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Why Technological Spillovers elude Developing Countries: A Dynamic Non-linear Model

By

Watu Wamae

Danish Research Unit for Industrial Dynamics

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Watu Wamae
Centre de Recherche sur les Dynamiques et Politiques Économiques et l'Économie des Ressources (CEDERS)
Faculté des Sciences Économiques et Gestion
Université de la Méditerranée
14 avenue Jules Ferry
13621 Aix en Provence
France
E-mail: watu.wamae@gmail.com

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Abstract:
This paper attempts to theoretically understand the process of catching-up or falling behind particularly within the context of developing countries. The main aim of the paper consists in investigating the impact of domestic innovation, via its interaction with the learning capability, on the technology gap of an economy. More specifically, we seek to shed some light on why the tendency for poor countries to fall further behind, despite efforts to improve their learning capabilities, appears pervasive. Our analysis is based on a simple model of technology gap elaborated by Verspagen (1991). We find that domestic innovation, a critical component for the development of an absorptive capacity, is a significant determinant of whether an economy catches-up or falls further behind.

Key words: Technology gap, absorptive capacity, developing countries
JEL Codes: O11, O15, O38

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1 Introduction

Amongst developing countries, there is a growing rift between the few economies that have managed to "take-off" and the overwhelming majority that is increasingly being marginalised by the current economic trend of rapid transformations. This paper addresses the question: *What lies behind the ability of a handful of developing countries to catch-up whilst the vast majority recedes further into marginalisation?* We use the Schumpeterian-inspired technology gap approach that has been developed within the evolutionary growth theory, and whose main assertion is that innovation and diffusion are the main sources of growth. It is an alternative perspective to the mainstream neo-classical inspired growth theory, and its main distinguishing characteristic is that interactions among firms, government and research institutes provide feedback mechanisms that involve learning; learning determines innovation that leads to technological change.[1] Emphasis is placed on enhancing the learning process rather than on providing the "right" economic incentives (notably patents and subsidies) to profit-maximising entrepreneurs who exploit "publicly" available knowledge: innovation is viewed as a complex phenomenon that is highly cumulative and path-dependent, and is influenced by various factors both measurable and immeasurable, including organisational,institutional and cultural set-ups.

The central question in the technology gap approach consists in investigating why growth rates differ across countries, and it is argued that the answer lies in differing rates of technology growth. Kaldor (1957) was the first to suggest that differing growth rates in the long-run could be explained by differences in endogenous technological progress. The underlying idea was that investment and learning were interrelated and formed the basis for technological progress: the rates at which investment and learning took place determined the rate of technological growth. Gerschenkron (1962) who studied

[1]See for example Rosenberg (1982) and Lundvall (1988)

international aspects of the process of innovation and learning pioneered the idea that technology gaps that exist between technology frontier economies and laggards provide great opportunities for the latter to acquire technology through assimilation of the existing backlog of knowledge. However, he emphasised that exploitation of the potential technology benefits by lagging countries is not an automatic process and may involve a lot of efforts and substantial costs in the development of new institutions, organisation and policies that support transitions into the more technologically productive industries.

It was not until the 1970s when this perspective was revisited by *inter alia* Gomulka (1971), Cornwall (1977), Maddison (1979), and Abramovitz (1979), leading to the so-called technology gap literature that has widely explored the catching-up process of countries that lag behind. The main hypotheses in this approach are that: technology growth rates have a positive impact on economic growth rates, lagging economies may exploit the backlog of existing knowledge through a catching-up process that allows them to approach the technology frontier, and an absorptive capacity that to a large extent depends on direct government intervention, particularly by steering resources to the most technologically progressive sectors of the economy, determines the ability of a lagging country to embark on a successful catching-up process.

An interesting technology gap model of economic growth per se was elaborated by Fagerberg (1988). In his model economic growth depends on three factors: domestic innovation, foreign innovation, whose contribution depends on the size of the technology gap, and the capacity to exploit both domestic knowledge (diffusion) and foreign knowledge (assimilation), which may be referred to as the absorptive capacity. Hence, the technology level of a country ultimately depends primarily on the level of its innovative activity. One of the most important insights of the model is that it emphasizes that innovation is not exclusively confined to industrialised countries because the ability of developing countries to benefit from international diffusion necessitates domestic innovation. Fagerberg (2002) summarises this point as follows: *"[...] successful imitation (or diffusion) often involves innovation as well, and that innovation and imitation generally draw on the same capabilities or resources."* From a developing country point of view emphasis is placed on incremental transformations, which are responsible for the bulk of technological knowledge. Scientific discovery through R&D is not the autonomous determinant of technical change. *"If we characterise the impact of some innovations as 'major', 'basic' or 'radical', it is only because of the continuous stream of incremental innovations following the introduction of a basic new design."*, Verspagen (2004).

