}$$

The monopolist realizes sales of $x_N(t)$ and earns operating profits per unit of time, $\pi_N(t)$.

$$\pi_N(t) = (1-\alpha)p_N(t)x_N(t) \tag{12}$$

If a firm in the laggard country adopts the advanced technology, then it has monopoly power over this technology. Thus the firm could charge its monopoly price without fear of competition from other firms in the same laggard country. The price and the profit functions are:

$$p_S(t) = \frac{r_S(t)}{\alpha} \tag{13}$$

$$\pi_S(t) = (1-\alpha)\, p_S(t)x_S(t). \tag{14}$$

3.1.3 Innovation and Technology Adoption Function

It is assumed that the introduction of new products and the technology adoption process need a resource. Here the resource is human capital. Based on Jones (1995), the microfoundations for the innovation and technology adoption function are technology transfer and externalities arising from duplications made in the R&D process.

The change of products introduced by the leader is assumed as,

$$\dot{A}_N(t) = \phi_N A_N^{\psi}(t) H_{AN}^{\xi}(t) \tag{15}$$

where $H_{AN}(t)$ is the human capital employed in technology innovation and ϕ_N is the productivity parameter in the innovation process. In this technological innovation function, $\psi < 0$ implies that the rate of innovation falls with the accumulated level of technology; $\psi > 0$ corresponds to the positive effect of the stock of technology that has already been discovered. $\psi = 0$ represents technology innovation that is independent of the stock of accumulated technology.[7] In addition, $0 < \xi \leqq 1$ is assumed, which implies that the duplication of research might reduce the total number of new ideas produced by H_{AN}. The level of human capital employed in the innovation process is defined as $h_N L_{AN}(t)$. h_N and $L_{AN}(t)$ are human capital per worker and labor force employed in R&D in the leading country, respectively.

As described in the simple catching up model, the incentive for the laggard in adopting the advanced technology is that adoption is easier and less costly than innovation. Combining the adoption capacity and the relative backwardness hypothesis, the technological adoption process in the laggard countries is then assumed.

$$\dot{A}_S(t) = \Theta_S G_S(t)^\eta A_S^\psi(t) H_{AS}^\xi(t) \tag{16}$$

where Θ_S reflects adoption capacity; G is the technology gap; and $H_{AS}(t) \equiv h_S L_{AS}(t)$ is the human capital employed in technology adoption, and h_S is the labor force efficiency rate $L_{AS}(t)$. Following the technology innovation function of the leading country, $\psi > 0$ implies a positive effect of accumulated level of technology, and *vice versa*. Finally, resources in the leading country are assumed to be more productive in undertaking innovation than are resources in the laggard countries, $\phi_N > \Theta_S$, and the growth rates of the labor forces are n_i for countries $i = N$ and S.

3.1.4 Free Entry Conditions in the *R&D* Sector

An entrepreneur who devotes $H_{AN}(t)$ units of human capital in the research sector for a time interval of length, dt, has the ability to produce new products by (15), i.e., $dA_N = \phi_N A_N^\psi(t) H_{AN}^\xi(t) dt$. The total cost to produce new products is $w_{AN} H_{AN}(t) dt$. Assuming no barriers to entry in the R&D sector, the free entry condition gives:

[7] For the positive steady state growth rate of technology derived later, $\psi < 1$ is assumed.

$$w_{AN}(t) = v_{AN}(t)\phi_N A_N^{\psi}(t) H_{AN}^{\xi-1}(t) \tag{17}$$

where $w_{AN}(t)$ is the wage rate of the human capital employed in the R&D sector, and $v_{AN}(t) = \int_t^{\infty} e^{-[r(\tau)-r(t)]}\pi_N(\tau)d\tau$ represents the market value of each blueprint.

The entrepreneurs in the laggard countries can enter freely into the activity of technology adoption. They decide how many and which products to adopt. Since all products yield identical profits by symmetry of the model, the laggard countries are assumed to choose them randomly among the stock of $A_N(t)$. These are products in the leading country that have not previously been adopted. Using the same analysis as that used in the leader, the free entry condition in the adoption process is given by,

$$w_{AS}(t) = v_{AS}(t)\Theta_S G^{\eta}(t) A_S^{\psi}(t) H_{AS}^{\xi-1}(t) \tag{18}$$

where $v_{AS}(t)$ is the value of a typical brand and $w_{AS}(t)$ is the wage rate of human capital in the technology adoption sector. This relationship, like (17), limits the value of a firm to the cost of market entry.

