Economic Growth Centre
Working Paper Series

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Working Paper No: 2006/07

INNOVATION, IMITATION AND ENTREPRENEURSHIP

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This paper analyzes the gradual shift in the technological paradigm of an economy as it approaches the world technology frontier. The model developed in this paper consists of firms which employ skilled workers as an important input in technological advancement, but the novel feature here is the entrepreneur, who is the brain of technological progress. The entrepreneur has to decide to undertake either imitative or innovative activities, of which decision both affects and is affected by the country's distance to frontier. Specifically, the entrepreneur needs to have a minimum ability threshold level in order to carry out innovation. This endogenous threshold level falls as the economy moves closer to the technological frontier, enabling more entrepreneurs to be engaged in an innovation-based strategy, and consequently, moving the economy from a technological structure that is based on imitation of foreign technologies to one where domestic innovation dominates. The transitional dynamics of the model shows that there exists a steady state distance from the world frontier that countries will eventually converge to. We also find that it is possible for countries under certain conditions, to be trapped in a regime carrying out only imitation of world technologies.

Keywords: Technology diffusion; innovation; entrepreneurship; growth

1. Introduction

1.1. *Technology trajectory*

A recently published book entitled 'Imitation to Innovation' (Kim, 1997) traces how Korea's technological paradigm has evolved from accumulating and assimilation of foreign technologies into an advanced industrialized country with indigenous technological capabilities to be able to generate American-style innovation as the country approaches the technological frontier.[1] In a similar vein, Audretsch and Fritsch (2003) investigating the cause of West Germany's structural change find evidence that high-tech startups by entrepreneurs are increasingly becoming a more important source of growth as the country ushers in the New Economy.

In this paper, a simple model is set up to explore the interdependence between a country's stage of development – its distance to frontier, and the internal organization of firms in terms of their technological strategy. In particular, the model is one of the pioneers in seeking to account for the pattern described above: how an economy progresses from a technological structure that is largely characterized by firms that adopt foreign technologies to one with a growing share of firms carrying out indigenous innovation as it moves towards the world frontier.

1.2. *Technology the lever of riches*

Since the classic 'Solow residual[2]' paper (Solow, 1957) which found increased capital intensity to account for only 13% of economic progress, economists have come to realize that factor accumulation is insufficient to explain economic growth and have instead focused on technical progress or total factor productivity (TFP) as the fundamental engine of economic growth (see for example, Romer, 1990; Grossman and Helpman, 1991a; Quah, 2002). In principle, TFP can encompass many possible interpretations – political barriers, monopoly inefficiencies, and so on. However in this paper, the main cause of productivity growth will be identified with knowledge creation – ideas for new products or production techniques, research and development (R&D), knowledge spillovers. Furthermore, following the lead of Romer (1990), technological change will not be taken to be exogenously given, to use the metaphor, 'falling from the sky'[3], but rather an intentional outcome of economic agents in response to profit incentives (i.e., endogenous).

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[1] Japan provides another illustration. The initial strategy for firms in the fifties was to imitate America's superior technology and but they later moved on to raising their own technology level by innovation and consequently closing the technology level gap. (Shimomura and Wong, 2001)

[2] The residual term refers to any factor that affects growth other than labor and capital inputs, and is often ascribed to technical or technological progress. (Scherer, 1999)

[3] It has been alternatively explained as discoveries from academic or government labs that are not profit motivated.

1.3. *Twin channels of technological progress*

Technological progress is a result of two main forms of learning, namely innovation and imitation (Grossman and Helpman, 1991a). The former consists of the domestic creation of new products or processes. While the latter entails importing and implementing existing technologies, usually from leading countries abroad through the channels of international trade, inward and outward foreign direct investment (FDI), reverse engineering of products, etc., (Keller, 2001).

One strand of literature has focused on technology diffusion from the world frontier as a major source of technical change leading to productivity growth in the developed and especially in the developing countries (Keller, 2001). This stems from the discovery by Coe, Helpman and Hoffmaister (1997)[4], that most developing countries make few significant new discoveries for the world market and that a large percentage of the world's R&D is concentrated in a small group of industrial countries.

This has led to R&D growth models (see for example, Pagageorgiou, 2002b; Segerstrom, 1991) including the one developed in this paper, to embody both an innovation as well as an imitation term in the economy's productivity function. Furthermore, this paper concurs with Grossman and Helpman (1991b) that effort such as the deliberate allocation of resources, which in the model developed here is taken as skilled workers, is required in the process of assimilating existing technologies and the creating of entirely new ones. Moreover, like Romer (1990), it is assumed, for simplification, that only skilled workers and knowledge is used to improve productivity – domestic stock of knowledge, in the case of innovation and world stock of ideas, in the case of imitation.

1.4. *Human capital*

Scherer (1999) has advocated that human capital is the most important input in the process of advancing technology. Not surprisingly, a growing body of literature has addressed the complementarities of human capital and technological progress. One of the earliest models developed is by Nelson and Phelps (1966) which suggested that the level of education speeds up technological diffusion. Their simple illustration was that of an educated farmer possessing ability to discern profitable ideas and thus adopting new processes or products more quickly than his uneducated counterpart.

Benhabib and Spiegel (2002), using cross country data obtain results consistent to Nelson and Phelps' hypothesis and extends the role of human capital to be an engine of domestic innovation besides being a facilitator of technology adoption. A paper by Kneller (2005) also lends empirical support that a country's absorptive capacity of international technology is dependent on human capital and domestic R&D. Similarly, Xu (2000, see also Blomstrom, Kokko and Zejan [1998]) finds that less developed countries unlike the advanced countries did not benefit from technology transfer by US multinational corporations (MNEs) because of insufficient human capital to absorb technology diffused. This emphasizes the view that the extraction of technological

[4] Cited in Papageprgiou, 2002b.

knowledge and utilizing it domestically is more successful when recipient nations have technically trained workers.

This paper, following the spirit of Mayer (2001) and Papageorgiou (2002a), holds to the view that human capital[5] is significant to a country's productivity growth as a determinant of its capacity to carry out innovation as well as to adopt and implement imported technology. This is distinct from the human-capital-augmented Solow model where human capital is treated as an input into the production process (Mayer, 2001).

However, the model developed here distinguishes from the above mentioned studies, in introducing the entrepreneur as the lead actor in spearheading technological activities.

1.5. *The entrepreneur*

Although entrepreneurship has generally been viewed as important for economic growth and technological advancement, most economic literature has downplayed its role, due partly to the difficulty of fitting the entrepreneur into the theory of the firm (Baumol, 1968). One paper that does look at the phenomenon of entrepreneurship is by Schmitz (1989), who presents a model in which entrepreneurship is a crucial factor of economic growth through its singular role in the imitation of existing technologies. In his paper, the diffusion of new knowledge is not a costless process but requires the work of an entrepreneur.

Another piece of work that has the entrepreneur as its main feature is Schumpeter's famous *Theory of Economic Development* (1934)[6]. The book introduces two main notions, firstly, innovation was the engine of economic development and secondly, that entrepreneurial activity was the source of that innovation. He also defined the entrepreneur as the 'founder of a new firm and as an innovator'.

These two R&D tasks are combined to be undertaken by the entrepreneur in our model, who is revived as the 'apex of the hierarchy that determines the behavior of the (intermediate) firm' (Baumol, 1968) deciding on whether to conduct indigenous innovation or adopt from the world frontier in order to improve productivity. The entrepreneur's decision is based on the relative rewards obtained from taking up either one of the R&D activities which in turn is dependent on the specific ability of the entrepreneur. This skill could comprise of the entrepreneurs' motivation, insight, tolerance of uncertainty, creative capacity, etc. Furthermore, the level of entrepreneur ability has a positive impact on the creation of new knowledge but not on imitation. Consequently, the higher the entrepreneurial skill, the more likely the firm would engage in innovation.

This idea bears some resemblance to the manager in Acemoglu, D., Aghion, P., and Zilibotti (2002a) who performs the tasks of innovation and adoption where skills are more important for the former activity. However, in their paper, the skill level takes on only two values to correspond to either a high or low-skill manager. Hence there is a corner to corner switch in the economy from an imitation-based to innovated-based

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[5] In the model developed later, the term human capital is replaced with skilled workers. This is not incorrect as we assume there is only one type of workers in the economy, namely, skilled workers.

[6] Cited in Scherer (1999)

equilibrium. We depart from their paper by allowing the ability to be distributed uniformly across the entrepreneurs. As a consequence, at each period, the economy consists of a range of firms undertaking imitation and innovation, with the specific firm embarking on either one of the R&D activities depending on the capability of the entrepreneur heading it.

The argument here that entrepreneurial skill is required for technological progress does not mean that all new products or processes in the market originate from entrepreneurs. A fair amount of innovative activity is carried out in government research labs and large corporations. The premise however, is that entrepreneurship plays an essential role in the creation of new knowledge. The world has much to thank for the innovative contributions of Bill Gates, Peter Drucker, Akio Morita and the like.