A vast amount of research using the technology gap approach has yielded a lot of interesting results with regard to the catching-up process. Notable examples in recent literature include Fagerberg (1987), Abramovitz (1994). Fagerberg (1987) analyses the differing growth performances of OECD countries as well as Brazil, Argentina, Mexico, South Korea, Hong Kong and Taiwan and finds that technology gap models adequately explain differences in growth amongst industrialised countries, and that rapid imitation and high growth in innovative activities, particularly in South Korea and Finland have led to the high growth rates. In the same vein, Abramovitz (1994) explains that successful post war catch-up by European countries vis a vis the United States was as a result of the enhanced capacity of the former to exploit the backlog of existing knowledge through the improvement of technological congruence and social capabilities. Various studies on catching-up by the newly industrialising economies (most of which brought the World Bank (1993) report under fire) stress the important role played by policy in steering economies to more technologically progressive sectors.[2]

Although the vast majority of laggards have continued to fall further be-

[2]See for example, Chang (2003) and Jomo (2001).

hind, scant literature is available on falling behind economies. Indeed, only a handful of developing countries have managed to engage in the catching-up process, and as Temple (1999) observed, *"Poor countries are not catching-up with the rich, and to some extent the international income distribution is becoming polarised."* Verspagen (1991) demonstrates that lagging economies may fall further behind because catching-up is not an automatic process, while Abramovitz (1994) implicitly suggests that it is the inability of developing countries to improve their technological congruence and social capabilities that thwarts their efforts to engage in a successful catch-up process. However, no work to my knowledge, focusing on unveiling the very nature of the pervasive process of marginalisation exists.

This paper is a first step in unveiling the pervasive phenomenon of falling behind. However, given the vastness in scope of the topic we shall only touch on the fringes by attempting to incorporate the Schumpeterian inspired idea that *"Innovation [...] is a pervasive phenomenon in contemporary capitalism and may be an important source of growth in poorer countries as well (though not necessarily in the same proportion as in a frontier nation)"*, Fagerberg (2002). We base our analysis on the technology gap model developed by Verspagen (1991) that we briefly present in the next section before incorporating the effect of domestic innovation on growth in developing countries in section III. The model is simulated in section IV followed by a discussion on implications for developing countries in section V. The last section concludes.

2 Modelling dynamics of the technology gap

The key contribution of Verspagen (1991) in explaining why both catching-up and falling behind are possible outcomes, is that his dynamic model captures the fact that assimilation or exploitation of the backlog of existing knowledge by a lagging country is not an automatic process.

A two country model is assumed in which a country North is at the technology frontier while a country South is lagging behind and may have the possibility of assimilating the backlog of knowledge spillovers and engaging in a catching-up process with North: the catching-up process is assumed to be possible due to the existence of both a technology gap and knowledge spillovers. All other sources of knowledge (aside from knowledge spillovers) are assumed to be exogenous.

The technology gap

The technology gap (G) is a logarithmic relation between the knowledge stocks (K) of the two countries so that a zero gap exists for countries with equal levels of knowledge stock.

$$G = ln\frac{K_n}{K_s} \tag{1}$$

Subscript n represents North while subscript s South.

The exogenous stock of knowledge

It is assumed that the stock of knowledge grows over time at an exogenous rate β for each country, where the stock of knowledge emanating from sources other than knowledge spillovers is exogenous. Hence, knowledge growth in the North is determined solely by the exogenous rate (β_n), while knowledge growth in the South is determined by both the exogenous rate (β_s) and knowledge spillovers (S) from the North. The model also assumes that the South neither catches-up completely nor overtakes the North because it is concerned with analysing the effect of spillovers ($\beta_n > \beta_s$).

$$\frac{\dot{K}_n}{\dot{K}_s} = \beta_n \quad and \quad \frac{\dot{K}_n}{\dot{K}_s} = \beta_s + S \tag{2}$$

The spillovers

In an attempt to take into account the fact that knowledge assimilation is not an automatic process, Verspagen makes a distinction between *potential* spillovers and *actual* spillovers, where the latter is a subset of the former and whose size depends on the capacity to acquire knowledge. This is done by assuming that the capacity to acquire knowledge depends on an intrinsic learning capability (δ) and on the technology gap (G). The intrinsic capability is determined by such factors as education, infrastructure etc, following Abramovitz (1986), while the technology gap reflects the fact that knowledge acquisition takes place in a cumulative manner. The functional form of knowledge spillovers term is represented by:

$$\underbrace{S}_{actual\ spillovers} = \underbrace{\alpha\, G}_{potential\ spillovers} \cdot \underbrace{e^{-\frac{G}{\delta}}}_{learning\ capability} \tag{3}$$

where $0< \alpha <1$

The size of the intrinsic learning capability (δ) in relation to the size of technology gap (G) determines the amount of actual spillovers.