3.1.5 The No-arbitrage Condition

The firm in country $i = N, S$ earns profits, $\pi_i(t)dt$, for a product produced during the length of time dt, and realizes a capital gain (or loss) of $\dot{v}_{Ai}(t)dt$. The no–arbitrage condition implies that the total return on equity claims must equal the opportunity cost, $r_i(t)$, of the invested capital:

$$\frac{\pi_i(t)}{v_{Ai}(t)} + \frac{\dot{v}_{Ai}(t)}{v_{Ai}(t)} = r_i(t). \tag{19}$$

3.1.6 The Factor Market Clearing Condition

While the human capital involved in the manufacturing sector of the final goods in the leading country is $H_{YN}(t)$ units, $\left(\frac{\dot{A}_N(t)}{\phi_N A_N^{\psi}(t)}\right)^{\frac{1}{\xi}}$ units are employed in the research sector from (15). Labor market equilibrium in the leading country requires that

$$\left[\frac{\dot{A}_N(t)}{\phi_N A_N^{\psi}(t)}\right]^{\frac{1}{\xi}} + H_{YN}(t) = H_N(t) \tag{20}$$

where $H_N(t)$ is the supply of human capital in the leading country. Since human capital is defined as $h_N L_N(t)$, (20) is the same as $L_{AN}(t)+L_{YN}(t) = L_N(t)$.

Similarly, for the laggard countries,

$$\left[\frac{\dot{A}_S(t)}{\Theta_S G^{\eta}(t) A_S^{\psi}(t)}\right]^{\frac{1}{\xi}} + H_{YS}(t) = H_S(t). \tag{21}$$

3.2 Consumer Behavior

Suppose consumers share identical preferences and maximize utility over an infinite horizon where the utility function has a constant intertemporal elasticity of substitution, $\frac{1}{\sigma}$. The consumer′s intertemporal optimization problem for both of the countries is to maximize utility subject to intertemporal budget constraints over an infinite horizon.

$$\max_{\{c(t)\}} U_0 = \int_0^{\infty} e^{-\rho t} L(t) \frac{c(t)^{1-\sigma} - 1}{1-\sigma} dt \tag{22}$$

$$s.t\ \dot{K}(t) = r(t)K(t) + w(t)(1-S_h)L(t) + A\bar{\pi} - c(t)L(t) \tag{23}$$

where ρ represents the subjective discount rate and $c(t)$ is an index of consumption per worker at time t. It is assumed that ρ is constant. Households can borrow or lend freely at the instantaneous interest rate $r(t)$, $w(t)$ is the wage rate, and $K(t)$ is the total capital stock. Here S_h is the constant fraction of time individuals spend in accumulating skills, and $\bar{\pi}$ is the monopoly profit in the intermediate goods sector.

The maximization of utility (22) subject to budget constraint (23) yields:

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma}(r(t) - \rho). \tag{24}$$

3.3 Steady State Analysis

3.3.1 The Steady State Growth Rate

It is easily shown that the growth rate of output per capita and consumption per capita in the steady state are equal to the growth rate of technology, i.e., introduction of new goods at each time period. Since the growth rate of researchers must be equal to the growth rate of the population in the steady state, the steady state growth rate is:

$$g = g_y = g_c = g_A = \frac{n\xi}{1-\psi} \tag{25}$$

where n is population growth rate and y is output per worker. The parameter, ψ, should be less than 1 to get a stable solution, implying a positive growth rate in the steady state.[8]

The steady state growth rate is determined by the parameters for the technology adoption (or innovation) function, ψ, and the growth rate of researchers in technology adoption (or innovation), n, which is the same as the population growth rate. Thus, the growth rate in the steady state is independent of the scale effect as shown in Jones (1995). Next, the level of the technology gap and the relative level of the final output per worker in the steady state are derived.

3.3.2 The Steady State Technology Gap

First, combining (15) and (16), the steady state technology gap is:

[8] Since the steady state growth rate of technology gap is not zero if two population growth rates are not the same, the steady state growth rates of technology will be $g_N = \frac{\xi n_N}{1-\psi}$ and $g_S = \frac{\xi(n_N\eta + (1-\psi)n_S)}{(1-\psi+\eta)(1-\psi)}$, where n_N and n_S are the population growth rates of two countries, respectively.

$$G^* = \left(\frac{g_S\phi_N}{g_N\Theta_S}\right)^{\frac{1}{1-\psi+\eta}} \left(\frac{H^*_{AN}}{H^*_{AS}}\right)^{\frac{\xi}{1-\psi+\eta}}. \tag{26}$$

This indicates that the steady state technology gap depends on the relative steady state growth rate and human capital stock invested in the innovation and adoption process. Then following the steps below, H^*_{AN} and H^*_{AS} are derived.

Substituting the demand for intermediate goods, (8), into the profit function, (12):

$$\pi_N(t) = (1-\alpha)p_N(t)x_N(t) = \alpha(1-\alpha)\frac{Y_N(t)}{A_N(t)} \tag{27}$$

where $Y_N(t) = A_N(t)H_Y^{1-\alpha}(t)x_N^{\alpha}(t)$ by symmetry of the model.