1.6. *Distance to frontier*

This paper draws on work by Acemoglu, D., Aghion, P., and Zilibotti (2002a) and (2002b) in their study of the relationship between a country's distance to the technological frontier and the internal organization of the firm. In the earlier paper, they show how an economy switches from an investment-based strategy to an innovation-based strategy with greater selection of firms and managers as it catches up with the frontier. The latter paper explores the trade-off faced by firms between vertically integrating versus outsourcing production which is again dependent on the distance to frontier.

This framework on the other hand, explores another pertinent firm choice: engaging in imitation of foreign technologies or home-grown innovation. This production decision both affects and is affected by the economy's distance to the world technology frontier. Furthermore, the entrepreneurs take a centre stage in the economy as the key decision maker. These entrepreneurs are endowed with certain talents that contribute to the success of innovative but not imitative activities, as adoption is considered to be relatively easier than innovation. In order for innovation to become more profitable than adoption, there is a minimum threshold level of skill that the entrepreneur must have.

The results of the model reveal that this endogenous threshold level of skill falls as the economy approaches the world frontier. Hence predicting the technological paradigm shift in the economy from one based on imitation of existing technologies to one where domestic innovation dominates as technology in the country advances. This is consistent with the general view that the relative importance of international sources of technology for a country's productivity growth decreases in the level of development of the country. (Keller, 2001).

This idea of a threshold entrepreneur skill is reminiscent of a study by Howitt and Mayer-Foulkes (2002) in which a country needs to surpass a minimum level of human capital in order to graduate from an adoption steady-state to an innovation steady-state, which level depends on the technological frontier. The model in this paper however is more realistic in that it allows for both innovation and adoption activities to take place within the same country.

This theory also casts light on Singapore's own experience. Historically, Singapore's spectacular growth since its independence in 1965 has been accompanied by continuous industrial structural changes. The initial strategy was to attract foreign direct investment (FDI) to locate their labor intensive parts of production in Singapore which would both provide needed employment and fuel export-oriented growth. In the subsequent decades, there was a transition to a higher quality ladder in manufacturing production and developing of the service sector.

The heart of this paper, which lies in the transition in the engine of technological progress from imitation to innovation, is akin to how Singapore is transforming its technological paradigm from one where progress stems largely from assimilating foreign technologies brought to its shore by foreign investors to the present gradual building up of its indigenous innovative capacity. Traditionally, Singapore’s figures for the number of patents and royalties[7] as well as researchers have been relatively low. However, in recent years, as the country moves closer to the world technology frontier, a few private domestically-owned firms, such as Creative Technology and Aztec Systems have emerged and the level of patenting activities have also increased (Blomstrom, Kokko and Sjoholm, 1998). Furthermore, a research study by Bloch & Tang (2000) using an integrated dual cost approach finds evidence indicating that human capital is one of the main contributors of Singapore's technical progress[8]. This provides some support to our model’s assumption that skilled workers are essential for a country’s absorbing of foreign technologies and developing of new knowledge.

1.7. *Structure of the paper*

The plan of the rest of the paper is as follows. Section two presents the basic model. Of particular interest is the distance to frontier function. Section three investigates the transitional dynamic properties of the model and how the country’s distance to frontier evolves. In Section four, the primary findings of the model and implications for policy-makers are analyzed and discussed. Finally, Section five concludes the paper.

2. The Basic Model

2.1. *Economic agents*

Following Acemoglu, D., Aghion, P., and Zilibotti (2002b), entrepreneurs with a mass of unity are endowed with entrepreneurial skills and are owners of the intermediate firms in the economy. The entrepreneurs are profit maximizing and have the option either to adopt foreign technology or carry out domestic innovation as its technology production method. Furthermore, to keep the analysis simple and highlight the effects of interest, it is assumed that there are a fixed number of skilled workers, who supply their labor to the entrepreneurs and are equally productive in both types of R&D activity.

[7] The number of patents and royalties typically reflect the stock of indigenously created technology (Blomstrom, Kokko, & Zejan, 1998)
[8] The other important determinant of technical progress was industry-specific R&D.

2.2. *Final-good sector*

The final good is produced competitively by using a continuum 1 of intermediate goods inputs, according to:

$$y_t = \frac{1}{\alpha}\int_0^1 \left(A_t(\upsilon)x_t(\upsilon)\right)^{\alpha} d\upsilon \,. \tag{1}$$

where $A_t(\upsilon)$ is a productivity parameter which reflects the quality of intermediate input υ at time t and will be specified later. $x_t(\upsilon)$ denotes the amount of intermediate goods used by the final good sector and is additive separable in nature[9].

The final-good producer is competitive and maximizes her instantaneous profits

$$\pi_t^F = y_t - \int_0^1 P_t(\upsilon)x_t(\upsilon)d\upsilon \,\cdot \tag{2}$$

where the final good is taken as the numeraire and $P_t(\upsilon)$ is the price of the intermediate good.

2.3. *Intermediate-good sector*

The intermediate goods sector consists of monopolistic producers or entrepreneurs of a variety of goods. Monopoly profits are required for entrepreneurs of intermediate goods to cover the production costs plus the costs of R&D activity (either imitation or innovation). It is assumed that the entrepreneur υ retains a perpetual monopoly of supplying good υ for production and that productivity improvement takes place within the firm as opposed to buying from an R&D sector.

Using Eq. (2), the intermediate firms face the demand schedule from final-good producers

$$x_t(\upsilon) = \left(\frac{A_t(\upsilon)^{\alpha}}{P_t(\upsilon)}\right)^{\frac{1}{1-\alpha}} \,. \tag{3}$$

As in Acemoglu, Aghion, and Zilibotti (2002a), the monopoly producer faces fringe competition that forces her to charge a limit price:

$$P_t(\upsilon) = \chi \,\cdot \tag{4}$$

where χ is the marginal costs of the fringe firm. We set $\chi > 1$ to imply that the entrepreneur, who uses only one unit of final good to produce one unit of the intermediate good, is more productive. While $\chi < 1/\alpha$ indicates that that their productivity gap is small enough such that the entrepreneur is compelled to charge a limit price to deter entry by the fringe. The parameter χ is a measure of the degree of competition in the market.

The equilibrium monopoly profits can then be obtained using Eqs. (3) and (4) as:

$$\pi(\upsilon) = \delta\left(A_t(\upsilon)\right)^{\frac{\alpha}{1-\alpha}} - w_t H_t(\upsilon) \cdot \tag{5}$$

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[9] This implies that the invention of new ideas does not make obsolete existing ones and that each intermediate good is of use independent of whether other intermediate goods are used. (Papageorgiou, 2002a)

where $\delta \equiv (\chi - 1)(\chi)^{\frac{-1}{1-\alpha}}$ and δ is monotonically increasing in χ. A higher δ or χ corresponds to lesser competition and higher monopoly profits which may be a consequence of factors such as government regulation. $H_t(\upsilon)$ is the total amount of skilled workers used in producing intermediate goods in sector υ and w_t is the skilled worker wage rate that is assumed to be given. Together, they represent the only variable costs to the firm.

The monopoly profits are taken to be the wage or reward of the entrepreneur and are proportional to its productivity parameter $A_t(\upsilon)$. In addition, the entrepreneur has to decide between two types of R&D activity: indigenous innovation or adoption from frontier technology.

2.3.1. *Innovative firms*

The productivity of intermediate good υ of the entrepreneur that chooses to innovate is expressed as:

$$A_t(\upsilon) = q_t(\upsilon) B H_t^I(\upsilon) A_{t-1}. \tag{6}$$

where $q_t(\upsilon)$ denotes the level of entrepreneurial ability that is uniformly distributed from [0,1] and $H_t^I(\upsilon)$ is the level of skilled workers employed for the innovative activity. The inclusion of the skilled worker term in the productivity equation is in accordance to reality, where technological advances are normally engineered by highly educated individuals. (Grossman and Helpman, 1991b)

Entrepreneurial ability $q_t(\upsilon)$ augments the effectiveness of the skilled worker engaged in research and is required for innovative but not imitative activities. The term $q_t(\upsilon)$ can also be viewed as the probability that an innovation is successful while the parameter B can be interpreted as the 'step size' of innovation to boost its effectiveness, where $B > 1$.

A_{t-1} denotes the average stock of domestic knowledge in the economy in period t-1 that researchers build on for new innovations. This implies that technological spillovers exist since innovations made in each sector contribute to the expansion of a pool of knowledge that is freely accessible to all sectors in the following period to facilitate further innovations. This makes use of the characteristic of knowledge as a nonrival and partially excludable input[10]. Hence, growth in domestic knowledge enhances the productivity of skilled workers in innovation in the next period.

Eq. (6) states that, the productivity of domestic innovation is positively dependent on the interaction of both the skilled worker and a country's stock of knowledge[11]. Therefore, a scientist holding a PhD doing research in the U.S would be more productive than a high-school graduate doing the same R&D activity in Ethiopia.

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[10] The former implies that a design once created can be used many times over again. The latter refers to the fact that an inventor has property rights over a design for production (excludable) but no control over its use for research by others (non-excludable) (Romer, 1990).

[11] The stock of knowledge is typically proportional to the number of domestically known product designs (Keller, 2001).