$$\text{if } \delta \begin{cases} \text{increases } e^{-\frac{G}{\delta}} \rightarrow 1 \text{ actual spillovers } = \text{ potential spillovers} \\ \\ \text{decreases } e^{-\frac{G}{\delta}} \rightarrow 0 \text{ actual spillovers } = 0 \end{cases}$$

The variation of the gap over time is obtained by taking the time derivative of equation (1) and substituting equations (2) and (3) as follows:

$$\dot{G} = \frac{\dot{K}_n}{K_n} - \frac{\dot{K}_s}{K_s} = \beta_n - (\beta_s + \alpha\, G e^{-\frac{G}{\delta}}) = \underbrace{(\beta_n - \beta_s)}_{\substack{technological \\ congruence}} - \underbrace{\alpha G e^{-\frac{G}{\delta}}}_{\substack{actual \\ spillovers}} \tag{4}$$

This formulation suggests that equilibrium occurs when the motion of technology gap equals zero ($\dot{G} = 0$) i.e. when the difference in knowledge growth rates (that reflects technological congruence level, Abramovitz 1994) equals actual spillovers. The expression of actual spillovers suggests two equilibrium points of the technology gap, a stable and an unstable equilibrium point that indicate the possibility of catching-up or falling behind. This analysis will be spelt out in the next sections where we consider the effect of domestic innovation on the technology gap.

3 The effect of domestic innovation on the technology gap

Cohen and Levinthal (1989) argue that *"while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate and exploit knowledge from the environment..."*. Cohen and Levinthal (1989) were the first to develop a model (at firm level) reflecting the observation - made by other scholars of technological change including Mowery (1983) and Fagerberg (1987) - that innovation is intended to develop the ability to utilise external knowledge. Cohen and Levinthal (1990) take this argument further and suggest that *"...firms may conduct basic research less for the particular results, than to be able to provide themselves with the general background knowledge that would permit them to exploit rapidly useful scientific and technological knowledge, through their own innovations or to be able to respond quickly when competitors come up with major advances."*

The underpinning idea is that investment in innovation (R&D to Cohen and Levinthal) widens the knowledge base and improves the critical overlap or the technological congruence that further facilitates the assimilation and exploitation of foreign knowledge. We take cue from this idea and argue that domestic investment in innovation, by improving technological congruence, provides further opportunities to engage in the domestic innovation process that in addition, leads to an enhanced cumulative and interactive process of knowledge accumulation and assimilation of foreign knowledge: the learning capability is bolstered by the existence of a commensurate investment in domestic innovation, which is in turn strengthened by the learning capability, leading to a virtuous feedback effect that leads to catching-up. Domestic innovation in developing countries specifically relates to innovative activities based mainly on incremental knowledge: our analysis is not concerned with frontier technology

The model

As in Verspagen (1991), we assume a two country model where a country North is at the technology frontier and a country South is lagging behind, but may engage in a catch-up process due to the existence of spillovers.

- *Redefining knowledge spillovers*

  Our knowledge spillover equation is expressed as in Verspagen (1991).

$$S = \alpha G e^{-\frac{G}{\Delta}} \tag{5}$$

  However, contrary to Verspagen (1991) where the learning capability is interpreted as the intrinsic learning capability, we use a more restrictive definition in that our learning capability only considers the population with technical skills. We consider that Δ, which represents the part of the population with technical skills, is the population that has an effective capacity to learn and cope with technological transformations. This capacity may be interpreted as the learning capability, Abramovitz (1986). This more restrictive definition will allow us to better understand the pervasive process of falling behind.

The spillovers equation represents actual spillovers as a function of potential spillovers and the absorptive capacity.

$$\underbrace{S}_{\textit{actual spillovers}} = \underbrace{\alpha\, G}_{\textit{potential spillovers}} \cdot \underbrace{e^{-\frac{G}{\Delta}}}_{\textit{learning capability}}$$

The variation of *actual* spillovers depends on the learning capability (Δ) and the technology gap (G). With regard to the formulation of the absorptive capacity, we note that while it may be interesting to use the sigmoid function that is perhaps better adapted to technology diffusion, the 'decay' function above produces similar results in terms of the analysis of spillovers, and has the advantage of simplifying the application. We now precede with the study of the learning capability (Δ) and the technology gap (G) variables.