Since the steady state growth rate of consumption per worker is constant by (25) and the parameters, σ and ρ, are assumed as constants, r_N is constant in the steady state. The equations (8), (11), and (12) imply:

$$\frac{\dot{\pi}_N(t)}{\pi_N(t)} = n_N. \tag{28}$$

Since it is assumed that the population growth rate is constant, the growth rate in the value of patent, $v_N(t)$, is constant by (19) and the fact that r_N is constant. Thus the following is derived by (19) and (28)

$$\frac{\dot{\pi}_N(t)}{\pi_N(t)} = \frac{\dot{v}_{AN}(t)}{v_{AN}(t)} = n_N. \tag{29}$$

Combining (19), (27), and (29),

$$v_{AN}(t) = \frac{\alpha(1-\alpha)}{r_N(t) - n_N}\frac{Y_N(t)}{A_N(t)}. \tag{30}$$

Since the wage rate in the final goods sector is the same as that in the R&D sector by free mobility of the labor force, then:

$$(1-\alpha)\frac{Y_N(t)}{H_{YN}(t)} = v_{AN}(t)\frac{\dot{A}_N(t)}{H_{AN}(t)}. \tag{31}$$

Combining (15) or (16) and full employment condition, (20) or (21) with (31), the steady state value of H_{Ai} for $i = N$ and S by symmetry is:

$$H_{Ai}^{*} = \frac{\alpha g_i H_i}{\alpha g_i + r_i(t) - n_i}. \tag{32}$$

Substituting (32) into (26),

$$G_S^{*}(t) = \left(\frac{g_S \phi_N}{g_N \Theta_S}\right)^{\frac{1}{1-\psi+\eta}} \left(\frac{H_N g_N \left(\alpha g_S + r_S - n_S\right)}{H_S g_S \left(\alpha g_N + r_N - n_N\right)}\right)^{\frac{\xi}{1-\psi+\eta}}. \tag{33}$$

Since the technology growth rates in the steady state and the interest rates are the same across countries under the assumption of same population growth rate across countries:

$$G_S^{*}(t) = \left(\frac{\phi_N}{\Theta_S}\right)^{\frac{1}{1-\psi+\eta}} \left(\frac{H_N(t)}{H_S(t)}\right)^{\frac{\xi}{1-\psi+\eta}}. \tag{34}$$

Since $\psi < 1$ and $\eta > 0$, $1 - \psi + \eta$ is positive. The technology gap in the steady state will depend on relative human capital stock, adoption capacity of the laggard countries, and the productivity parameter for the R&D sector in the leading country. Given the level of adoption capacity, the countries that have a higher level of human capital stock have a higher level of technology, implying a decrease in the steady state technology gap.

The steady state technology gap gives the general equilibrium version of the simple catching up model in section 2, and the remarks made in the simple model remain valid in this general equilibrium model setup as well. First, the laggard country cannot reach the technology level of the leading country unless it has a high adoption capacity or a large human capital stock. Thus, countries with small human capital should increase their adoption capacity. Second, a government can increase the technology level by improving adoption capacity through policies conducive to technology adoption.

In addition, the symmetric aggregate production function and the demand functions for intermediate goods lead to the following steady state output per worker:

$$\frac{y_N^*}{y_S^*} = \frac{h_{YN}}{h_{YS}} \hat{p} G^* \tag{35}$$

where $\hat{p} \equiv \left(\frac{p_S}{p_N}\right)^{\frac{\alpha}{1-\alpha}}$.

Substituting the steady state value of the technology gap, (34), the following relative output per worker in the steady state is derived.

$$\frac{y_N^*}{y_S^*} = \hat{p}\frac{h_{YN}}{h_{YS}} \left(\frac{g_S \phi_N}{g_N \Theta_S}\right)^{\frac{1}{1-\psi+\eta}} \left(\frac{H_N g_N (\alpha g_S + r_S - n_S)}{H_S g_S (\alpha g_N + r_N - n_N)}\right)^{\frac{\xi}{1-\psi+\eta}} \tag{36}$$

The relative output per worker is affected by relative population growth rate, relative steady state growth rate and relative human capital stock. As Jones (1999) summarizes, this result holds for other endogenous growth models if the steady state technology stock depends on the human capital stock invested in the technology progress.