The monopoly profits of the entrepreneur that innovates can be derived simply from substituting Eq. (6), the productivity function, into Eq. (5).

$$\pi^{I}(\upsilon) = \delta^{I}\left(q_t(\upsilon)BH_t^{I}(\upsilon)A_{t-1}\right)^{\frac{\alpha}{1-\alpha}} - w_t H_t^{I}(\upsilon)\,. \tag{7}$$

where δ^I is a measure of the degree of competition among the firms that innovate. The representative entrepreneur then chooses the profit maximizing level of skilled workers to employ by taking the derivative with respect to $H_t^I(\upsilon)$ and setting it equal to zero. The optimum $H_t^I(\upsilon)$ is

$$H_t^{I}(\upsilon) = \left(\frac{\delta^{I}\left(\dfrac{\alpha}{1-\alpha}\right)}{w_t}\right)^{\frac{1-\alpha}{1-2\alpha}} \left(q_t(\upsilon)BA_{t-1}\right)^{\frac{\alpha}{1-2\alpha}}\,. \tag{8}$$

where it is assumed that $\alpha < 0.5$. To see why this condition is set, if $\alpha > 0.5$, this would mean that as the wage rate increases, the firm demands more workers, which is counterintuitive. Substituting Eq. (8) back into Eq. (7) yields the explicit profit function

$$\pi_t^{I}(\upsilon) = (\delta^{I})^{\frac{1-\alpha}{1-2\alpha}}\left(\frac{\alpha}{(1-\alpha)w_t}\right)^{\frac{\alpha}{1-2\alpha}} \left(q_t(\upsilon)BA_{t-1}\right)^{\frac{\alpha}{1-2\alpha}}\left(1-\frac{\alpha}{1-\alpha}\right). \tag{9}$$

In this equation, it can be seen that the surplus for the entrepreneur that innovates is positively related to the stock of knowledge in the domestic economy. Note that in order for profits to be positive, $\alpha < 0.5$, and this has been ensured by the earlier assumption.

2.3.2. *Imitative firm*

On the other hand, the productivity of intermediate good υ of the entrepreneur that adopts technology is given as

$$A_t(\upsilon) = H_t^{A}(\upsilon)\overline{A_{t-1}}\ . \tag{10}$$

where $H_t^A(\upsilon)$ is the level of skilled workers employed in imitative activity and $\overline{A_{t-1}}$ denotes the body of world knowledge in the previous period. According to the above equation, the process of imitation is not a passive and costless activity, but skilled workers must be devoted to the activity to exploit the benefits of world technology.

The profits of the entrepreneur who imitates can be similarly expressed by substituting Eq. (10) into the profit schedule of Eq. (5)

$$\pi_t^{A}(\upsilon) = \delta^{A}\left(H_t^{A}(\upsilon)\overline{A_{t-1}}\right)^{\frac{\alpha}{1-\alpha}} - w_t H_t^{A}(\upsilon)\,. \tag{11}$$

where δ^A measures the degree of competition among firms that adopt foreign technologies. Solving for the optimum $H_t^A(\upsilon)$ employed gives

$$H_t^A(\upsilon)=\left(\frac{\delta^A\left(\frac{\alpha}{1-\alpha}\right)}{w_t}\right)^{\frac{1-\alpha}{1-2\alpha}}\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-2\alpha}}\ . \tag{12}$$

The corresponding explicit profit function can be obtained by substituting Eq. (12) into (11)

$$\pi_t^A(\upsilon)=(\delta^A)^{\frac{1-\alpha}{1-2\alpha}}\left(\frac{\alpha}{(1-\alpha)w_t}\right)^{\frac{\alpha}{1-2\alpha}}\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-2\alpha}}\left(1-\frac{\alpha}{1-\alpha}\right). \tag{13}$$

From Eq. (13), it can be noted that the profit function of the imitative firm is dependent on the stock of world technologies.

2.4. *Threshold level of ability*

This section analyzes the entrepreneur's decision on whether to carry out imitation or innovation and predicts the underlying industrial organization at each date, that is, the fraction of firms engaging in adoption frontier technologies and those undertaking innovative activities. This is done by solving for the endogenous threshold entrepreneurial skill level, q^*, which we find to be a function of the economy's distance to frontier.

Setting $\pi_t^A(\upsilon)=\pi_t^I(\upsilon)$ from Eq.s (9) and (13) yields the critical threshold level of entrepreneur ability[12]

$$q^*=\min\left\{\left(\frac{\overline{A_{t-1}}}{BA_{t-1}}\right)\left(\frac{\delta^A}{\delta^I}\right)^{\frac{1-\alpha}{\alpha}},1\right\}. \tag{14}$$

Furthermore, we define

$$a_{t-1}=\frac{A_{t-1}}{\overline{A_{t-1}}}\ . \tag{15}$$

where a_{t-1} is an (inverse) measure of the country's distance to frontier with a_{t-1} increasing in size as the country approaches the world technology frontier. It is also assumed that all country's have a state of technology that is at least less than the world frontier, hence $A_{t-1}\leq\overline{A_{t-1}}$ or similarly, $a_{t-1}\leq 1$

Eq. (14) can then be rewritten as:

$$q^*=\min\left\{\left(\frac{1}{Ba_{t-1}}\right)\left(\frac{\delta^A}{\delta^I}\right)^{\frac{1-\alpha}{\alpha}},1\right\}=q\min\left\{\left(\bar{B},\bar{a}_{t-1},\frac{\bar{\delta}^I}{\delta^A}\right),1\right\}\ . \tag{16}$$

A few things can be noted about Eq. (16). Firstly, there exists a unique q^* such that entrepreneurs with ability level $q_t(\upsilon)\leq q^*$ will find it more profitable to choose to imitate

[12]An arbitrage condition is that in equilibrium, a skilled worker employed in innovation or imitation receives the same wage.

while those with $q_t(v) > q^*$ will decide to engage in innovation. Secondly, q^* is limited by the value 1 to correspond to the entrepreneurial ability, $q_t(v)$~ U(0,1). When $q^* = 1$, this means that all entrepreneurs find it profit-maximizing to choose to undertake adoption. On the other hand, when $0 < q^* < 1$, the entrepreneurs will decide to imitate or innovate depending on their individual capability, $q_t(v)$. In addition, there is a threshold level of distance to frontier is given by

$$a^*=\left(\frac{1}{B}\right)\left(\frac{\delta^A}{\delta^I}\right)^{\frac{1-\alpha}{\alpha}}=a\left(\bar{B},\frac{\bar{\delta}^I}{\delta^A}\right). \tag{17}$$

whereby countries at a distance further from the frontier than a^* will have an entrepreneurial threshold ability $q^* = 1$. To illustrate with an example, a country like Burma, that is far away from the world technology frontier, such that $a_{t-1} \leq a^*$, will carry out only imitation of foreign technology but no indigenous innovation. Beyond this threshold, the economy will consist of a mixture of firms that opt for either an innovation-based strategy or imitation-based strategy to improve productivity, depending on the entrepreneur's skill level.

It can be easily deduced from Eq. (17) that a higher B or δ^I/δ^A will result in a smaller a^*. To summarize,

$0<q^*<1$	if	$a_{t-1} > a^*$	Both innovation and adoption occurs
$q^*=1$		$a_{t-1} \leq a^*$	Only adoption occurs

From Eq. (16), we formalize how the distance to frontier affects a country's technological paradigm at each period: as the economy approaches the world technology frontier, a_{t-1} increases, and thus q^* decreases. This tilts the balance towards entrepreneur choices that favor innovation over imitation. In other words, as a country gets close to the technological frontier, the proportion of firms carrying out innovative activities relative to firms that adopt from established technologies will rise.

Another observation that be made is that when monopoly power is higher for the innovating entrepreneur as compared to the entrepreneur that imitates, the threshold q^* is lowered and innovation is preferred. The reason is that where monopoly power is higher, the entrepreneur will be more likely to employ that particular technological production method since there are higher profits to be reaped, ceteris paribus. This is consistent with the Schumpeterian hypothesis that monopoly rent induces R&D. Lastly, the unique q^* is inversely related to the 'step size' that boosts innovation productivity. Intuitively, holding other things constant, factors that facilitate innovation favors that production method and lowers the minimum threshold entrepreneur ability for profitably engaging in innovation.

Figure 1 depicts the profit function with respect to the entrepreneur skill level q_t for the imitating and innovating firm, labeled π^A and π^I respectively. The function π^A is a horizontal straight line since the profits of the imitating firm is independent of q, according to Eq. (13). The function π^I, on the other hand is increasing in q, consistent with Eq. (9). The minimum threshold entrepreneurial ability level can be found from the intersection of the two profit functions as indicated by q^* in the diagram. As mentioned above, entrepreneurs with capability level $q_t(v) \leq q^*$ will opt to imitate while those with $q_t(v) > q^*$ will engage in innovation. Therefore, Figure 1 also reveals the share of firms that adopt foreign technologies as q^*, while firms that carry out indigenous innovation as $(1 - q^*)$.

