ECONOMIC GROWTH CENTER

YALE UNIVERSITY

P.O. Box 208629
New Haven, CT 06520-8269
http://www.econ.yale.edu/~egcenter/

CENTER DISCUSSION PAPER NO. 1002

Technology Change: Sources and Impediments

Gustav Ranis
Yale University

Mallory Irons
Johns Hopkins University

Yanjing Huang
Yale University

September 2011

Notes: Center discussion papers are preliminary materials circulated to stimulate discussion and critical comments.

Technology Change: Sources and Impediments

Gustav Ranis, Mallory Irons and Yanjing Huang

Abstract

There is little doubt that technology change, both in terms of its process and quality dimensions, represents the principal driving force to explain comparative economic performance at both micro and macro levels. This paper examines the sources of technology change and the impediments to the full realization of its opportunities, both abstractly and in the context of a comparison among six typologically diverse developing countries. Among the external sources, we examine the roles of trade, foreign patents and FDI; among the internal sources we examine the roles of investment, domestic R&D, domestic patents, S&T personnel and secondary education alternatives. Among impediments, we analyze certain public and private policy frameworks which tend to impede the realization of technological opportunities. We detect some reasons for the better TFP performance of the East Asian in comparison with the Latin American countries.

Keywords: Development, Technological Change

JEL Codes: O11, O14, O33

TECHNOLOGY CHANGE: SOURCES AND IMPEDIMENTS*

Gustav Ranis, Mallory Irons and Yanjing Huang**

I. Introduction

The relationship between technology change and economic growth has been of interest to economists for centuries, but especially since Robert Solow made his seminal contribution to the neoclassical model of economic growth in the 1950s leading to an explosion in the follow-up literature. Interest in technology change waned perceptibly in the '80s. However, with the arrival of the "new growth theory" a notable revival of focus on the subject can be noticed. Overall, there remains little doubt that there exists a consensus that technology change, both in terms of its process and quality dimensions, represents the principal driving force in explaining comparative economic performance at both micro and macro levels. That said, exactly *how* technology change is generated and what impedes it remains less clear.

The standard neoclassical approach assumes the rate of technological change to be exogenously determined. Solow's model predicts that rich and poor countries alike will in the long term converge to steady rates of growth that are determined by technological progress, the savings rate, and the growth of the labor force. While the model confirms that higher savings rates lead to higher rates of growth, capital accumulation takes a back seat to technological

* Paper prepared for the September 17-18, 2009 Oxford Conference in Honor of Frances Stewart

** Gustav Ranis is the Frank Altschul Professor Emeritus of International Economics at Yale University. Mallory Irons was a BA graduate and Yanjing Huang an MA graduate at Yale. The assistance of Sara Lowes is gratefully acknowledged as are the helpful comments on an earlier draft of Valpy Fitzgerald, Frances Steward and Adrian Wood.

change.[1] This is not to deny that investment is likely to be required to "carry" technology change.

The "new growth theory" attempts to render technology change endogenous and, by asserting that externalities permit the maintenance of sustained growth in spite of an increase in the rate of investment,[2] thus avoids the diminishing returns to investment issue that troubled the Solow model, Consequently, endogenous growth theory' authors have reinvigorated the debate over the role of technology change in economic growth and have endeavored to construct macroeconomic models built upon microeconomic foundations. The forces that are generally seen to give rise to endogenous technological progress include education, research and development, external influences and domestic government policies. While empirical evidence in support of endogenous growth theory is still relatively weak, the main contribution of the model to date has been to reinvigorate the discussion surrounding the sources of technological progress.

In the context of this renewed contemporary interest surrounding technology change and economic growth, it seems less useful to differentiate between technology choice and technology change, in the recognition that the two are really indistinguishable, i.e. any "choice" is almost always modified to render it a "change". Technologies are rarely ever successfully taken off the shelf and deployed as is; rather, a considerable amount of adaptation must inevitably occur in order for them to be utilized effectively in any given environment. Frances Stewart recognized

[1] Solow, Robert (1956)
[2] For example, see Romer, Paul (1990)

the importance of the appropriateness of technology early on. As she put it "what is needed above all is local technical innovation directed towards local needs."[3]

A closely related dimension focuses on the links between economic growth, technology change, and human development. Human development and economic growth have been analyzed as affecting each other through two "channels": the first, running from economic growth to human development, is fueled by household and government expenditures as well as technology change. It is not as well understood as the second channel, which runs from improvements in human development, is fueled by foreign and domestic savings, as well as, once again, technology, and leads to the enhancement of GDP growth[4]. The first represents a production function converting public and private expenditures on health, education and nutrition, etc. into increases in life expectancy, reductions in infant mortality, educational achievement, and the enhancement of other human capabilities. This conversion, of course, depends on technology, but it has thus far proved harder to understand exactly *how* technology change affects human development. We do know, for example, that per capita income significantly affects life expectancy levels[5] and that human development is positively affected by household and government expenditures on health and education. However, as Behrman has carefully, and rather painfully, pointed out, there are many interrelated inputs, including home schooling, home health inputs, the distribution of income, nutrition, as well as the relevance of a variety of household characteristics and alternative organizations of the public sector, that render it difficult to get a good fix on this production function.[6] It reminds one of the problem

---

[3] Technology and Underdevelopment, MacMillan, 1977. p278. See also her edited volume Macro-Policies for Appropriate Technology in Developing Countries, Westview Press, 1987.

[4] Ranis, Stewart and Ramirez (2003)

[5] Preston (1986)

[6] Behrman (1990)

encountered early on in properly defining its agricultural sector counterpart, given multiple quantitative inputs and the somewhat mysterious role of international as well as domestic adaptive technology.