Under the assumption of the same population growth rates across countries,

$$\left(\frac{y_N(t)}{y_S(t)}\right)^* = \frac{h_{YN}}{h_{YS}} \left(\frac{\phi_N}{\Theta_S}\right)^{\frac{1}{1-\psi+\eta}} \left(\frac{H_N}{H_S}\right)^{\frac{\xi}{1-\psi+\eta}}. \tag{37}$$

Given the adoption capacity and a high human capital per worker, a larger labor force leads to a higher GDP per worker. While a larger labor force can increase the output per worker given the human capital per worker, its increase with the support of the adoption capacity makes this increase of the real GDP per worker more effective. China and India, which have large labor forces, are not guaranteed to have high levels of GDP per worker because a larger labor force is not the same as a high level of human capital, which is the input for producing final goods and adopting advanced technologies. Thus, even if the relative output per worker depends on the relative labor force between two countries, the level of adoption capacity and the efficiency of human capital should be supported to get higher output per worker as well.[9]

4 The Empirical Tests

Based on the catching up theories described in sections 2 and 3, this section analyzes the association between the growth rate of TFP and the factors that affect the level of adoption capacity by using regression analyses. The approximate speeds of technological catching up and their standard errors are also derived.

4.1 Total Factor Productivity (TFP)

Substituting (6) and (7) into the production function, (5), the Cobb–Douglas form of the production function with respect to physical and human capital is derived.

$$Y_i(t) = K_i(t)^{\alpha}(A_i(t)H_i(t))^{1-\alpha} \tag{38}$$

After equation (38) is divided by labor force, the levels and growth rates of TFP are derived. Following Psacharopoulos (1994) and Hall and Jones (1999), the estimates of the rates of the return to schooling are used. For the first 4 years of education, the rate of return is 13.4 percent, and for the next 4 years and beyond 8 years, these are 10.1 and 6.8 percent, respectively. The data for real GDP per worker and the labor force are from Heston–Summer Mark 5.6. S_h is assumed as the average years of secondary schooling, which is from Barro–Lee (1996). Capital stock is derived by using the perpetual inventory method. The initial value of the 1960 capital stock is derived by $\frac{I_{60}}{g+\delta}$ where I_{60} is the investment rate in 1960 and g is the average growth

[9] While the theoretical models assume that human capital per worker, h, is constant across countries, this is relaxed in empirical tests with the efficiency of the average years of secondary schooling.

rate from 1960 to 1970 of the investment series. The depreciation rate, δ, is assumed as 6 percent, and that $\alpha = 1/3$ is also assumed.

4.2 Estimation

4.2.1 Model

Let $G_S^*(t)$ be the steady-state level of the technology gap given by (4) in the simple catching up model and (34) in the general equilibrium model, and let $G_S(t)$ be the actual value of the technology gap between the leading and the laggard countries.

First, the technology adoption function, (16), is approximated by using a log linearization with a first order Taylor series expansion around the steady state value of the technology gap.

$$\begin{aligned}\frac{d\ln A_S(t)}{dt} \quad &\cong \quad g + \eta g\left[\ln G_S(t) - \ln G_S^*\right] + (\psi - 1)g(\ln A_S - \ln A_S^*) \\ &\quad\;\; + g\left[\ln H_{AS}(t) - \ln H_{AS}^*\right] \end{aligned} \tag{39}$$

where g is the steady state growth rate of TFP.

Similarly, the technology innovation function of the leading country is approximated as:

$$\frac{d\ln A_N(t)}{dt} \cong g + (\psi - 1)g(\ln A_N - \ln A_N^*) + g\left[\ln H_{AN}(t) - \ln H_{AN}^*\right]. \tag{40}$$

Subtracting (39) from (40):

$$\begin{aligned}\frac{d\ln A_N(t)}{dt} - \frac{d\ln A_S(t)}{dt} \quad &\cong \quad -\lambda\left[\ln G_S(t) - \ln G_S^*\right] - g\left[\ln H_{AS}(t) - \ln H_{AS}^*\right] \\ &\quad\;\; + g(\ln H_{AN} - \ln H_{AN}^*) \end{aligned} \tag{41}$$

where $\lambda \equiv (1 - \psi + \eta)g$. Since the growth rate and the technology level of the leading country are constant through the equation, λ is the speed of technological catching up of the laggard countries. This shows how rapidly the actual technology gap between the leading and the laggard countries approaches its steady state value each year.

Since $\frac{d\ln G(t)}{dt} = \frac{d\ln A_N}{dt} - \frac{d\ln A_S(t)}{dt}$, (41) is integrated from $t = 0$ to $t = T$,

$$\begin{aligned}
&\int_0^T \left(\frac{d\ln G(t)}{dt} + \lambda \ln G_S(t) \right) e^{\lambda t} dt = \\
&\lambda \ln G^* \int_0^T e^{\lambda t} dt + \eta g \int_0^T e^{\lambda t} \ln H_{AN} dt - \eta g \ln H_{AN}^* \int_0^T e^{\lambda t} dt \\
&-g \int_0^T e^{\lambda t} \ln H_{AS} dt + g \ln H_{AS}^* \int_0^T e^{\lambda t} dt. \qquad (42)
\end{aligned}$$

Using the total human capital stock instead of the human capital stock employed in technology innovation and adoption process, the integration leads to the following regression equation.[10]

$$\begin{aligned}
\frac{\ln A_S(T) - \ln A_S(0)}{T} &= \text{constant} + \beta \ln G_S(0) - \beta \ln G_S^* \\
&\quad + \frac{g\beta}{\lambda} [\ln h_S + \ln L_S(0)] - \frac{g\beta}{\lambda} \ln H_S^* + \xi_S \quad (43)
\end{aligned}$$

where all variables for the leading country are constant, and $\beta = \frac{1-e^{-\lambda T}}{T}$, and ξ_S is a residual of regression.