- *Defining the learning capability*

  Assumption 1

  We assume that the learning capability is equal to the part of the population with technical skills and may be represented by:

  $$\Delta = \frac{P_s}{P}$$

  where P_s is the population with technical skills
  and P the total population

  Assumption 2

  The variation variation of the learning capability $\dot{\Delta}$ depends on:

  - the rate at which the population with technical skills (P_s) is growing $\left(\frac{\dot{P}_s}{P_s}\right)$ relative to the growth rate of the total population $\left(\frac{\dot{P}}{P}\right)$

- The existing part of population with technical skills Δ

$$where \quad 0 < \Delta < 1$$

The variation of the learning capability ($\dot{\Delta}$) is therefore expressed by:

$$\dot{\Delta} = \Delta \left(\frac{\dot{P}_s}{P_s} - \frac{\dot{P}}{P} \right) \tag{6}$$

$$where \quad \frac{\dot{P}_s}{P_s} > \frac{\dot{P}}{P}$$

Assumption 3
The variation of the part of population with technical skills ($\dot{P}_s$) depends on:

- the rate at which the population with no technical skills is being converted to a population with technical skills i.e. the rate of acquiring technical skills (δ)
- the rate at which the population with technical skills (P_s) emigrates, which is taken to be a function of the rate of emigration in general (θ) and the technology gap (G) of the country.

The variation of population with technical skills is given by the difference between the increase of the population with technical skills and the population with technical skills that emigrates, which is expressed as:

$$\dot{P}_s = \delta(P - P_s) - P_s(1 - e^{-\theta G}) \tag{7}$$

If $\theta G_{\to 1}$ then $P_s(1 - e^{-\theta G}) = P_s$: the whole population with technical skills emigrates.
If $\theta G_{\to 0}$ then $P_s(1 - e^{-\theta G}) = 0$: no population with technical skills emigrates.

$$if\ \theta G = \begin{cases} 0 & there\ are\ no\ emigrants\ with\ technical\ skills \\ 1 & the\ whole\ population\ with\ technical\ skills\ emigrates \end{cases}$$

The variation of total population $\dot{P}$ may be expressed as:

$$\dot{P} = \gamma P - P_s(1 - e^{-\theta G}) \tag{8}$$

$$where\ the\ rate\ of\ population\ growth \quad \gamma = \frac{\dot{P}}{P}$$

The dynamic equation of the learning capability

By substituting equations (7) and (8) into equation (6) and noting that $\Delta = \frac{P_s}{P}$, the dynamic equation of the learning capability ($\dot{\Delta}$) may be rewritten as:

$$\dot{\Delta} = \Delta \left(\delta \left(\frac{1}{\Delta} - 1 \right) - \gamma + (\Delta - 1) \left(1 - e^{-\theta G} \right) \right) \tag{9}$$

- *Redefining the growth rate of knowledge in the South*

  The rate of knowledge growth is represented as in Verspagen (1991) by:

$$\frac{\dot{K}_n}{\dot{K}_n} = \beta_n \quad and \quad \frac{\dot{K}_s}{\dot{K}_s} = \beta_s + S \tag{10}$$

  However, contrary to Verspagen (1991) we consider that domestic innovation in the South improves the technological congruence of knowledge between the South and the North, and thus provides further opportunities that act as incentives for the highly skilled population to engage in the domestic innovation process. A virtuous feedback mechanism between domestic innovation and the learning capability then sets in, thereby strengthening the interactive and cumulative process of knowledge accumulation and assimilation of foreign knowledge.

A relation between the knowledge growth rate and the learning capability of the South may be established. Since we are concerned with assimilation of knowledge spillovers by the South we maintain Verspagen's assumption that the knowledge growth rate in the North (β_n) is exogenous.

Assumption 4
The South's knowledge growth rate is a function of its learning capability ($\beta_s = f(\Delta)$) such that

$$if\ \Delta = \begin{cases} 0 & f(0) = 0 \\ 1 & f(1) = \beta_n \end{cases}$$

$$\beta_s = \Delta\beta_n \tag{11}$$

The dynamics of technology gap
As in Verspagen (1991) the dynamics of technology gap are represented by

$$\dot{G} = \beta_n - \beta_s - S \tag{12}$$

Hence, the dynamic equation of the technology gap may be obtained by substituting equation (5) and (11) in (12) as follows:

$$\dot{G} = \beta_n\left(1 - \Delta\right) - \alpha G e^{-\frac{G}{\Delta}} \tag{13}$$

4 Model Simulation

We use a system of two equations (9) and (13) in our analysis of dynamics of technology gap.

$$\dot{\Delta} = \Delta \left(\delta \left(\frac{1}{\Delta} - 1 \right) - \gamma + (\Delta - 1) \left(1 - e^{-\theta G} \right) \right)$$

$$\dot{G} = \beta_n (1 - \Delta) - \alpha G e^{-\frac{G}{\Delta}}$$

Δ = level of learning capability (the part of the population with technical skills)

G = the gap between the north and the south

Simulations

We assume a set of initial conditions that may characterise a country in the south.