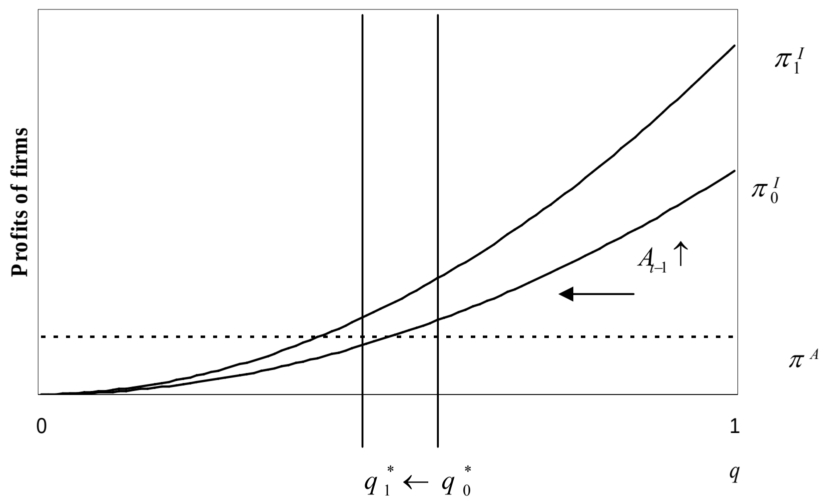

Fig. 1. Profits of adopting and innovating firm.

Now suppose that a_{t-1} increases, for example, if A_{t-1} rises holding $\overline{A_{t-1}}$ constant. From Eq. (9) it is clear that π^I function would shift up and as a result, the critical ability threshold moves from q_0^* to q_1^*. At a lower q^*, more entrepreneurs will find it optimal to switch from imitation to innovation to improve firm productivity. Hence this clearly shows how the distance to world frontier affects the technological structure of a country. Specifically, as an economy moves closer to the frontier, the technological paradigm gradually shifts away from adoption of world technologies towards indigenous innovation.

2.5. *Labor market equilibrium*

At time t, total skilled workers in the economy is allocated in R&D activity between innovation and imitation for the case where $0 < q^* < 1$. If we sum across all skilled workers engaged in R&D, the total human capital is given by:

$$\overline{H} = \int_0^{q^*} H_t^A(q)dq + \int_{q^*}^1 H_t^I(q)dq \text{, for } 0 < q^* < 1. \tag{18}$$

By substituting Eq.s (12), (8), (16) and (15) inside, this can be written as:

$$\overline{H}=\left(\frac{\alpha\delta^{I}}{(1-\alpha)w_t}\right)^{\frac{1-\alpha}{1-2\alpha}}\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-2\alpha}}\left\{\frac{1}{Ba_{t-1}}\left(\frac{\delta^{A}}{\delta^{I}}\right)^{\frac{(\alpha-1)^2}{\alpha(1-2\alpha)}}+\left(Ba_{t-1}\right)^{\frac{\alpha}{1-2\alpha}}\left(\frac{1-2\alpha}{1-\alpha}\right)\left[1-\left(\frac{1}{Ba_{t-1}}\right)^{\frac{1-\alpha}{1-2\alpha}}\left(\left(\frac{\delta^{A}}{\delta^{I}}\right)\right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}}\right]\right\}.$$

(19)

As the economy approaches the frontier, q^* decreases and more firms choose to engage in innovation. This result in a decrease in the proportion of skilled workers demanded for imitation and a subsequent rise in the skilled workers employed for innovation.

From Eq. (19), the equilibrium wage rate of skilled workers, w_t can then be derived easily to be

$$w_t=\left(\frac{\alpha\delta^{I}}{(1-\alpha)}\right)\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-\alpha}}\left\{\left(\frac{1}{\overline{\overline{H}}}\right)\left[\frac{1}{Ba_{t-1}}\left(\frac{\delta^{A}}{\delta^{I}}\right)^{\frac{(\alpha-1)^2}{\alpha(1-2\alpha)}}+\left(Ba_{t-1}\right)^{\frac{\alpha}{1-2\alpha}}\left(\frac{1-2\alpha}{1-\alpha}\right)\left[1-\left(\frac{1}{Ba_{t-1}}\right)^{\frac{1-\alpha}{1-2\alpha}}\left(\left(\frac{\delta^{A}}{\delta^{I}}\right)\right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}}\right]\right]\right\}^{\left(\frac{1-2\alpha}{1-\alpha}\right)}.$$

(20)

In the situation of a technologically backward country when $q^* = 1$, skilled workers are only employed in adopting technology. This is given by

$$\overline{H}=\int_0^{q^*}H_t^A(q)dq\,. \tag{21}$$

Substituting Eq.s (12) and (16) into (21) gives

$$\overline{H}=\left(\frac{\alpha\delta^{A}}{(1-\alpha)w_t}\right)^{\frac{\alpha}{1-2\alpha}}\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-2\alpha}}\frac{1}{Ba_{t-1}}\left(\frac{\delta^{A}}{\delta^{I}}\right)^{\frac{(1-\alpha)}{\alpha}}. \tag{22}$$

The equilibrium wage rate of skilled labor in the technologically backward economy that is engaged in only adoption can be similarly derived as

$$w_t=\left(\frac{\alpha\delta^{A}}{(1-\alpha)}\right)\left(\overline{A_{t-1}}\right)^{\frac{\alpha}{1-\alpha}}\left[\left(\frac{1}{\overline{\overline{H}}Ba_{t-1}}\right)\left(\frac{\delta^{A}}{\delta^{I}}\right)^{\frac{(1-\alpha)}{\alpha}}\right]^{\left(\frac{1-2\alpha}{1-\alpha}\right)}. \tag{23}$$

This is lower than the wage rate in Eq. (20) for the economy nearer the frontier ($a_{t-1} > a^*$) that engages in both adoption of foreign technologies and home-grown innovation activities. This implies that identically productive skilled workers in the country that is more technologically advanced will enjoy a higher wage than the country whose distance to frontier falls below the threshold a^*.

2.6. *Technological progress*

Finally, the average productivity of the economy that consists of a mixture of firms that carries out adoption or innovation at time t, A_{t-1}, is specified as

$$A_t=\int_0^{q^*}\overline{A_{t-1}}H_t^A(q)dq+\int_{q^*}^{1}qBA_{t-1}H_t^I(q)dq\text{ , for }0<q^*<1. \quad (24)$$

where the productivity level is summed across all intermediate goods. Again by substituting Eq.s (12), (8), (16) and (15) inside we have,

$$A_t = \left(\frac{\overline{A_{t-1}} \alpha \delta^I}{(1-\alpha) w_t} \right)^{\frac{1-\alpha}{1-2\alpha}} \left\{ \frac{1}{Ba_{t-1}} \left(\frac{\delta^A}{\delta^I} \right)^{\frac{(\alpha-1)^2}{\alpha(1-2\alpha)}} + (Ba_{t-1})^{\frac{1-\alpha}{1-2\alpha}} \left(\frac{1-2\alpha}{2-3\alpha} \right) \left[1 - \left(\frac{1}{Ba_{t-1}} \right)^{\frac{2-3\alpha}{1-2\alpha}} \left(\left(\frac{\delta^A}{\delta^I} \right) \right)^{\frac{(1-\alpha)(2-3\alpha)}{\alpha(1-2\alpha)}} \right] \right\}.$$

(25)

Inspection of the above expressions reveals several things. Firstly, it can be seen from Eq. (24) that productivity growth in the country is captured by the two dimensions of innovation and adoption. Secondly, Eq. (25) shows that when a country progresses nearer to the world technology frontier, a_{t-1} increases, the contribution of imitative activities to the advancement of technology in the economy decreases and domestic innovation takes over as the major source of technological progress. To put it differently, a technologically backward country will raise productivity level mainly by adopting advanced technologies while one closer the world frontier will depend more on the channel of innovation. Furthermore, the size of the 'step size' innovation, B, also determines the weight of the imitative and innovative activities for a given a_{t-1}, where a higher B causes innovation to play a more important role in advancing the country's technology.

Next, w_t is endogenized from Eq. (20) and substituted into Eq. (25)

$$A_t = \overline{H}\,\overline{A_{t-1}} \left\{ \frac{1 + (Ba_{t-1})^{\frac{2-3\alpha}{1-2\alpha}} \left(\frac{\delta^I}{\delta^A} \right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}} \left(\frac{1-2\alpha}{2-3\alpha} \right) - \left(\frac{\delta^I}{\delta^A} \right)^{\frac{(\alpha-1)}{\alpha}} \left(\frac{1-2\alpha}{2-3\alpha} \right)}{1 + (Ba_{t-1})^{\frac{1-\alpha}{1-2\alpha}} \left(\frac{\delta^I}{\delta^A} \right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}} \left(\frac{1-2\alpha}{1-\alpha} \right) - \left(\frac{1-2\alpha}{1-\alpha} \right)} \right\}. \tag{26}$$

For the situation when $q^* = 1$, where firms carries out only adoption of frontier technology to improve productivity, the average productivity of the economy is

$$A_t = \int_0^{q^*} \overline{A_{t-1}} H_t^A(q) dq \text{ , for } q^* = 1. \tag{27}$$

After substituting Eq. (12) and (16), we have

$$A_t = \left(\frac{\alpha \delta^A}{(1-\alpha) w_t} \right)^{\frac{\alpha}{1-2\alpha}} \left(\overline{A_{t-1}} \right)^{\frac{1-\alpha}{1-2\alpha}} \frac{1}{Ba_{t-1}} \left(\frac{\delta^A}{\delta^I} \right)^{\frac{(1-\alpha)}{\alpha}}. \tag{28}$$

Finally, we once more endogenize w_t by substituting Eq. (23) the equilibrium wage rate of skilled workers that imitate technologies, to obtain

$$A_t = \overline{H}\,\overline{A_{t-1}}. \tag{29}$$

Not surprisingly, Eq. (29) can also be obtained by aggregating the productivity function of the firm that adopts technology in Eq. (10) since the economy's productivity level depends only on one type of R&D activity, namely, imitation.