The second production function, linking human development to economic growth, with the support of domestic and foreign investment plus, significantly, technology change, is better understood and this is where most of the attention of the "new growth theory" literature has been placed to date. It is in this context that we intend to examine the sources of technology change (TFP) and the impediments to the full realization of technological opportunities, both abstractly and in the context of a comparison among six typologically diverse developing economies. Among the sources of TFP we will examine R&D, investment, various types of patents, FDI, openness, science and technology (S&T) personnel, and other education-related human development indicators. Among impediments, we will analyze public and private policy frameworks that tend to block the realization of existing technological opportunities. Throughout, we will focus on the non-agricultural sector. We proceed as follows: in Section II, we present a general discussion of the sources and impediments to the full realization of the opportunities for technology change in the developing countries, broken down into external factors (i.e. foreign patents, openness to trade, the role of the multinational corporation, etc.) and internal factors (i.e. domestic patents, research and development, investment, education, etc. The empirical analysis of six diverse developing countries – Brazil, China, India, Mexico, Taiwan and South Korea – is then brought to bear, demonstrating why the Asian countries seem to have witnessed a relatively stronger performance than their Latin American counterparts. In Section III we summarize and discuss some implications for policy.

II. Sources and Impediments

A. External Sources and Impediments

1) Openness to Trade and FDI

A cursory look at the relative economic performance of rich and poor countries highlights, in many cases, large income and productivity gaps between the developed and developing worlds. It is well understood, by neo-classical and new growth theorists alike, that total factor productivity, with all its shortcomings, is the best measure of technology change and has the dominant influence on an economy's growth performance. Accordingly, we accept the TFP estimates provided by UNIDO[7] and try to understand what lies behind them. We also acknowledge the well-known weaknesses of the TFP variable which constitutes a residual containing considerable "noise," e.g. economies of scale, terms of trade effects and the like, in addition to pure technology change.

While our data set was not large enough to render it meaningful, we tried panel analysis, with exports, FDI, investment, R&D, regular patents, and utility models on the right-hand side. Only patents, investment and exports proved significant, at the 5% level. We moreover don't claim to present a behavioral model here but to restrict ourselves to observing differential country trends over time. Nor do we assert that such correlations imply causation. As our six country data indicate (see Figure 1), a particular country's openness to trade seems to be highly correlated with technology change. Four of our countries, Brazil, Mexico, Taiwan and South Korea, initially enjoyed relatively high TFP growth. Later on, the Latin American countries, in particular, suffered from much lower rates of technology change, while China and, still later,

[7] UNIDO, World Productivity Database (2007)

India, joined the other East Asian countries. On the other hand, except in the case of China, and, to a lesser extent, Korea, FDI does not seem to have had much of an impact on TFP.

Keller (2004) argues that, overall, foreign sources of technology account for about 90% of the growth in most countries, and further notes that worldwide technology change is determined in large part by technology diffusion carried by trade and FDI across borders.[8] The impact of a country's relative openness to trade is clearly by no means limited to the importation of machinery; it focuses heavily on the transfer of knowledge. Keller notes that foreign research and development (R&D) has been shown to substantially raise domestic TFP in LDCs, with greater rates of trade and global openness permitting technology diffusion via FDI.

1. External Sources- Openness and FDI

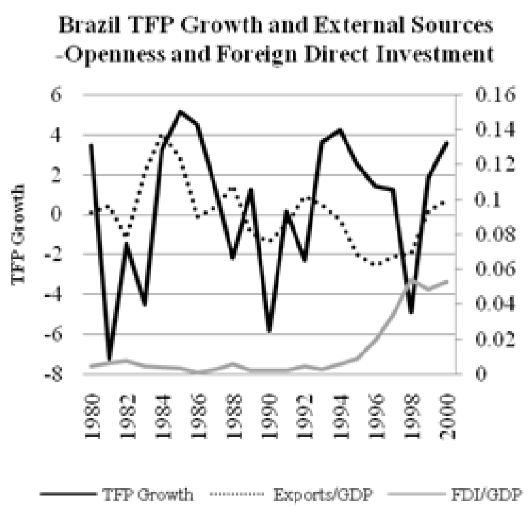


Figure 1a.

Figure 1b.

[8] Keller (2004) 752

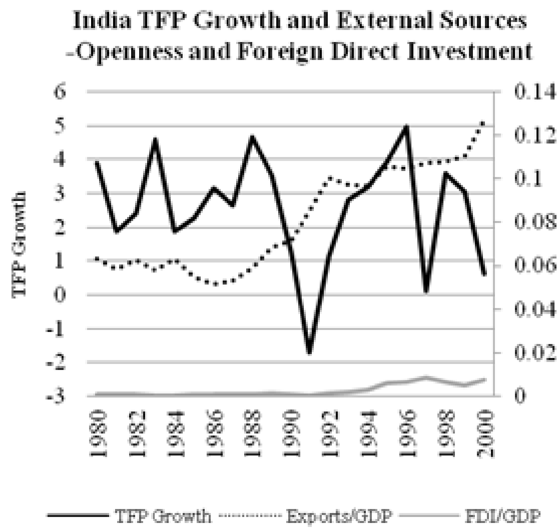


Figure 1c.

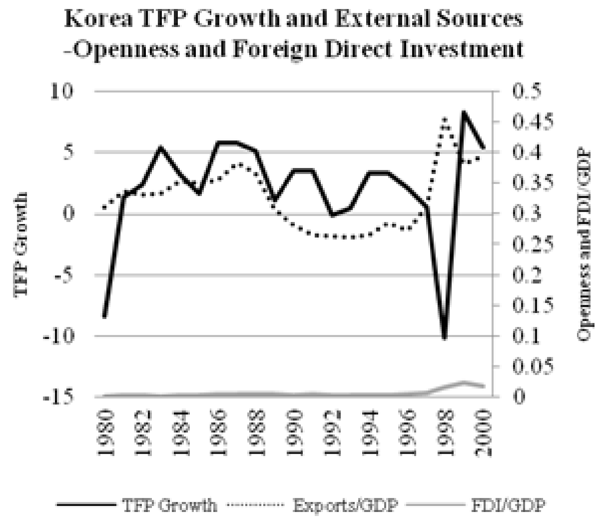


Figure 1d.