Since the relative backwardness in the steady state, (34), is a negative function of the adoption capacity and human capital of the laggard country, and assuming that the level of adoption capacity is determined by the factors listed in the next subsection, the following regression equation is used.

$$Gtfp7089_S = \text{constant } + \beta \ln G_S(0) + \sum_{m=0} \alpha^m \ln B_S^m(0) + \gamma \ln L_S(0) + \xi_S \qquad (44)$$

where $Gtfp7089_S$ and $G_S(0)$ imply the growth rate of TFP from 1970 to 1989 and the technology gap in 1970 of country S, respectively, and $B_S^m(0)$

[10] The derivation is available on request.

reflects the mth determinant of the adoption capacity of country S in 1970. Population as one of the independent variables is based on the production function (38) and the technology adoption function of the laggard countries (16), and γ reflects $\frac{g\beta}{\lambda}$. Here the regression equations divide human capital stock into population size, L_S, and human capital per worker, h_S, following equation (7). The technology gap is defined as TFP gap where the United States is the leading country.[11]

4.2.2 Data

Policy variables and the income distribution index are used as approximate indicators of adoption capacity.[12] Due to a lack of data availability, only a limited number of variables are used.

First, the variable chosen to represent human capital is the average years of secondary schooling. These data come from Barro and Lee (1996).[13]

Second, the black market premium (BMP) has been used as a measure of exchange control or government trade policy. This measure reflects the degree of the distortion of the foreign exchange market. In this analysis the data available for use, which comes from Collins and Bosworth (1996) are the average values from 1970 to 1980.

Third, two openness indices have been used. It is assumed that these indices reflect the openness to foreign competition. The first index is defined as the average value of the ratio of the sum of exports and imports to GDP in current international prices from 1960 to 1969 (Penn World Tables 5.6). This is denoted as Openness as in the regression results. For the second one, the Sachs and Warner (1996) index (Openness SW) in 1970 is used

[11] It can be assumed that the leading country is G7 or a group of developed countries which are on the frontier of some technologies.

[12] The effect of economic policies on economic growth is discussed in Abramovitz (1995), Abramovitz and David (1996), Collins and Bosworth (1996), and Jones (1998b).

[13] Benhabib and Spiegel (1994) argue that human capital contributes to productivity by facilitating the adoption and implementation of new technologies rather than causing economic growth directly.

as an alternative proxy for the degree of openness. This proxy is defined as a dummy variable: 1 for open economies and 0 if a country is closed.[14] Because the Sachs-Warner openness index includes BMP by definition, this variable is excluded in the regressions.

Fourth, the ratio of gross claims on the private sector by central and deposit banks to GDP is used to represent the domestic financial status. This factor reflects the overall size of the public sector including the degree of public sector borrowing, thus, implying a broad array of financial indicators. The index used is from King and Levine (1993) and denoted as Finance in the regressions. McKinnon (1973) and Shaw (1973) found a positive relationship between financial development and economic growth, and King and Levine (1993), and Levine and Zervos (1998) show that the financial systems are both positively and robustly correlated with productivity growth and capital accumulation, as well as, economic growth.

Fifth, the Gini coefficient is included as an approximation of income inequality in the society. These data come from Deininger and Squire (1996). Income inequality may be harmful to economic growth because the concerns about social and political conflict are more likely to lead to government policies that hinder growth.

Lastly, in order to test the scale effects on the technological adoption process, the population size used is from the Penn World Tables 5.6.

The mean and variance of the dependent and independent variables are summarized in Table 1. All variables except the TFP growth rate and human capital are in log form and BMP is defined as the log of (1+ black market premium).

[14] It is equal to 0 if a country scored a 1 on either the BMP, the SOC (dummy variable equals 1 if the country was classified as socialist), the EXM variable (dummy variable equals 1 if a country had a score of 4 on the export marketing index), or the OWQID (dummy variable equals 1 if OWQI>0.4). OWQI indicates coverage of quotas on imports of intermediate and capital goods.