Furthermore, we define the growth rate of world technology frontier, $\overline{A_t}$, by g

$$\overline{A_t} = (1+g)^t \overline{A_0}\,. \tag{30}$$

which enables us to rewrite Eq.s (25) and (29) as

$$a_t = \begin{cases} \dfrac{\overline{H}}{1+g} & \text{if } a_{t-1} \le a^* \\[2ex] \dfrac{\overline{H}}{1+g}\left\{ \dfrac{1+\left(Ba_{t-1}\right)^{\frac{2-3\alpha}{1-2\alpha}} \left(\dfrac{\delta^I}{\delta^A}\right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}} \left(\dfrac{1-2\alpha}{2-3\alpha}\right) - \left(\dfrac{\delta^I}{\delta^A}\right)^{\frac{(\alpha-1)}{\alpha}} \left(\dfrac{1-2\alpha}{2-3\alpha}\right)}{1+\left(Ba_{t-1}\right)^{\frac{1-\alpha}{1-2\alpha}} \left(\dfrac{\delta^I}{\delta^A}\right)^{\frac{(1-\alpha)^2}{\alpha(1-2\alpha)}} \left(\dfrac{1-2\alpha}{1-\alpha}\right) - \left(\dfrac{1-2\alpha}{1-\alpha}\right)} \right\} & \text{if } a_{t-1} > a^* \end{cases}$$

(31)

Eq. (31) gives us the equilibrium law of motion of a_t. It states that the growth of country that is far off from the world frontier and only carries out adoption of existing technologies (i.e., $a_{t-1} \le a^*$) depends only on the level of skilled workers. However, once the technological gap is sufficiently small, so that $a_{t-1} > a^*$, the economy will consists of a mixture of imitating and innovating firms and growth will be affected by the stock of skilled workers, as well as the parameters B, δ^I/δ^A, a_0 and α.

3. Transitional Dynamics

3.1. *Baseline simulation*

In this section, the transitional dynamics implied by the equilibrium law of motion of a_t, Eq. (31), is investigated by means of a simulation exercise. The results show that technologically backward countries can potentially narrow their distance to the world frontier and eventually converge to a steady state a^{SS}, higher than when it started. As implied by the model, this convergence is done through the channels of only adoption when $a_{t-1} \le a^*$ and both imitation and innovation for $a_{t-1} > a^*$. The long run equilibrium steady state is found to be below that of the world technology frontier, in other words, there is no final convergence to the frontier. Therefore, advanced countries whose technological gap is initially smaller than the steady state, $a_{t-1} > a^*$, will converge in the long run to the lower a^{SS}, further from the world frontier. Furthermore, under certain conditions, it is possible that the economy's steady state a^{SS} remains less than or equal to a^* and productivity growth is based solely on the adoption of world technologies. We term this situation an *adoption trap.*

Parameters used in the baseline simulation are given in Table 1.

Table 1. Parameter values for baseline simulation.

a_0	0.10	$\overline{H}$	0.13
α	0.4	B	10
g	0.02	δ^I/δ^A	1

The world technological frontier is assumed to be exogenous and growing at a value of 0.02 to approximately match the average per capita growth rate of the United States of America (U.S.A). The country is assumed to be technologically backward and therefore, the baseline initial distance to frontier is set as $a_0 = 0.1$. Consistent with $\alpha < 0.5$ in the earlier condition from Eq. (8), we impose $\alpha = 0.4$ assign values for $\overline{H}$, B and δ^I/δ^A to ensure that the assumption $a_t \leq 1$ is satisfied.

The continued line in Figure 2 illustrates the transitional path for the country's distance to frontier, a_t, resulting from the baseline simulation exercise. As mentioned earlier, firms in countries with technology level $a_0 \leq a^*$ start out by carrying out only imitation of established technologies, as is the case for our benchmark country, $a_0 = a^*$. In the following period however, the technological gap is reduced, $a_t > a^*$ and hence, technological progress becomes a result of both adoption and innovation with the latter increasing in contribution as the distance to frontier narrows. It can be observed that a_t finally converges to a higher steady state, $a_0 < a^{SS} < 1$. This implies that the technology gap will not be closed fully in the long run and the world frontier's technology continues to be more advanced than the domestic technology.

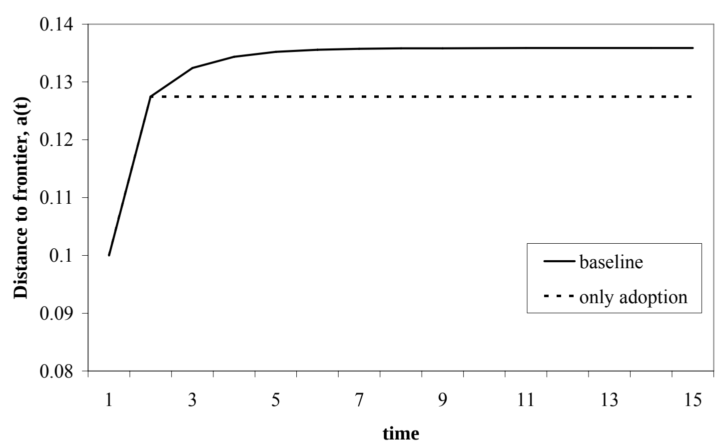

Fig. 2. Transitional distance to frontier path.

It is also possible for an economy to be trapped in the adoption-based technological paradigm with its technological gap a_t continually less than or equal to a^*. The transitional path of a_t for such an economy that is in an adoption trap is illustrated by the discontinued line in Figure 2. In the next period, the economy moves to the steady state a^{SS} that corresponds to $\overline{H}/(1+g)$[13] and growth in the country depends only on the level of skilled workers which is exogenously fixed in this model.

3.2. *Evolution of a_t*

The Eq. (31) implicitly expresses a_t as a function of a_{t-1}, therefore, we can use it to check in this section if equilibrium value(s) of a_t exists. Taking the earlier baseline parameters, Figure 3 illustrates a_t as a function of a_{t-1} and shows how it crosses the 45-degree line at a single point where $a_t = a_{t-1}$. This denotes a unique and globally stable equilibrium a^{SS} or to put it simply, whatever the initial value of a_t is, it will converge gradually to a^{SS}. In other words, holding other things equal, countries of differing relative productivities will converge to a common distance to frontier a^{SS}.

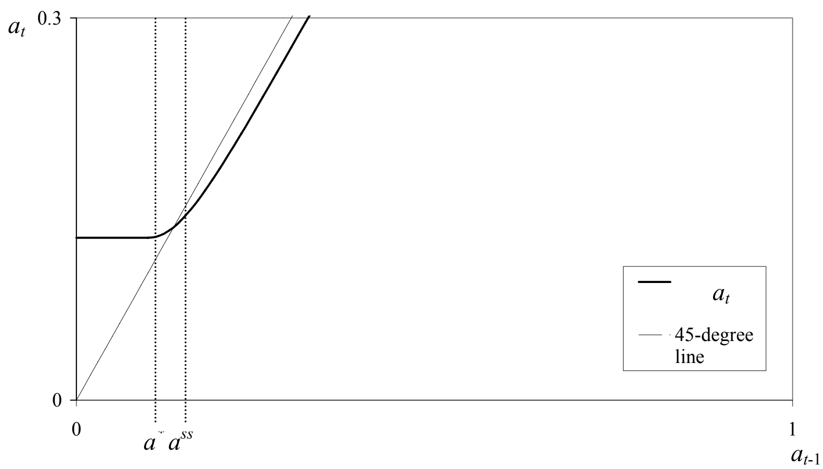

Fig. 3. Transitional distance to frontier path.

The parameters can also be varied to obtain multiple equilibrium values of a_t. This occurs if $\overline{H}$[14], B and δ^I/δ^A are set too high and produces both a stable and an unstable equilibrium. However, we will only focus on the case with one unique and stable steady state.

One interesting feature that is observed below is that the a_t function is constant for all $a_{t-1} \leq a^*(=0.10)$. This means that other things being equal, countries with an initial technological gap less than or equal to 0.10 will catch up to the same distance to frontier in the next period, a_1. The reason is that the productivity of adopting foreign technologies depends on the stock of world knowledge which is equally accessible to all[15], and not on

[13] According to Eq. (31)
[14] For instance if we set $\overline{H} > 0.13623113$.
[15] We do not investigate the existence of barriers to technology dissemination in this paper. See Parente and Prescott (1994) for a discussion on this.

the domestic productivity. A second implication that is captured here is that countries that begin by solely carrying out imitation can potentially catch up quickly to a position sufficiently close to the frontier which allows for both imitation and innovation activities to profitably take place in the country.