Figure 1e.

Figure 1f.

Sources: UNIDO, World Productivity Database; United Nations Statistics Division, Commodity Trade Database; UNCTAD, Foreign Direct Investment Database; Republic of Taiwan, National Statistics.

Trade with more technologically advanced countries can, of course, be beneficial to LDCs in that it affords them access to frontier technologies without having to invest a great deal of time and resources into developing such technologies on their own. But the key is the extent to which such frontier technologies are adapted to the local context. Moreover, it is not only the importing of technologies that can be beneficial to LDCs; in some cases, exporting may be advantageous as well. Several studies have noted that there may be "learning-by-doing" effects that make exporters relatively more productive than their non-exporting counterparts, in particular due to their interactions with Northern consumers. However, since Northern consumers usually have different quality standards from Southern consumers, adaptation to the domestic market is essential. This applies centrally to technology change of the product adaptation variety, the main focus of entrepreneurs, as well as to the process adaptation type, focused on by most academic economists. Frances Stewart early on stressed the importance of selecting the appropriate commodity attributes as an important contribution to technology change in the South.[9]

One of the impediments in this part of the conceptual arena is the threat of protectionism, especially at a time of overall economic weakness. Currently, while a repeat of the massive "beggar thy neighbor" policies of the 1930's is not on offer, there are disturbing signs of "under the radar" mercantilist measures being implemented, including a rise in anti-dumping measures, "buy domestic" legislation, and the like.

Turning to FDI, Borensztein et al[10] point out that human development, in the form of education levels (see below) is a prerequisite for a country to take full advantage of these

---

[9] Stewart, F. and J. James (1982)
[10] Borensztein (1998)

inflows. Similarly, Xu[11] notes a positive relationship between FDI and TFP but that this relationship is stronger in middle income (and middle HDI) countries. Moreover, the positive spillovers from FDI are more pronounced in high-technology, rather than low-technology, sectors. Larraín, Lopez-Calva, and Rodríguez-Claré (2001) emphasize the potential benefits from FDI with respect to technological progress. They present the case of Intel, a manufacturer of microprocessors, and its involvement in Costa Rica, a country that is "very small…when compared with other potential locations for a company of that nature."[12] The presence of Intel in Costa Rica generated large positive spillovers in terms of increased rates of technology diffusion. These positive gains were accomplished through two avenues: Intel funded schools that taught workers technical and vocational skills, which were not necessarily Intel-specific. Secondly, Intel's FDI served as a signaling mechanism: by making such a large and profitable investment in Costa Rica, Intel effectively signaled others to invest in Costa Rica. One of the frequently encountered impediments is the expansive definition of "strategic sectors" in which FDI is not admitted.

However, FDI can be a two-edged sword, i.e. both a source and an impediment to the generation of domestic TFP changes. As Keller (2004) emphasizes, multi-national companies can stimulate technological learning through labor training and reduced turnover, and through the provision of high quality intermediate inputs.[13] However, it should also be noted that their real contribution cannot be assessed independently of time and place,[14] i.e. it must be related to the particular phase of an LDC's life cycle, as well as to the type (size, resource endowment, etc.) of the LDC in question. In the idealized scenario, the multinational corporation begins as a

---

[11] Xu (2000)
[12] Larraín, Lopez-Calva, and Rodríguez-Claré (2001) 197.
[13] Keller (2004)
[14] Ranis (1976)

wholly-owned subsidiary, then becomes a joint venture, and finally gives way to licensing, management contracts, etc. as the country matures. In this idealized world, a disinvestment/transformation timeframe would be agreed upon *ex ante*, in order to make the eventual transition easier. While the multinational corporation can be particularly helpful to the developing country in the early stages of its independence, in particular during the customary import substitution subphase of its development, in such an ideal world FDI would continue to be supportive when the LDC moves out of this subphase.

However, departures from the above idealized scenario have sometimes prevented this relationship from working well in practice. First, in the absence of any changes in the nature of the initial contract, the relationship between the two parties is likely to become less advantageous for the LDC and more advantageous for the multinational corporation over time. Under most arrangements, the multinational corporation is likely to enjoy a monopoly-like position, and consequently behaves as a "satisficer." This means it may adversely affect technology change by promoting inappropriate "luxury goods," and "luxury processes," encouraging local consumers to conform their tastes and attitudes toward internationally specified rather than appropriate or adaptive domestic goods and local producers toward inappropriate technologies. The multinational corporation may also restrict entry to would-be local competitors and prevent their subsidiaries from entering the export market which could threaten market sharing arrangements with other MNCs. Frances Stewart raised early warning signals concerning the two-edged sword feature of FDI and suggested that more attention be paid to South-South trade and investment contacts.[15] Given the march of globalization since she wrote, as well as the

---

[15] See especially Chapter 7 in her 1977 volume Technology and Underdevelopment, op. cit.

emergence of a substantial number of dynamic middle income countries, her early warnings and suggestions have been fully borne out by recent events.