Table 1. Summary Statistics of Adoption Capacity Determinants

Variables	Mean	Standard Deviation	Min	Max
Growth Rate of TFP	0.0016	0.0142	- 0.0421	0.0235
TFP gap	0.6850	0.4401	- 0.2429	1.8290
Openness	- 0.8870	0.6080	- 2.3230	0.9761
Human	0.4580	0.1840	0.0042	0.8181
BMP	0.1511	0.2771	0.0000	1.6730
Finance	- 1.7770	0.8023	- 4.8940	0.0276
Gini	- 0.9081	0.2479	- 1.3820	- 0.3567
Population	9.1760	1.4418	5.4760	13.2100

4.2.3 The Regression Results

All regression coefficients are estimated by OLS and the results are reported in Table 2. Data availability reduces the sample size to 67 in the first two models and 66 in other models.[15] The empirical results strongly support the catching up theory. The technology gap, which is conditional on the factors of adoption capacity, is significantly correlated with the TFP growth rate. Furthermore, the robust role of country size is found.

A simple relation between TFP growth rate and the degree of relative backwardness is first estimated.[16] The technology gap is not significant and R^2 is almost zero, suggesting the rejection of an absolute technological catching up. Thus, the relative backwardness alone is not sufficient to catch up with the technology of the leading country. The correlation between the

[15] Collins and Bosworth (1996) show the contribution of TFP growth through growth accounting for East Asia and test the association between growth of output per worker (and capital accumulation and TFP growth) and macroeconomic policy variables.

[16] The estimated coefficient for initial gap is 0.0049 (t statistic = 1.3823) and R^2 is 0.02.

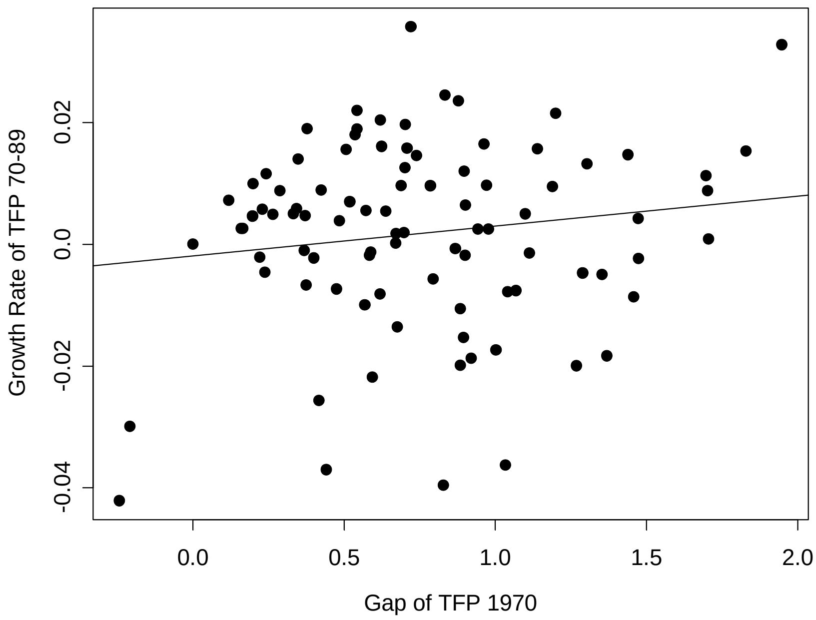

Figure 2: Growth Rate and Gap of TFP (70-89)

TFP growth rate and the degree of relative backwardness is shown in Figure 2 with the regression line. Thus, the respective adoption capacity should be considered.

Models (I) and (II) show the effect of the degree of openness, human capital, gini coefficient, financial development and the country size on the TFP growth rate. The first openness variable is not significant. Openness is interpreted as the factor which promotes technology transfer even if the general equilibrium model of this paper ignores the trade in commodities. However, this result should be interpreted carefully. The openness might not reflect the complete flow of new ideas or technology through trade because this definition includes all kinds of trade, for example, agricultural goods that are not sensitive to technological transfer.

The empirical results produced by using a different openness index, i.e., Sachs-Warner index, are presented in Models (III) and (IV). Openness is significant in the specifications. However, the results might come from different interpretations of openness. The definition of this index takes into account the black market premium and quota index. Thus, the implication is different from the openness index in the Penn data that considers the simple average ratio of the exports and imports to GDP.

Model (II) shows the effect of the black market premium. As it was interpreted in previous section, BMP is the degree of distortion of the foreign exchange market. This variable plays a significant role in explaining the TFP growth rate, which implies that the foreign exchange market should be included in explaining the technological adoption process. Since the black market premium is considered as one of determinants of the Sachs and Warner openness index, this is excluded in regressions (III) and (IV).

The effect of the domestic financial development is found in models (I), (II), and (IV). While the first two models show the robust correlation between the financial system and TFP growth rates, the other model does not.[17]

All models include the gini coefficient as an equity factor and human capital variable. The human capital is significant in all models, the same as the results in the empirical growth models of Barro (1991), and Mankiw, Romer and Weil (1992) etc. Except in the second model, the role of income distribution is not significant. The second model shows that the explanatory power of the Gini coefficient is almost the same as that of the initial gap.[18] Income distribution is known as a trade off with economic growth. How-

[17] Even with a different definition of financial development (the ratio of the liquid liabilities of a financial system to GDP from King and Levine), the regression results are the same.