3.3. *Sensitivity analysis*

It is interesting in the analysis to determine the transitional paths of countries that have different market structures, level of skilled workers, step-size innovation and distance to frontier. To do this, changes on the parameters $\overline{H}$, B, δ^I/δ^A and a_0 are made and illustrated in the following figures. Sensitivity analysis of these parameters also enables one to better understand the properties of the a_t equation and reveal some further insights.

3.3.1. *Exogenous increase in δ^I/δ^A*

In Figure 4, an increase in the monopoly power among the firms that pursue an innovative-based strategy relative to firms that are adopting, δ^I/δ^A [16], shifts the whole transitional path upward and leads to a higher steady state a^{SS}. This seems to suggests that an economy where there are greater monopoly rents to be gained for the entrepreneur that produces through innovation will settle at a long-run productivity level closer to the world frontier compared to one where there is greater monopoly power among firms that engage in adoption.

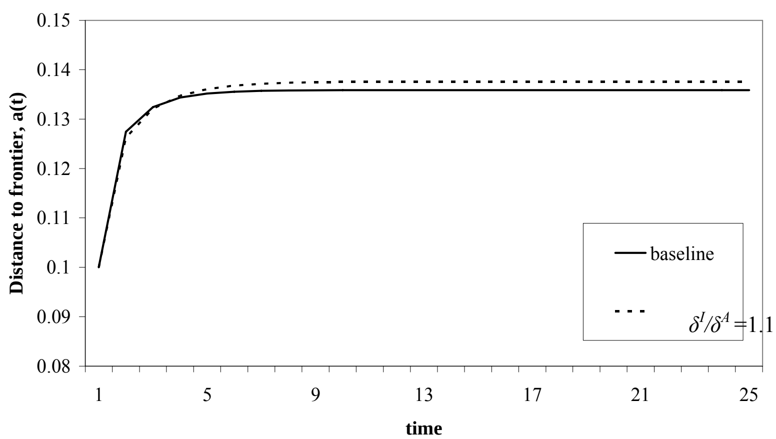

Fig. 4. Sensitivity analysis of δ^I/δ^A.

However, it was found that for values of $\delta^I/\delta^A > 1.2667$, the economy actually converges to a lower steady state a^{SS}. One possible explanation for the results is that as δ^I/δ^A grows larger, this pushes up the profits for firms that innovate relative to adopt

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[16] Recall that $\delta \equiv (\chi - 1)(\chi)^{\frac{-1}{1-\alpha}}$, where χ is a measure of the degree of competition in the market.

technology. Correspondingly, more entrepreneurs decide to engage in innovation because their ability level exceeds the threshold. However, the entrepreneurs at the lower end of the ability spectrum are not as efficient in innovation and this leads to an inferior long-run growth rate. As this is more clearly shown in the next chapter, we leave further elaboration and the policy implications till later.

3.3.2. *Exogenous increase in* $\overline{H}$

Figure 5 reveals that the size of the skilled labor force is vital in determining the productivity level of a country. A higher level of skilled workers increases an economy's capacity to carry out adoption of technology and indigenous innovation and unambiguously leads to a smaller steady state technology gap from the world frontier.

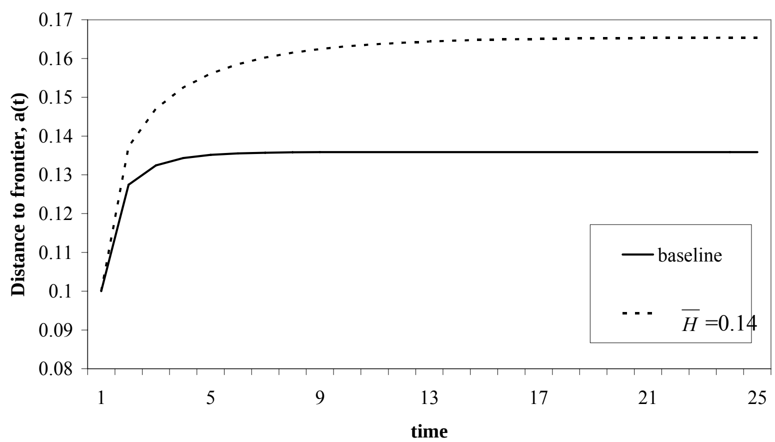

Fig. 5. Sensitivity analysis of $\overline{H}$.

3.3.3. *Exogenous increase in B*

Figure 6 shows how a change in the step-size innovation *B* affects the transitional path of the distance to frontier. The findings inform us that, everything else being equal, the larger the *B* the higher the steady state a^{SS}. The intuition for this result is that a larger *B* parameter leads to a larger boost on the effect that innovation has on productivity for the firms that engage in this type of R&D activity and hence a higher overall productivity for the economy.

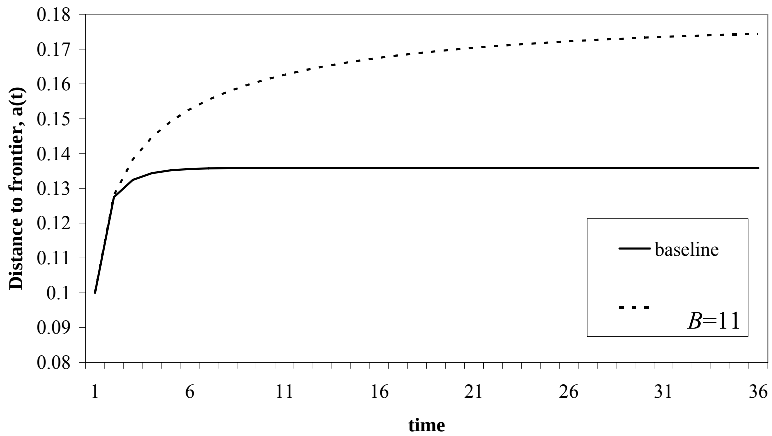

Fig. 6. Sensitivity analysis of *B*

3.3.4. *Exogenous increase in a_0*

Finally, Figure 7 reveals that holding other things constant, a decrease in the distance to frontier will lead to a faster convergence to the steady-state. Increasing a_0 from 0.10 to 0.12 shifts the transitional dynamic path of a_t to the left, affecting the transitional growth but not the long-run growth rate. This suggests that countries nearer to the world technological frontier will experience a higher growth in the transition period compared to countries that are more backward. This is similar to the notion of "contiguous knowledge" (Papegeorgiou, 2000a) which holds to the view that countries that are closer to the frontier are better able to take advantage of new technologies than those more backward and contrary to the idea that a country's rate of catching up is a positive function of its relative backwardness.

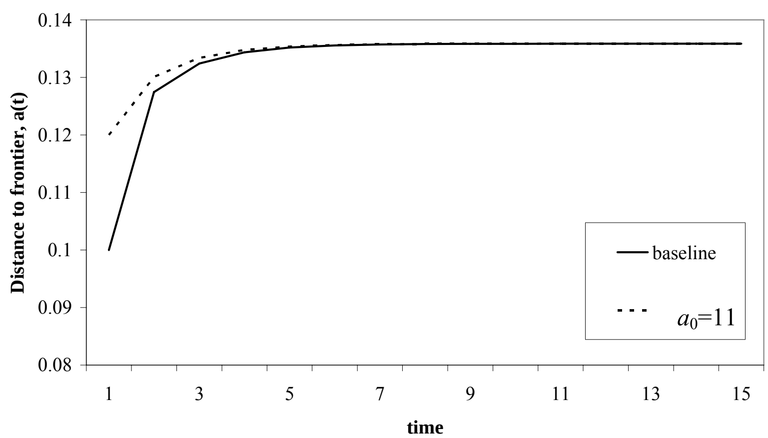

Fig. 7. Sensitivity analysis of a_0

3.4. *Summary*

To summarize the results, our simulation analysis reveals that $\overline{H}$ and B has a positive influence on lowering the long-run steady state distance to frontier of a country, a^{SS} ; δ^I/δ^A has a positive impact on a^{SS} for $\delta^I/\delta^A \leq 1.2667$ and an adverse effect thereafter; while a_0, the initial technological gap, affects the economy's process of technological convergence but not the long-run growth.

4. Discussion of the Model

A central question that naturally arises from the model is how can countries reduce their long-run distance to frontier or equivalently, obtain a higher steady state, a^{SS}. However before attempting to answer the question, we summarize relevant insights that have been established and interpretations which would assist in understanding the analysis in the subsequent sections.