Keller (2004) illuminates another potential departure from the evolutionary ideal between the host country and the corporation. He describes two common avenues of technology transfer: one, the corporation's subsidiary disseminates technology and information to domestic firms in the host country (and thus assists with the diffusion of possibly inappropriate international technology); or two, the subsidiary picks up adaptive technologies from local LDC firms (and then "sources" such technology outward to third parties.). Such detrimental patterns may occur because the multinational corporation subsidiary is likely to have more market power than the average domestic firm and may thus be better at sourcing or because it has been set up with the express purpose of sourcing in the first place.[16]

2) Foreign Patents

Economists and politicians alike have long touted intellectual property rights including trademarks, patents, and copyrights, as integral to technological progress and economic development. The authors of the 2001 Human Development Report noted that intellectual property rights are intimately intertwined with technology change and growth because they make it possible for individual innovators to reap an assured return on their initial R&D investment.[17] Given the WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), the debate over the implementation of such rights in developing countries has been sharpened, and the potential benefits and impediments to their successful execution have come into clearer focus.

---

[16] Keller (2004), 769.
[17] UNDP (2001), 102.

With respect to foreign patents, for example, it has been emphasized that, in addition to incentivizing innovation, patents can serve as a stimulus for the transfer of technology from developed to developing countries. However, just as patents can stimulate technology change, they can also serve as a barrier to the provision of socially valuable goods at a socially appropriate cost. The 2001 Human Development Report cites, as an example, the development of antiretroviral drugs, as indicative of the potential social costs associated with patents. Antiretroviral therapy, which has dramatically cut AIDS deaths in industrial countries, remains an extremely expensive cocktail that has been produced under U.S. and European patents for some time. Before the introduction of generic versions of these drugs, the cocktail was simply unaffordable by the majority of HIV-positive individuals in the LDC's. Still, while pharmaceutical companies in the developed countries, which have much larger research and development budgets and are thus able to develop large number of new drugs, are protected financially by intellectual property rights, life-saving medication has generally been too expensive for individuals in the countries that need it the most.

In addition to incentivizing risk-taking and sparking innovation, established intellectual property rights can encourage an increased flow of FDI associated with patents. While some scholars note that this in and of itself may encourage an over-reliance on developed countries and thus decrease domestic innovation in LDCs, others note that the flow of ideas and technologies incorporated in foreign patents can definitely be helpful in generating recipient country TFP. As figure 2 indicates, TFP change moves with foreign patents, especially in the case of the three East Asian countries.

Figure 2a.

Figure 2b.

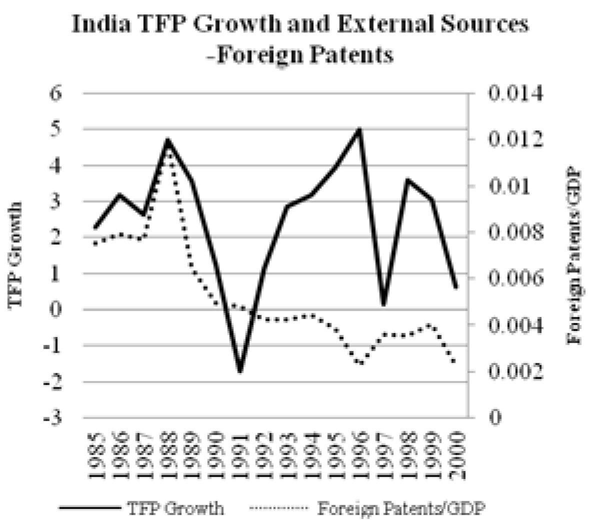


Figure 2c.

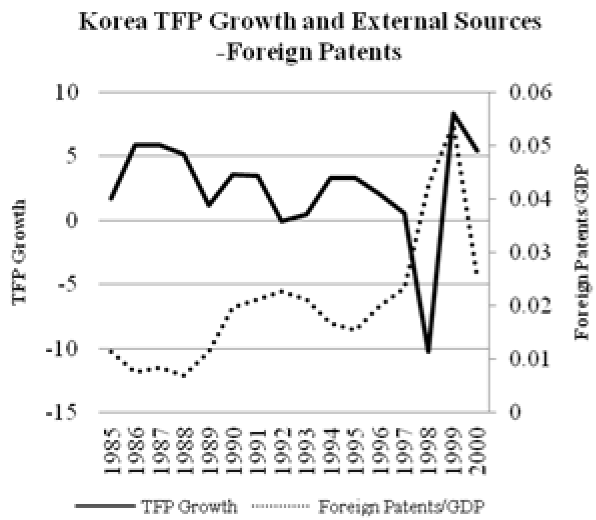


Figure 2d.

Figure 2e.

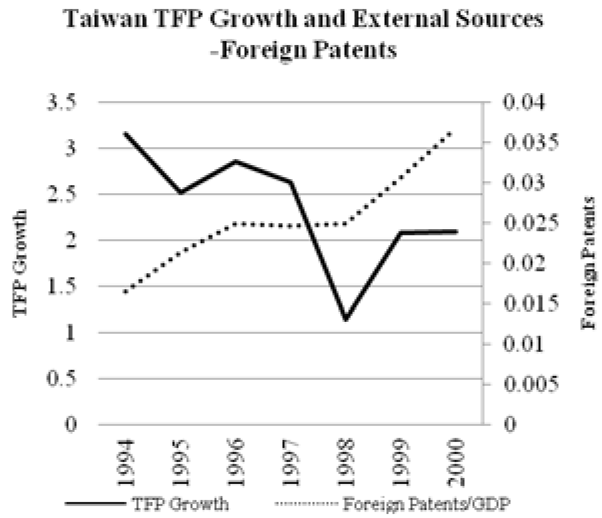


Figure 2f.