[18] Recent empirical works tend to support a negative relationship, that the greater a society′s income inequality is the slower its growth. Perrson and Guido (1994) find a strong negative relationship between income inequality and growth in GDP per head. Furthermore, Perotti (1996) supports these predictions through diverse channels such as fertility, investment in education, fiscal policy, and sociopolitical instability.

ever, these empirical results suggest more research is needed on the relation between equity factor and TFP growth rates.

Surprisingly, we found that the role of population is significant. All regression coefficients on the level of population are strongly significant at the 5% significance level. Supporting the definition of the technological adoption function in the theoretical framework, the results suggest that the human capital investment in the R&D sector plays a significant role in increasing the implementation and adoption of advanced technologies.

4.2.4 The Robustness of Scale Effects

Table 3 reports the results of robustness tests of scale effect. The second model specification of Table 2 is used as the base because this includes all possible combinations of the independent variables used in the empirical tests. The other specifications do not affect the results of robustness tests as well.

Before we go over the regression tests, the TFP level and growth rate are compared with Klenow and Rodrigues-Clare (1997). To get the correlation for the same year, the TFP level at 1985 is derived as well by using the same method in paper. The correlation coefficient between the two TFP levels at 1985 is 0.96. For the two growth rates, while their given growth rates cover the years 1960 to 1985, this paper covers 1970 to 1985. The correlation coefficient of the two growth rates is 0.87.

Going over the regression results, the White heteroskedastic-consistent estimate, which tests the inconsistency of the estimated coefficients, is reported. This estimation computes standard errors that are consistent even in the presence of unknown heteroskedasticity. The estimated coefficient does not affect the significant role of population.

Specification B tests the effects of outliers. The outliers are identified through residual plots, Cook's distance, and partial regression plots for population. Even after the outliers (Uganda, Guyana and Iran) are removed, the coefficient on the population is 0.0039 which is not much different from the results in the original models.

Third, to consider the sample selection bias, different sample sizes are used by removing independent variables having a small sample. Here the number of the maximum sample is 91 excluding Gini coefficient, BMP and financial development. However, it does not affect the explanatory power of the population either.

Next, the two model specifications take account of the missing variable bias problem. Except for the determinants in the main empirical specifications, several variables are then selected. These are the distance from the equator and the fraction of population speaking English as a mother tongue, which might reflect the effect of Western European expansion in World history.

Specification D includes the distance from the equator as another independent variable which is measured as the absolute value of latitude in degrees divided by 90 as in Hall and Jones (1999). It is widely known that economies further from the equator are more successful. In addition, specification E includes the fraction of population speaking English as a mother tongue, and the distance from the equator. This reflects that familiarity with English might influence the process of technology transfer. These two different specifications show that there is little change in the coefficient of the country size. The data of latitude and language are from Hall and Jones (1999).

Finally, by including the population size as one of the independent variables, two different model specifications as in Barro (1991) and Mankiw, Romer, and Weil (1992) are estimated, even if the dependent variable is the growth rate of income per capita. The coefficient on population level is not guaranteed to be significant, reflecting that the effect of population on economic growth is an unresolved problem and suggests more work in the future. For Mankiw, Romer and Weil, the population growth rate and level are not significant at the 5% significance level. However, the model specifications without human capital show the more significant role of population than that of population growth rate. For Barro specifications, the results are sensitive to the combinations of independent variables. It is concluded that while the regression with the government expenditure share to GDP as one of the independent variables does not show the role of population to be significant, those with an investment share to GDP do show a strong role.

As several robustness tests show above, the effect of the population level might be sensitive to the model specifications and more research on the role of country size is suggested.

4.2.5 The Speeds of Technological Catching Up

The speed of technological catching up, λ, in equation (41) shows how rapidly the TFP gap approaches its steady state value. The value of speed is derived by using the coefficient on the initial technology gap of regression equation (44) since $\beta = \frac{1-e^{-\lambda T}}{T}$ in equation (43). In addition to the speeds of technological catching up, their standard errors are derived by assuming that the coefficients for the initial technology gap follow normal distribution, with mean, $\tilde{\beta}$, and variances, $\sigma^2_{\tilde{\beta}}$. Taking linearization of β around the mean, $E[\beta] = \tilde{\beta}$,

$$\lambda \cong \frac{1}{1-\tilde{\beta}T}(\beta - \tilde{\beta}). \tag{45}$$

Since $\tilde{\beta}$ is a coefficient for the initial technology gap and T is 19, λ follows normal distribution with mean, 0, and variance, $\left[\frac{1}{1-\tilde{\beta}T}\right]^2 \sigma^2_{\tilde{\beta}}$. Using the regression results in Table 2, the speeds of TFP catching up and their standard errors are reported in Table 4.