(1) There is a threshold distance to frontier, a^*, whereby countries surpassing it will switch from a solely adoption-based regime to an adoption-and-innovation-based technological structure. According to Eq. (17) and holding other things equal, the switch will occur earlier for an economy that has a higher δ^I/δ^A or B. Intuitively, policies that bring about potentially higher monopoly rents for firms that innovate and a larger step size boost to innovation, makes being in an adoption trap less likely.
(2) For an economy with a mixture of imitating and innovating firms, the transition mechanism from adoption towards indigenous innovation is portrayed through a minimum endogenous entrepreneurial level of capability q^*, that the entrepreneur must possess before innovation becomes more profitable than imitation. This critical value, which gives the fraction of firms that adopt technologies, is decreasing in a_{t-1}, δ^I/δ^A and B[17] from Eq. (16). In other words, increasing these factors tilts the balance towards entrepreneurs innovating.
(3) For some parameter values, an economy can be stuck in a steady state in which the technological paradigm only adopts established technologies but does not carry out domestic innovation. The long run growth will then be limited to depending on the size of the skilled labor force, as seen from Eq. (31) where $a^{SS} = \overline{H}/(1+g) \leq a^*$
(4) If the economy's steady state is $a^{SS} > a^*$, then consistent with Eq. (31) and the simulation findings, the long run growth is positively affected by $\overline{H}$, B and a certain range of δ^I/δ^A.
(5) The results of the model show that it is the relative competitive structures of the intermediate firms that innovate over those that imitate, δ^I/δ^A, rather than the absolute monopoly power that has a bearing on the technological gap, a_t.

[17] The intuition behind this has been discussed in Section 2.4 and is therefore not repeated here.

(6) Finally, the parameter B is open to several interpretations such as the availability of knowledge institutions, openness in knowledge flows and other policies that facilitate the innovation process and increase its probability of success.

In the following sections, we study strategy(s) to move closer to the world frontier for countries in two different scenarios:

(i) a country that is initially at a steady state with only adoption

(ii) one which both adopts and innovates at its steady state.

The comparative static analyses consist in examining the effect on the steady state a^{SS} by exogenously increasing the parameters $\overline{H}$, B and δ^I/δ^A.

4.1. *Case I: Steady state with only adoption*

Table 2 shows the parameter values chosen for the benchmark country that is trapped in a solely adopting steady state.

Table 2. Parameter values for benchmark country that only adopts.

a_0	0.10	$\overline{H}$	**0.08**
α	0.4	B	**8**
g	0.02	δ^I/δ^A	**0.8**

The values for the right column are deliberately set sufficiently low so that the economy's a^{SS} is less than a^*. This implies that whatever the country's initial technological gap, it will finally converge to a technological paradigm that only imitates.

This is clearly depicted in Figures 8 - 10 in which the continuous line intersects the 45-degree line at its horizontal section. As explained under Section 3.2, this is because when there are only adopting firms, the economy's productivity is independent of its initial a_t and relies on the world's frontier, A_t.

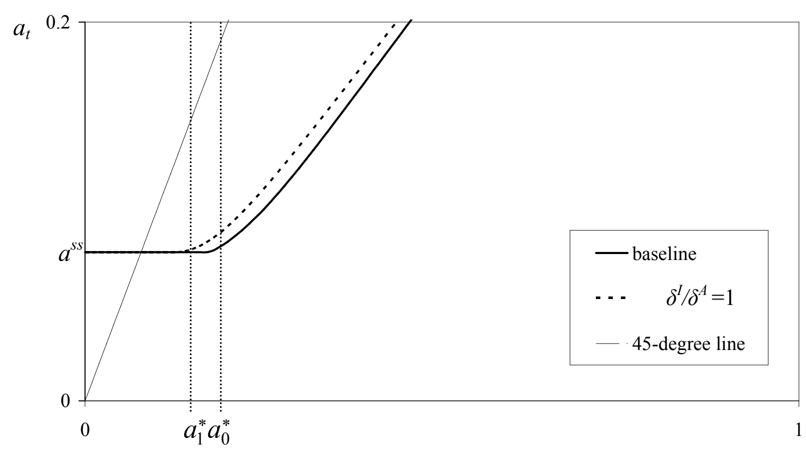

Fig. 8. Impact of a^{SS} – increase in δ^I/δ^A.

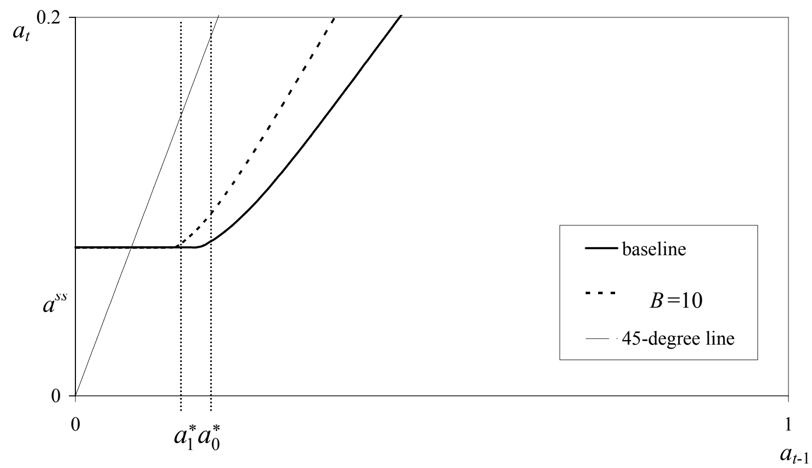

Fig. 9. Impact of a^{SS} – increase in B.

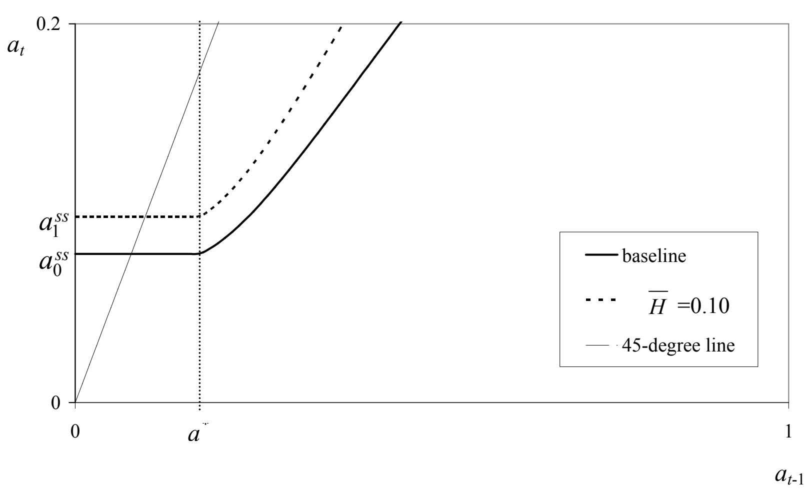

Fig. 10. Impact of a^{SS} – increase in $\overline{H}$.

Some other things to note is firstly, the y-axis and x-axis for the following diagrams have again been scaled down without losing other relevant information as the steady state is unique (i.e., it crosses the 45-degree line only once), this is done so that changes that occur are more obvious. Secondly, there exist certain thresholds of $\overline{H}$ and B sufficiently large for the economy to switch out of the adoption trap. However, in this section it is assumed that changes in the parameters made do not bring the country out of the solely adopting regime. This is done in order to analyze the optimal policy to implement for a country whose a^{SS} remains less than a^*. This brings us to the last point: comparison of optimal choices of $\overline{H}$, B and δ^I/δ^A are discussed in our analysis although neither the role of the government nor the opportunity cost to a country to change these parameters is formally introduced in the model, which are left as an area for future research.

Figure 8 and Figure 9 reveal that an increase in δ^I/δ^A or in B results in a fall in the critical threshold, a_0^* that determines an economy's switch from an adoption trap to both adoption and innovation (a_0^* to a_1^*). However, the change in the parameters is not sufficiently large and consequently the country's long-run steady state a^{SS} is not affected. The firms continue to remain doing only imitation of technologies with $a^{SS} < a^*$.

On the other hand, Figure 10 shows that a rise in $\overline{H}$ brings the economy to a higher steady state a^{SS} while the critical threshold a^* is unchanged. This holds true even when the increase in $\overline{H}$ is not particularly large and the country remains in the adoption trap. It can be noted that the graphical analysis behaves according to the Eq.s (31) and (17) of a^{SS} and a^* respectively.

In light of our findings, we can conclude that the optimal strategy for countries that are far off from the frontier and whose firms only engage in imitation is to enlarge $\overline{H}$. The intuition lies in the fact that absorption of technologies from abroad relies only on the stock of skilled workers and the world knowledge and therefore policies that facilitate innovation (increase in δ^I/δ^A or B) do not affect the long run distance to frontier.

4.2. *Case II: Steady State with both adoption and innovation*

Table 3 shows the parameter values chosen for the benchmark country that is in equilibrium with a mixture of firms either imitating or innovating.

Table 3. Parameter values for benchmark country that adopts and innovates.

a_0	0.10	$\overline{H}$	**0.12**
α	0.4	B	**10**
g	0.02	δ^I/δ^A	**1**

Again, the values for the right column are deliberately set high enough such that the economy's a^{SS} is greater than a^* and the economy will finally converge to a technological paradigm where there is a mixture of firms either imitating or innovating. This can be seen from Figures 11 - 13 where the sloping part of the continuous line intersects the 45-degree line once. The threshold a^* has not been marked out in the following figures as it does not have any policy implications in this section and to avoid complicating the diagrams but we can expect the rise in B and δ^I/δ^A to lower a^* while changing $\overline{H}$ has no effect on a^*.