Sources: World Intellectual Property Organization; UNIDO, World Productivity Database; Republic of Taiwan, National Statistics; United Nations Statistical Division; Taiwan Intellectual Property Office

Of course, there exist legitimate concerns with respect to formalizing intellectual property (IP)rights in the developing world. The first is a problem of coordination. Acemoglu and Zilibotti (2001) note that, while most developing nations agree that intellectual property rights are necessary, at least in theory, in practice a prisoner's dilemma may exist, particularly in the early stages of development. They note that LDCs acknowledge that IP rights can encourage the flow of ideas and technologies from North to South, and that more formal IP rights in LDCs may even encourage developed countries to devise new technologies that are more appropriate for use in LDC environments. However, each LDC may hesitate to be the first one to enforce IP rights while other LDCs take advantage of the new technologies. Acemoglu and Zilibotti point out that the existence of this prisoner's dilemma suggests that there may be a role for a third-party, e.g. an international institution, to coordinate intellectual property rights in the developing world to overcome this coordination failure.[18]

Another more serious concern surrounding intellectual property rights is that their actual implementation can be at odds with the LDC's public interest. Since individual developed country innovators face incentives to develop new technologies relevant to their large home markets where they are guaranteed to earn a profit on their investments (through patents, copyrights, etc.), their actions may hurt technology change abroad. For example, in many cases foreign patents restrict other LDC technology entry, protect their markets against local enterprise, restrict exports, or permit firms to charge too high a price for their product. Ranis (1979) notes an example of this phenomenon, in which the granting of patents in the Colombian pharmaceutical industry presented a threat to the development of the local industry, "not only [by failing] to promote foreign investment, but [also by forcing] the sale of local firms to transnationals."[19] In this case, while the granting of patents encouraged the flow of ideas and technologies across borders, it also represented an obstacle for domestic Colombian pharmaceutical firms and hurt Colombian consumers.

Moving from the general to the more specific issue of TRIPS implementation leads us to another concern associated with patents, namely, that it has been extremely difficult to enforce the provisions of the TRIPS agreement fairly across LDCs. Different national situations, i.e. distinctive cultures and diverse national legislative systems and policies make it extraordinarily challenging to even-handedly execute the terms of the agreement. The 2001 Human Development Report noted that, while TRIPS may benefit middle-income countries such as Brazil, which are likely to profit from the increased local innovation resulting from intellectual

[18] Acemoglu and Zilibotti (2001)
[19] Ranis (1979), 36.

property rights legislation, poorer LDCs that lack formal innovation structures and institutional mechanisms have faced higher costs without counterbalancing benefits. As to the future, a differential application of TRIPS to developing countries, depending on their stage of development, would seem to make sense on a permanent basis (currently there is only a time delay granted before full application goes into effect). It is no accident that the more successful LDCs of East Asia were intellectual property "pirates" until they began to become concerned about their own IP rights being infringed upon by the next wave of emerging economies.

B. Internal Sources and Impediments

The existence of an international advanced country technology frontier clearly dominates the opportunities for technology change in the typical developing country. Yet making appropriate choices on what to adapt, how to adapt, and what to reject is critical and differentiates the more from the less successful countries in the developing world and that, in turn, depends largely on the quality and quantity of relevant domestic activities.

1) Domestic Patents and Utility Models

Technology transfer, with adaptation, clearly presents a unique opportunity. As new technologies are devised abroad, the adaptation of these new processes or products can decrease capital-labor ratios, make more efficient use of a relatively unskilled labor force, and offer consumers new product attributes that align more closely with their preferences and tastes – all developments that can lead to a sustained increase in TFP, and hence growth. But the emphasis must be on the extent to which imported technologies are converted into technologies appropriate to the new environment, i.e. the quality of that adaptation process. Echoing Frances

Stewart's early work, we are emphasizing here the importance of the adaptation of transferred technologies.[20]

The equilibrium state is that the development of most new technologies at the "frontier" occurs first in those countries or regions where the human skill level and technical capacity required are superior – i.e. in the developed countries. It is accepted theory and practice that LDCs should to some extent rely on these more advanced countries (including increasingly some middle income countries in the South), and thus avoid the cost of research and development that went into the generation of those technologies. However, as Frances Stewart insisted, the *transplantation* of new technologies is only step one and can lead to insufficient or inappropriately biased adaptations, and such inappropriate adaptations could entail heavy opportunity costs for LDCs. While the factor proportions used to produce a given quality product differ substantially between a typical Northern and Southern country, the difference is typically much smaller than the gap in their endowments. With the proper type of adaptation to local conditions, LDCs can reap the benefits of developed countries' investments in the invention process without having to incur relatively large opportunity costs. The success of this effort depends in large part on domestic patents and domestic R&D, both formal and informal.

Pack and Westphal (1986) address essentially the same concern related to the "tradability" of technology, noting that it is only partially tradable: that is, an individual LDC's capability to make perfect use of new knowledge and new technologies is, at best, uncertain. They assert that this is because technology is often tacit and the problems of communication and organizational differences, especially given long distances, institutional and cultural more than geographic, render the implementation of adaptation difficult. Moreover, because technological

---

[20] Stewart, F. (1977) op cit.

elements are only partially tradable, they may require complementary institutional investments.[21] Domestic patents and utility models may be useful in converting tacit into explicit technical knowledge. Foreign patents are likely to induce domestic patents, and domestic patents in turn are likely to induce utility model patents[22] (where they legally exist). As Figure 3 shows, the utility model is dominant in Korea and Taiwan and seems to have a high correlation with TFP growth, while, somewhat surprisingly, we may note a close relationship in the case of domestic patents for Brazil and Mexico – perhaps due to their relatively more closed economies. Late-comer China catches up quickly in deploying the utility model. In a given industry what is frequently observed is a sequencing, from the licensing of foreign patents, to an increase in domestic patents, followed by a burst of the utility model which is especially helpful to medium and small-scale firms.