Initial conditions

$\Delta = 0.01$ $(0 < \Delta < 1)$

G = 0.38 $(0 < G < 1)$

Parameters

The set of parameters that lead to convergence are as follows:

$\delta = 0.05$ (rate of imparting technical skills $0 < \delta < 1$ but is usually < 0.1)

$\gamma = 0.03$ (population growth rate $0 < \gamma < 1$)

$\theta = 0.17$ (the rate of emigration $\theta > 0$)

$\alpha = 0.55$ (degree to which spillovers occur $0 < \alpha < 1$)

$\beta = 0.05$ (growth rate of knowledge in the north $0 < \beta < 1$)

Results

Given our set of parameter and a learning capability Δ=0.01, the threshold technology gap that leads to convergence is G=0.38. We use bifurcation diagrams to analyse the effect of the parameters δ (rate of acquiring technical skills), γ (population growth rate) and θ (emigration rate) on Δ (the learning capability) in order to understand their effects on the gap, which either lead to catching-up or falling behind.

Figure **??** below indicates that the learning capability (Δ) grows with the rate of imparting technical skills (δ). A higher rate of imparting technical skills therefore favours the growth of the learning capability that consequently leads to a reduction of the gap through the catching-up process. However, at very low rates of learning capability (Δ=0.0659) an unstable equilibrium that leads to falling behind is reached. A stable equilibrium, leading to catchin-gup, is reached at G=0.609.

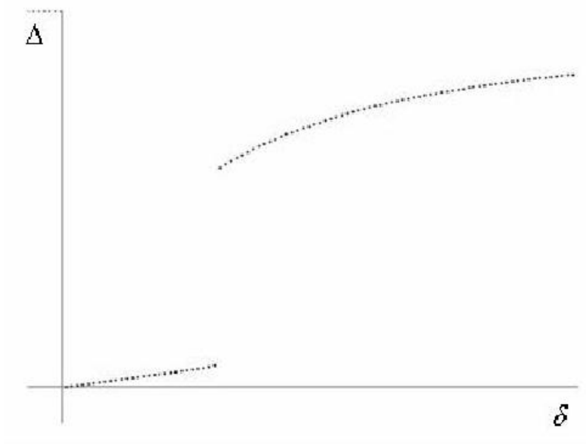

Figure 1: *Bifurcation diagram for rate of imparting tech-skill versus learning capability*

In figure **??** below, we observe that population growth (γ) does not favour catching-up: the learning capability falls with an increase in the population growth rate, resulting in a larger technology gap, and the economy falls further behind as it becomes increasingly difficult to increase the part of the population with technical skills (Δ) i.e. the learning capability. In our example the threshold population growth is γ=0.03.

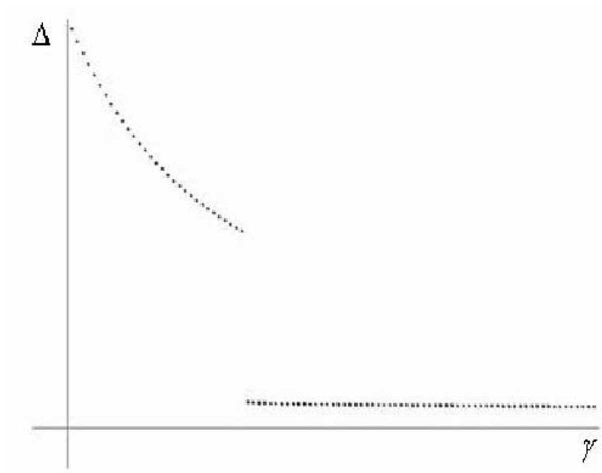

Figure 2: *Bifurcation diagram for population growth rate versus learning capability*

With regard to the rate of emigration (θ), figure **??** below shows that the learning capability falls with an increase in the rate of emigration, and the economy falls further behind. In our model, we note that an increase in the rate of emigration (θ) that affects the population with technical skills is perhaps triggered by an increase in the part of the population with technical skills or learning capability (Δ) that is not matched with an increase in domestic investment in innovation: an increase in domestic innovation that corresponds to the increase in the technical skills, acts as an incentive for the population with technical skills to engage in the domestic innovation process rather seek opportunities abroad that are created by innovation investment in the foreign economy.