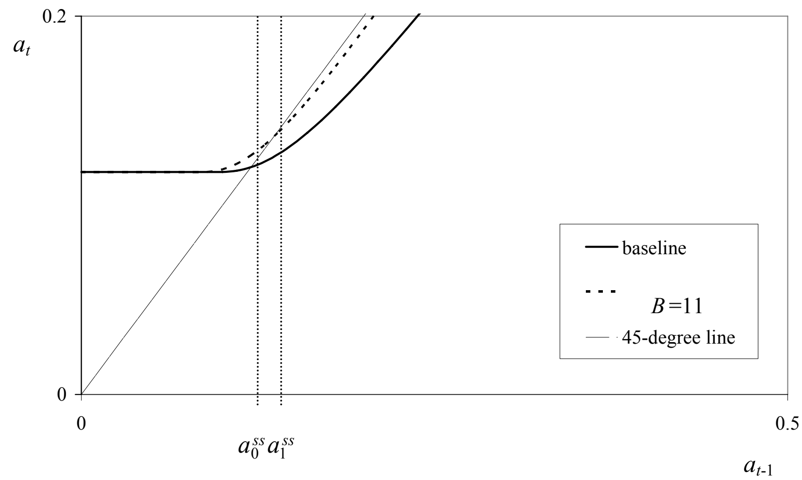

Fig.11. Impact of a^{SS} – increase in B.

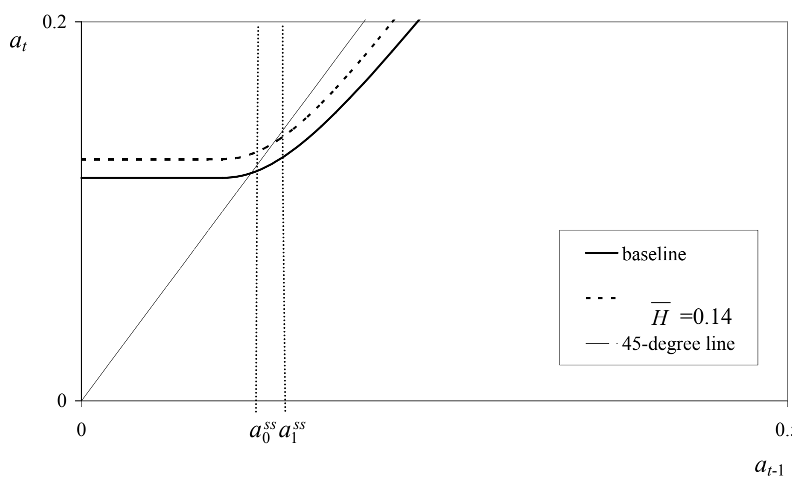

Fig. 12. Impact of a^{SS} – increase in $\overline{H}$.

Figures 11 and 12 illustrate how an increase in B and $\overline{H}$ affects the benchmark economy's steady state distance to frontier, moving from a_0^{SS} to a_1^{SS}. The figures demonstrate that raising either parameter enables the economy to achieve a smaller long-run distance to frontier.

We have deliberately left the analysis of an increase in δ^I/δ^A as the last comparative static due to its unusual effect on the evolution of a_t as depicted in Figure 13[18].

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[18] The qualitative results are the same for any $\delta^I/\delta^A > 1.062$.

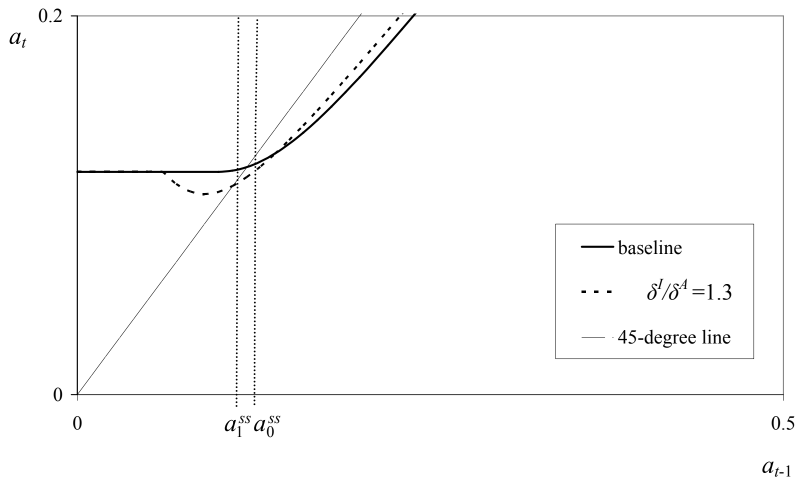

Fig. 13. Impact of a^{SS} – increase in δ^I/δ^A.

The dynamics of a_t is as follows:

(i) where the discontinued line departs from the horizontal portion describes how a^* is reduced due to a higher δ^I/δ^A and the economy would emerge from a solely adopting regime to one with both types of R&D activities at a lower threshold technology level.

(ii) the downward sloping discontinued line implies that a_t is decreasing in $a_{t\text{-}1}$. The line then reaches a minimum before a_t increases in $a_{t\text{-}1}$ as per normal.

(iii) the discontinued line finally crosses the 45-degree line at a lower point than the baseline simulation, hence a_0^{SS} reduces to a_1^{SS}.

One plausible conjecture for the change in the slopes of how a_t evolves is that a higher δ^I/δ^A lowers the threshold ability level which in turns leads to more entrepreneurs with less skill level undertaking innovation. When the domestic stock of knowledge is relatively low, the productivity of the innovative firms could be affected adversely so that a_t is decreasing in $a_{t\text{-}1.}$ After reaching a certain distance to the frontier however, the opposite occurs and an increase in a_t is beneficial to the following period's technological gap. The economic intuition lies in the fact that when the domestic technology stock is higher, the productivity of innovation is enhanced as seen from Eq. (6).

What then are the appropriate policies for moving closer to the world frontier the economy should implement in this scenario? Firstly, the government can opt to either promote B or $\overline{H}$ since in both cases, long run distance to frontier is improved. The final decision might depend on the marginal benefit each brings to growth which we have not modeled in this paper. Intuitively, compared to the country where firms only adopt technology, having more skilled workers plays an additional part in raising an economy's relative productivity by facilitating home-grown innovation. In a similar vein, policies that increase B boost the success rate of innovations resulting in convergence to a smaller technological gap from the frontier.

Secondly, from the analysis of δ^I/δ^A we can draw the conclusion that the optimal strategy for economies in an equilibrium which carries out both types of R&D activities is to maintain the relative monopoly power among the firms that innovates and firms that imitates.

4.3. *Summary*

In economies that remain in the solely adoption trap, the government should intervene to increase the skilled labor force to move closer to the technology frontier whereas policies that boost B or δ^I/δ^A reap no benefit for the economy in the long run. However, if the economy wants to switch out of the adoption trap to carry out both adoption and innovation, it must implement steps to increase the skilled labor force or B sufficiently. Finally, in countries in which both imitation of leading-edge technologies and domestic innovation take place, increasing either B or $\overline{H}$ leads to a higher steady state a^{SS}. In contrast, doing the same for δ^I/δ^A is harmful to the economy's final distance to frontier.

5. Conclusion

This paper models the technology trajectory of an economy as it moves closer to the world frontier. Our discussion takes a fresh approach by including the entrepreneur who, consistent with the economic literature, is paramount in determining the R&D activities within an economy. In particular, we capture how countries transit from a technological paradigm exclusively or largely based on imitation of foreign technologies to one with an increasing percentage of domestic innovation. The interaction between the country's stage of development and the upgrading of its R&D activities is portrayed through the profit-maximizing entrepreneur who has to surpass a threshold level of capability before the payoffs for undertaking innovation become more attractive than imitation. Furthermore, this entrepreneurial ability threshold is endogenized and found to be decreasing in the technological gap. This provides the fundamental basis for the changing technological structure as the country approaches the world frontier.

Interestingly, the model predicts a unique distance to frontier equilibrium that countries converge to in the long run. In this final steady state, the economy consists of a mixture of firms that either imitate or innovate technology. However, it is also possible for a country to be trapped in a structure that only adopts from the frontier if the environment for firms to innovate is unfavorable.

The theoretical framework sheds light to the developments in the world whereby technologically backward countries initially start off by imitating foreign ideas. Then, as the country builds up its own stock of knowledge and progresses towards the frontier, more and more innovative activities take place within the economy. The existence of an adoption trap in our model also tallies with the observation that in the real world, very technologically backward countries conduct little or no innovative R&D.

Future research could possibly incorporate endogenous human capital accumulation of the skilled workers and its subsequent effect on the productivity level of a country as well as modeling the cost for policy-makers to change the relevant parameters that affects the country's steady state. It also remains to test the hypothesis empirically, whether a country's distance to frontier truly affects the share of imitation and innovation activities.

Finally, we show that for a country to surmount the technological gap threshold and come out from the adoption trap, the government can intervene to enlarge the skilled workers base or implement measures that boost innovation. Policies that allow an economy to achieve a closer distance to frontier depend on whether the country is in a solely imitating steady state or one with both types of R&D activity. In the formal scenario, the strategy is straightforward: increase the skilled labor force. In the latter case, the optimal policy is to either enlarge B or $\overline{H}$. Interestingly, we also find that inducing more innovation at the expense of adoption through higher monopoly rents may be detrimental to the country's long run distance to frontier, especially when the country is technologically backward.

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