[21] Pack and Westphal (1986)
[22] A low threshold, short protection type of patent

3. Internal Sources-Utility Models and Domestic Patents

Figure 3a.

Figure 3b.

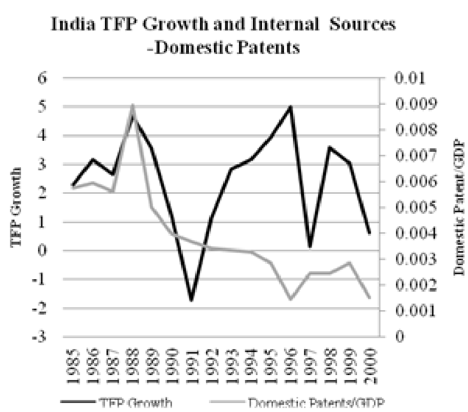


Figure 3c.

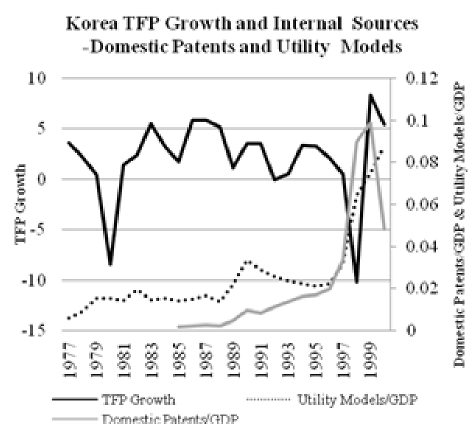


Figure 3d.

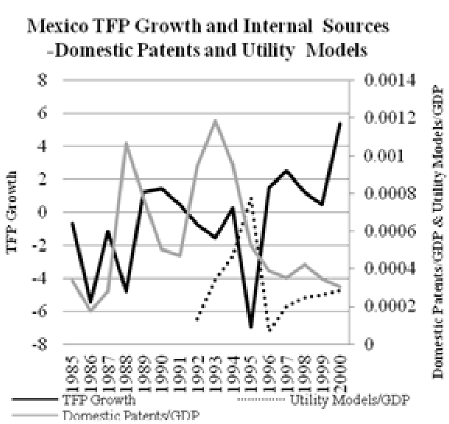


Figure 3e.

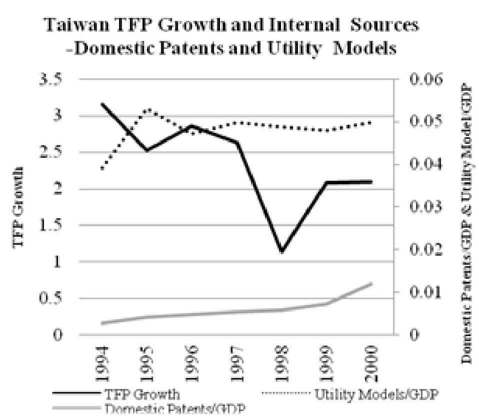


Figure 3f.

Sources: WIPO; UNIDO; Republic of Taiwan, National Statistics; UNSD; TIPO

Where the intellectual property rights regime is weak, individuals and firms face fewer incentives to innovate because they lack formal mechanisms by which to reap returns on their investment. Due to the fact that patents grant a firm (or an individual) a temporary monopoly position, firms are able to recoup the costs of their initial investments, as well as earn a profit, by setting a price above their marginal costs. However, if formal intellectual property rights are not put in place, this quasi-monopoly position disappears. In this situation, firms are not guaranteed to recover the costs of their initial investments, let alone earn a profit from their new technologies. Thus, formal intellectual property rights increase the incentives for risk-taking by guaranteeing a financially "secure" outcome after the initial investment.

2) Domestic Investment

Clearly an important domestic source of TFP growth is domestic investment which is required to "carry" technology, whether changes in TFP are theoretically viewed as exogenous or endogenous. Using data on gross capital formation[23] as the best measure of the domestic investment rate (see Figure 4), we may note a closer positive relationship between TFP growth and the investment rate in the case of Mexico than in some of the other country cases depicted.

The experience of China and India indicates that high investment rates are not necessarily associated with high rates of TFP growth. This may be the result of "over-investing" resulting from very high savings rates, plus an emphasis – especially in the case of China – on maintaining extremely high growth rates and the resulting declines in the rate of return to capital and rising capital–output ratios in both countries. Taiwan seems to have maintained stability in TFP growth

23 From World Development Indicators and the Taiwan Bureau of Statistics.

at much lower levels of the investment rate. There appears little relationship between TFP growth and investment in the cases of Korea and Brazil.

3) Secondary Education Choice, S&T Personnel and R&D

"New growth" theorists stress the importance of human development, specifically education, in developing nations, arguing that it improves the *absorptive capacity* of domestic firms. In this context, "absorptive capacity" refers to the firm's ability to successfully select and adapt foreign technology. They argue that in order for technologies to be appropriately adapted, workers must possess a basic skill level. These educational requirements of course change over time, with increased emphasis on vocational secondary education and, subsequently, science and technology oriented education (see Figure 5).[24] An East Asia/Latin America contrast holds for Science and Technology (S&T) personnel and for the role of secondary vocational education, though data on the latter is deficient.

[24] We here substitute highly correlated GDP growth for TFP growth.