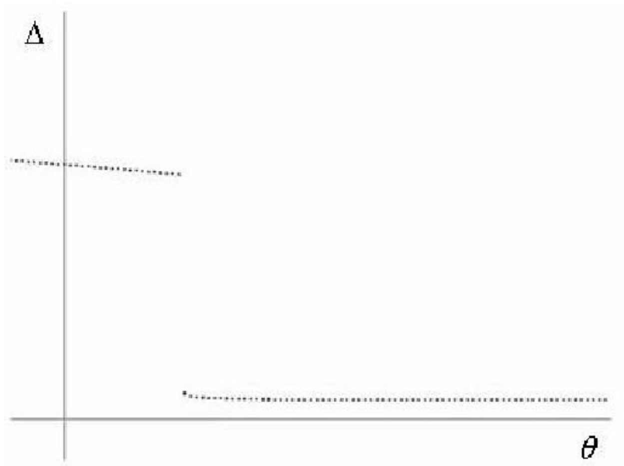

Figure 3: *Bifurcation diagram for rate of emigration versus learning capability*

Dynamics of technology gap

In figures **??** and **??** below, we study the dynamics of technology gap. The linear curves b represent the difference between the rates of growth of the knowledge stocks in the two countries, which reflects the technological congruence level where $b=\beta_s - \beta_n$ (the higher the curve on the y-axis the higher the technological incongruence level and the larger the technology gap). The hump-shaped curves represent different knowledge spillovers, which result from different rates of imparting technical skills (δ), leading to variations in the technology gap.

In figure **??**, it is assumed that the technology congruence level is not affected by the learning capability i.e. the rate of growth of knowledge stock in the South is not a function of the learning capability, $\beta_s \neq f(\Delta)$, and the technology gap varies purely due to changes in the exogenous knowledge stock growth rates in both countries, Verspagen (1991).

As mentioned above, equilibrium occurs at two points when the motion of technology gap equals zero ($\dot{G} = 0$): when the technological incongru-

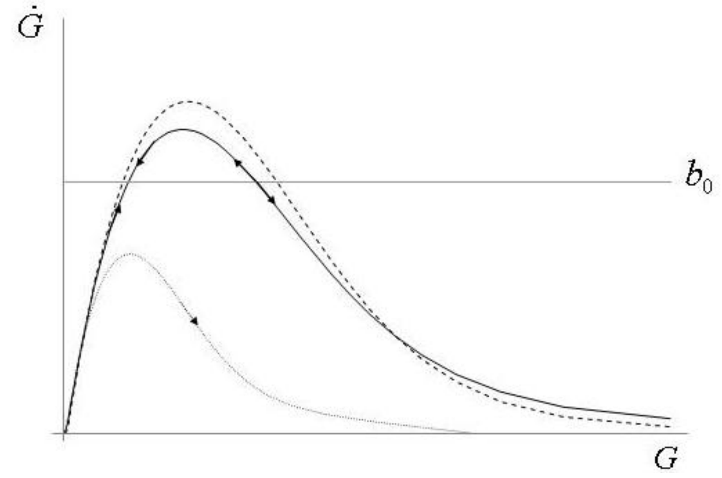

Figure 4: *Simulations for δ=0.05 and δ=0.095 with exogenous knowledge*

ence/congruence line b_0 equals *actual* knowledge spillover curves. One equilibrium point of the technology gap is stable while the other is unstable, suggesting the possibility of catching-up or falling behind. A stable equilibrium occurs whenever the spillover curves cut the b_0 line with a positive slope, and an unstable equilibrium is obtained in the inverse case. The unstable equilibrium point may be viewed as the take-off point that leads to the process of catching-up.

At very low levels of δ there are no net spillovers because the exogenous increase in the technology gap exceeds knowledge spillovers as indicated by the spillovers curve that lies entirely below the b_0 line; complete divergence sets in. The curves that cut the b_0 line represent knowledge spillovers for δ=0.05 and δ=0.095. A higher δ as shown by the dotted curve (in comparison to the continuous curve) affords larger knowledge spillovers that allow take-off to occur earlier (at a higher technology gap that would lead to divergence for a lower level of δ) and to converge at a smaller technology gap, implying that the impact of the learning capability on catching-up is more effective in closing the gap before investment in domestic innovation becomes critical for complete closure of the technology gap. For total convergence or closure of the technology gap to occur, an economy can no longer rely on spillovers beyond the stable equilibrium point and must engage in domestic innovation (investment in R&D). This analysis is similar to the one demonstrated by Verspagen (1991).

We differ from Verspagen (1991) by incorporating the idea that a higher technology congruence level may be obtained if the observation that domestic innovation widens the knowledge base and improves the critical overlap further facilitating the assimilation and exploitation of foreign knowledge, Cohen and Levinthal (1989). Consequently the virtuous feedback mechanism between the cumulative and interactive process of knowledge accumulation and assimilation of foreign knowledge that leads to catching-up is strengthened, and eventually leads to a higher knowledge stock (K).