The speeds of TFP catching up are from 1.7 to 2.4 percent, which imply similar speeds to those for GDP per capita derived by Mankiw, Romer and Weil (1992). Finally, assuming around 2% speed of TFP catching up, the economy moves halfway to a steady state in about 35 years.

5 Conclusion

Based on the recent empirical findings that the technology levels and growth rates are different across countries, this paper suggests the simple and extended catching up models. These models show how the innovation in the leading countries are adopted by the laggard countries. Combining the extended catching up model with the R&D based endogenous growth models, the theoretical model demonstrates that even if the steady state growth rates of the technology of two countries are independent of the scale effect, the steady state relative backwardness depends on the level of adoption capacity, the productivity of the R&D sector, and the relative human capital stock.

Supporting the predictions from the models, the empirical results show that the technology catching up occurs even without the diminishing marginal productivity of capital. Since TFP is one component of real GDP per worker, the extended version of the catching up theory suggests that the channel of TFP catching up might constitute one of the major forces for the conditional convergence process of real GDP per worker.

It is shown that the policies for building adoption capacity are very important. These policies include human capital, financial development, exchange rate policy and so on. If the government succeeds in improving adoption capacity, it might escape underdevelopment and move into the catching up process. If the level of adoption capacity falls because of policy failure, a country even in the catching up process might slide back to the state of underdevelopment.

Contrary to the recent empirical results that reject the role of population, the robust role of country size is found. In order to test the robustness of the empirical results, several tests are taken. They are regressions with different combinations of independent variables as well as without outliers identified by diagnostic plots and partial regressions. Thus, the possible problems of sample selection bias, and outliers do not affect the main conclusions of this paper. The comparisons with the results of the recent empirical specifications, however, show that the robust role of population in growth rate of real GDP per capita cannot be strongly accepted. With these results, this paper concludes that the scale effect is an unresolved problem and more work on this should be done in the future.

The estimated speed of technological catching up is around 2%, implying that the actual technology gap moves halfway to the steady state technology gap in about 35 years. Finally, the general equilibrium model does not allow trade in commodities. Since trade in commodities is one of the important channels for transferring advanced technologies, this factor needs to considered in future research. Furthermore, the factors affecting adoption capacity include institutional factors in addition to human capital and policy variables. Hence, these indicators should also be considered as well.

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Table 2. TFP Growth Rates and Policy Determinants

	I	II	III	IV
constant	- 0.0548	- 0.0563	- 0.0543	- 0.0478
-	(- 4.1951)	(- 4.4647)	(- 4.9237)	(- 4.2095)
Initial Gap	0.0170	0.0193	0.0146	0.0167
-	(4.3429)	(4.9378)	(4.1490)	(4.5935)
Openness	0.0021	0.0018		
-	(0.6249)	(0.5450)		
Openness			0.0126	0.0105
(SW)			(3.8488)	(3.0622)
Human	0.0325	0.0309	0.0264	0.0241
-	(3.3400)	(3.2838)	(2.7779)	(2.5518)
BMP		- 0.0124		
-		(- 2.3465)		
Finance	0.0055	0.0048		0.0037
-	(2.6944)	(2.3813)		(1.8401)
Gini	- 0.0108	- 0.0136	- 0.0036	- 0.0044
-	(- 1.8480)	(- 2.3593)	(- 0.6101)	(- 0.7650)
Population	0.0035	0.0033	0.0027	0.0027
-	(2.4876)	(2.4500)	(2.9601)	(3.0331)
R^2	0.46	0.50	0.50	0.53
sample	67	67	66	66

Note: t-statistics are in parentheses.

Table 3. Robustness Tests of Population Size

	TFP Gap	Population	New Variable	R^2
A (robust)	0.0196 (3.4601)	0.0035 (2.5423)		0.51
B (outlier)	0.0158 (3.7319)	0.0039 (2.9500)		0.48
C (sample)	0.0141 (4.5206)	0.0033 (2.5875)		0.40
D (latitude)	0.0298 (3.0861)	0.0035 (2.5495)	0.0298 (3.0861)	0.47
E (English)	0.0202 (5.1283)	0.0030 (2.2067)	- 0.0060 (- 1.2155)	0.50

Note: t-statistics are in parentheses.

Table 4. The Speeds of TFP Catching Up

	Coefficients (β)	Standard Error (β)	Speed (λ)	Standard Error (λ)
Model I	0.0170	0.0039	0.0205	0.0058
Model II	0.0193	0.0039	0.0240	0.0062
Model III	0.0146	0.0035	0.0171	0.0048
Model IV	0.0167	0.0036	0.0201	0.0053