4. Internal Sources: Gross Domestic Investment Ratio

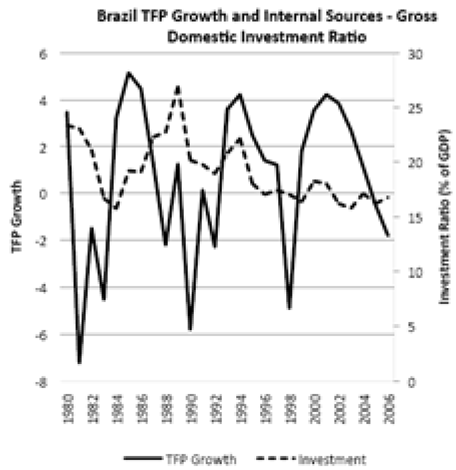


Figure 4a

Figure 4b

Figure 4c

Figure 4d

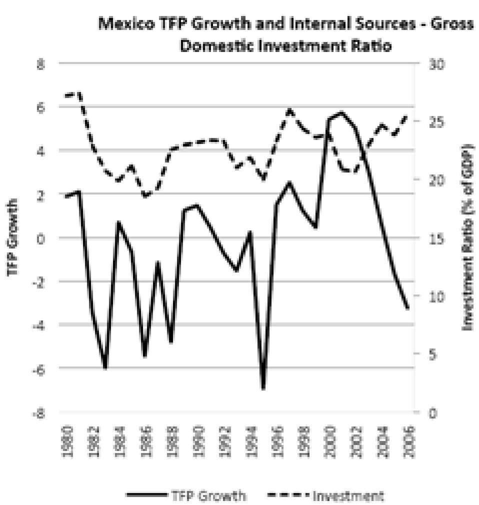


Figure 4e

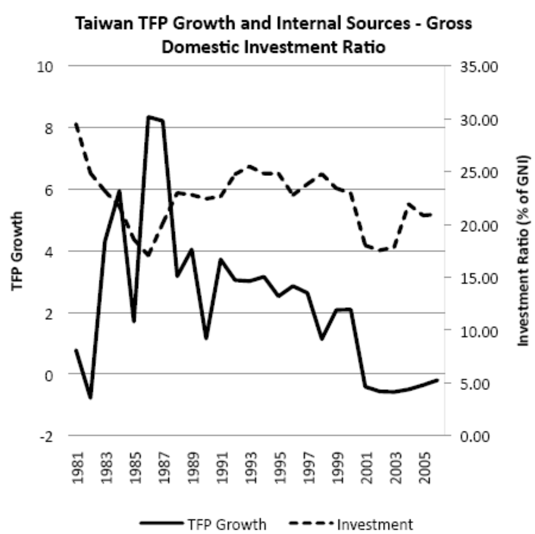


Figure 4f

5. Internal Sources: S&T personnel, R&D expenditure, vocational education

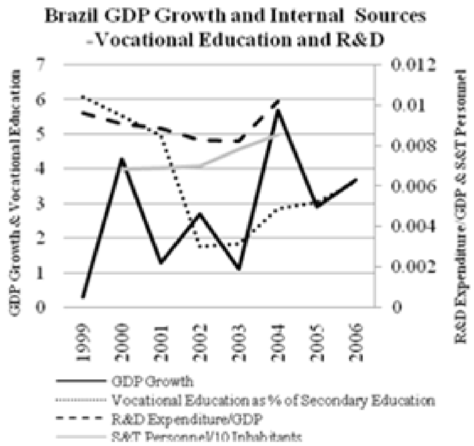


Figure 5a

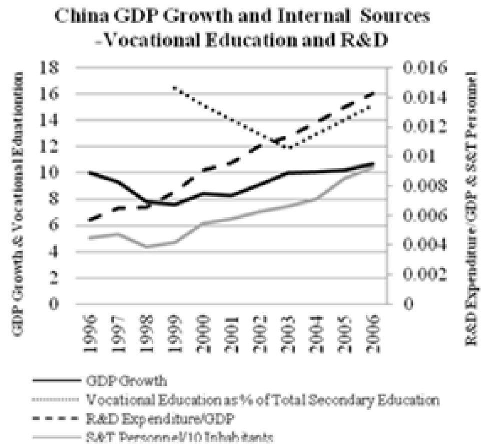


Figure 5b

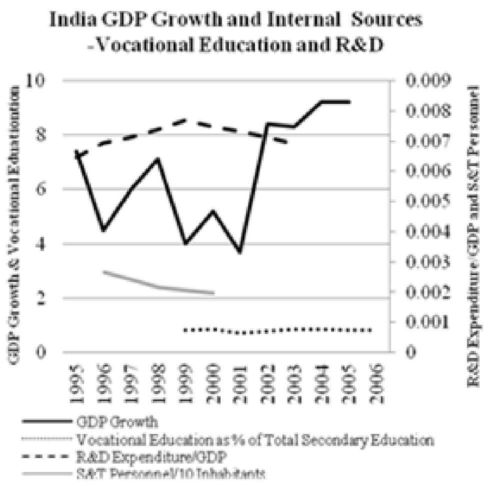
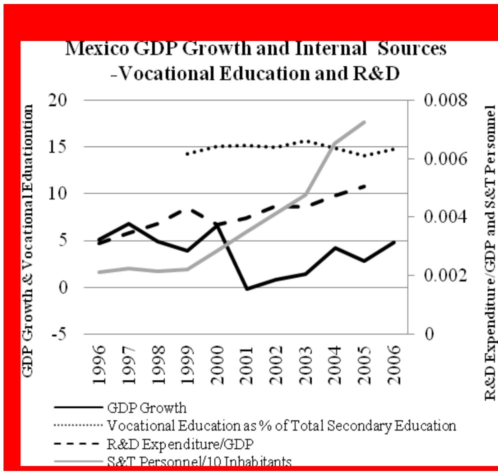