In figure **??** we allow the learning capability to affect the rate of growth of knowledge stock in the South, $\beta_s = f(\Delta)$ where Δ increases with δ, the rate of imparting technical skills. $b_1 = \beta_n - \beta_s = \beta_n (1 - \Delta)$ for δ=0.05 and $b_2 = \beta_n - \beta_s = \beta_n (1 - \Delta)$ for δ=0.095 i.e. $b_2 < b_1$. Indeed, improved technological congruence is obtained when $\beta_s = f(\Delta)$ than when $\beta_s \neq f(\Delta)$: in the former case the learning capability enhances the critical overlap of knowledge ($b_2 < b_1 < b_0$).

As in figure **??**, the dotted spillovers curve in figure **??** represents δ=0.095, while the continuous curve δ=0.05. For δ=0.05 take-off occurs at point C and the effect of the absorptive capacity peters off at point B and total closing up of the gap becomes entirely dependent on domestic R&D efforts. In the case of δ=0.095, take-off occurs at point D (at a larger technology gap than at point C) and own R&D becomes critical at A (at a smaller technology gap than at point B). A higher rate of acquiring technical skills (δ) is invariably more favourable to the catching-up process.

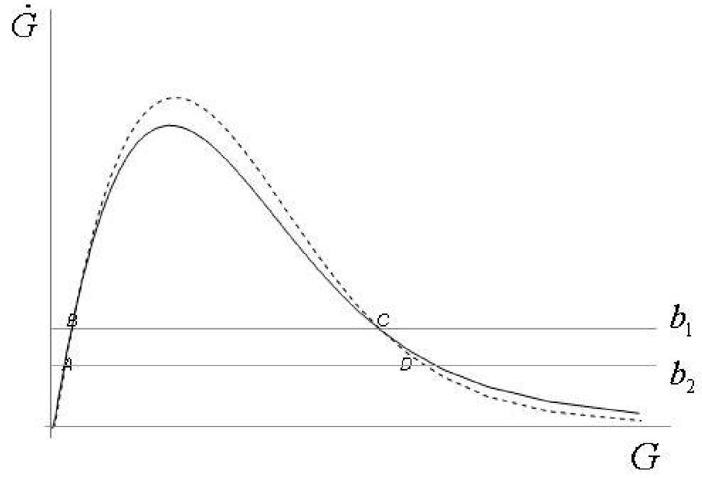

Figure 5: *Simulations for δ=0.05 and δ=0.095 with β_s = f(Δ)*

One important point to note, nevertheless, is that in the case where the difference in the rates of knowledge stocks in the two economies wipes off the possibility of the lagging country to benefit from knowledge spillovers (the level of technological incongruence is too high so that there are no actual spillovers), the lagging country will consistently fall further behind. Moreover, any efforts to improve the learning capability by raising the rate of acquiring technical skills (δ) rather than have positive effects that lead to catching-up, strengthen the process of falling behind. This point is demonstrated by figure **??** where we observe that to the right of point D, where falling behind occurs for both the continuous and dotted spillover curves that correspond to δ=0.05 and δ=0.095 respectively, divergence takes place faster in the latter case than in the former. The reason for this outcome is that the skilled population emigrates at a higher rate in an economy that is locked in a process of marginalisation: any attempts to improve the learning capability (Δ) via an increased rate of imparting technical skills (δ) contribute to making the falling behind phenomenon pervasive. The absence of domestic innovation translates into unavailability of suitable work opportunities for population with technical skills, and therefore acts as a catalyst for emigration of this population.

5 Some implications for economic growth in developing countries

Notwithstanding the importance of improving the learning capability (δ), with a view to enhancing growth, this paper demonstrates that the pervasiveness of marginalisation may result in a situation where improving (δ) worsens rather than improves the growth outcome in economies where the rate of growth of technological incongruence balances off the possibility of benefiting from spillovers. Our model indicates that this tenacious growth inhibiting process may transpire via emigration of the population with technical skills, which is heightened by the lack of opportunities in the innovation process or the sheer absence of an innovation process. Contrary to Romer (1990), this finding suggests that competence building does not automatically spur growth. Romer's (1990) policy prescription that competence building subsidies are the best substitutes for R&D subsidies is rather disconcerting; competence building subsidies are complements rather than substitutes for domestic innovation subsidies.

Domestic innovation, which is critical for development of an absorptive capacity, attenuates the emigration of the population with technical skills because it is able to find opportunities that match its competences, which then serve as incentives for this population to engage in the domestic innovation process rather than seek favourable opportunities abroad. The policy implication here is that in order for a favourable outcome to be realised, efforts should be made on all fronts. Focusing on the learning capability (δ), which is only one front while ignoring other crucial ones, particularly domestic innovation, amounts to a double loss for the lagging economy: resources are expended in producing technical skills that will eventually be drained out of the economy into a better performing one, and especially to a frontier economy. The population with technical skills emigrates at a higher rate in an economy that is locked in a process of marginalisation, and any efforts to improve the learning capability (Δ), via an increased rate of imparting technical skills (δ), in the absence of domestic innovation appear to strengthen marginalisation.

Differences in absorptive capacities across countries may be only partly explained by investment in technical skills. Other elements, some of which may not be measurable, that lead to successful investment in domestic innovation are crucial. As pointed out by the technology gap literature, proactive government policies that steer resources to the most technologically progressive sectors of the economy have been found to provide the best recipe for high growth. These policies include the creation of institutions that are favourable for the achievement of successful shifts towards more technology-intensive sectors in a specific country context that takes into account immeasurable factors such as culture. Indeed, as pointed out by Fagerberg (2002) p. xiii, there must be *"...emphasis on growth as transformation, that is, as a process of qualitative (and structural) change, in which the success (or lack of such) of individual countries to a large extent depends on their ability to transform economic, social and institutional structures."*

Efforts to steer developing economies to sectors with higher growth potential, difficult as it may be as it requires structural change, is one of the main solutions to growth. Undoubtedly, such efforts require government intervention: unless conscious policy in favour of technologically progressive sectors is successfully implemented, reversing the increasing marginalisation process observed in most developing countries will remain illusory. Not only is the technology frontier a moving target, take-off, let alone catching-up, as we have seen, is not an automatic process. In the contemporary world successful growth involves mainly qualitative (structure) rather than quantitative (economies of scale) change and therefore depends on the ability of an economy to transform its economic, social and institutional structures. Contrary to commonly held views, it is in the interest of developing countries, particularly those that are facing marginalisation and despite their meagre resources, to wholeheartedly embrace this challenge no matter how difficult and costly it is.

6 Conclusion

The analysis of the dynamics of falling behind (and catching-up) in this paper has demonstrated two points: well coordinated policies with the primary goal of progressively shifting economies to technologically progressive sectors are paramount, and embracing this challenge is a matter of urgency because time is continuously running out against developing countries. The quasi-permanent and accelerated marginalisation of lagging economies vis a vis industrialised countries poses a double challenge to the former. Not only do they have to fight against time, but they will have to implement policies and develop institutions (a time consuming and increasingly costly venture) that will enable them to successfully embark on an innovation-driven path.

Our view is confirmed by the observation that no industrialised country starting with promotion of wool manufacturing in the fifteenth century England by Henry VII, to the eighteenth century British industrialisation, the Hamiltonian inspired structural transformations from production of raw material to manufacturing (after the long drawn controversy between Smith and Hamilton) in the United States, down to the post-war catching-up economies of western Europe and recent cases of spectacular catch-up including Finland, the newly industrialising countries of Asia, as well as the most recent case of Ireland, have been able to embark on a successful innovation-driven path without aggressive implementation of technology conscious policies. As is evident, China has fully digested this lesson.

Innovation (and diffusion) remains the single most feasible determinant of sustainable growth, even in the poorest of economies. Indeed, any argument supporting the view that marginalised countries, due to their dire growth outcomes, should carve out a different recipe for growth inter alia, specialisation in labour intensive activities and importation of high technology goods in lieu of domestic innovation is purely misguided. Similarly, the suggestion that competence building subsidies will automatically stimulate knowledge generation in economies that *'cannot undertake research'*, Romer (1990), is perhaps short-sighted: direct efforts promoting domestic innovative activities are critical for growth in all economies. It may be observed that amongst developing countries, the main distinguishing characteristic between the 'better performing' ones and the others is that the latter either have no technology policy or have a defunct one.

The effectiveness and efficiency of learning depends on the ability to *produce* and *use* knowledge. Thus, general technical knowledge that is acquired through formal education and training systems has to be complemented with firm-specific knowledge (that is made possible through domestic innovation) in order for it to be productive. However, this analysis is beyond the scope of this paper, which is a first step in an effort to demonstrate that *potential spillovers* from foreign knowledge require the existence of an absorptive capacity - that primarily depends on domestic innovation - for translation into *actual spillovers*. Our findings indicate that the absorptive capacity is the element of the technology acquisition process that is responsible for creating an interface between domestic and foreign knowledge: it provides developing countries with the ability to benefit from the *potential* foreign-knowledge spillovers.

An empirical analysis testing the findings in this paper may be carried out to test our hypothesis that domestic innovation is fundamental in developing an absorptive capacity that is required to allow developing countries to break away from the process of marginalisation. More specifically, an empirical estimation may be used to verify that while it is important to improve competences (through, for example, improved rate of imparting technical skills through education and training outside the industry), technological benefits are not likely to accrue unless the improved competences are supported by domestic innovation. In other words, if improvement of technical skills is not matched with domestic innovation, an economy may experience adverse effects. This will be the next step in our investigations.

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