Figure 5c

Figure 5d



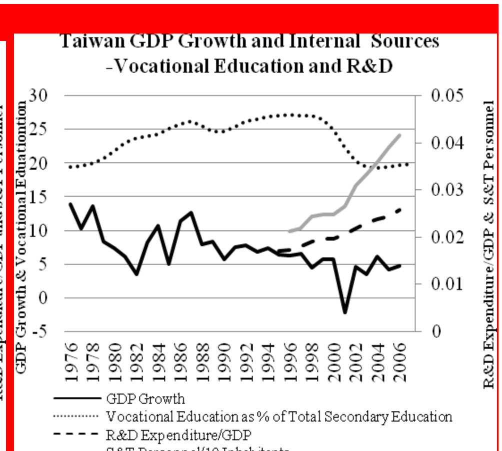


Figure 5e

Figure 5f

Sources: UNESCO, UNSD; Republic of Taiwan, National Statistics

Acemoglu and Zilibotti (2001) add that the skill level of workers in individual developing countries can largely explain relative productivity differences and income gaps between the developed and developing world. They argue that, even when all countries have access to the same technology, there will still be income gaps and large cross-country differences due to the relatively less-skilled LDC labor force. Since most R&D investment takes place in developed countries, the technologies that result from that investment will naturally yield "North-biased" technologies. Workers who are less conventionally skilled will thus not be able to make effective use of such imported technologies. If the Northern bias in favor of skill-intensive technologies continues, LDCs may be increasingly inclined to reject frontier technologies and miss an opportunity to adapt them to their own needs and demands. To avoid this from happening requires general scientific, vocational and technical literacy, not copying the educational system of the North. By encouraging timely investments in education, particularly with respect to programs that aim to improve the skill level of the average LDC worker, it becomes possible for LDCs to encourage the appropriate adaptation of imported technologies.

Accordingly, the consensus in the literature is that the universal attainment of primary and, later, secondary education should be a goal for LDCs. Stewart has insisted that vocational and technical education at the secondary level be encouraged[25]. Indeed, an important issue is the distinction between education and associated R&D efforts which are mainly science-based or empirically-based. The former is defined as "technology that arises from a change in our basic understanding of the laws governing the environment," and the latter as "technology that arises after trial-and-error."[26] Ranis cautions against an over-reliance on empirically-based technologies, which he cites as a contributing factor for the relative decline of Britain's

[25] Stewart (1977)
[26] Ranis (1978)

economic growth and performance in the years after World War I, following its earlier industrial success. Many new technologies in developing countries arise as the result of “tinkering” – for example, so-called “blue collar” R&D in textiles, metal working, brick making and beer brewing led to early TFP advances in Japan which did not need to rely on basic scientific advances but made use of its abundant labor supply. Britain was the pioneer. Germany, as a follower, facing natural resources scarcity, focused on post-Liebig research labs and engineering schools and outdistanced everyone else in the chemical/pharmaceutical, iron and steel, and electrical machinery industries by devising new technologies based on a fundamental understanding of science. The U.S. endowment favored empirically-based change, and mass as opposed to niche production. As Kuznets points out, the capacity to use science wisely, and the capacity to absorb science as a necessary basis for importing and adapting technology, is related to the education system and to the types of interventions, either direct or indirect, practiced by governments. An education system that imparts a modicum of scientific understanding to a substantial portion of the population can provide basic building blocks for a discriminating science capacity at a relatively early stage of a country’s development. Moreover, as the examples of Japan and the United States illustrate, the same country may, further along in its development, itself acquire the capacity to advance the frontiers of science and directly contribute to the frontier. Higher education relevant to more advanced technologies becomes crucial at a later stage.

That new empirically based technologies in the North can have an extraordinary impact on total factor productivity in the South has been demonstrated time and time again throughout history. Otsuka et al[27], for example, refer to the example of the Indian and Japanese cotton spinning industries and argue that a substantial increase in TFP in Japan in the late-19th century

---

[27] Otsuka, Ranis, Saxonhouse (1985)

occurred as the direct result of the utilization of an imported technology – the ring – to replace an old one – the mule. In contrast to its Indian counterpart, the Japanese cotton spinning industry witnessed a "virtually instantaneous switch from mules to rings" in the space of two years (1887-1889), which, in turn, prompted major adaptations in such ancillary processes as higher speeds of machinery utilization, the introduction of cotton-mixing, and the employment of more women to repair broken threads. The authors attribute an overall decline in the capital-labor ratio around the turn of the century to the industry's switch to the ring and its subsequent labor-using adaptation processes. By contrast, India imported two million new mules between 1883 (the date of the first Indian experimentation with rings) and 1900, for cultural reasons failed to include women in the labor force, and did not use cotton mixing to decrease its reliance on mule technology. As a consequence, Japanese-owned mills in China, a market previously owned by Indian exporters, expanded capacity more than eightfold between 1915 and 1928, and the number of Japanese-owned looms increased 15 times over the same period. Domestic adaptive R&D in Japan was clearly superior to that in India. The Indian colonial managing agency system focused on output quotas instead of profits and thus did not provide the necessary incentives.

Keller (2004) notes that countries with higher levels of expenditure on R&D experience higher rates of productivity growth because such expenditures are critical for appropriate adaptive responses to international technology. Only 5% of the world's formal R&D is expended by the developing countries and the typical LDC spends 0.5% of its GDP in this fashion, compared to 5% for developed countries. The East Asian economies spend between 1.5% to 3.0% of their GDP on official R&D while the Latin American countries fall below 1%. Firms in LDCs often lack tax or other incentives to invest privately or to take advantage of public sector R&D opportunities. The adequacy of domestic R&D in the context of generating TFP hinges on fiscal incentives, institutional innovations, as well as education strategies.

The incentives faced by firms to invest in R&D differ depending on the size and market position of the firms in question. For large firms with a relative monopoly position, there may exist the ability but a low incentive to innovate; i.e. the firm is either maximizing profits or coming as close as possible to doing so, and thus has no reason to find a new or efficient means of doing what they have already "perfected." More likely, it is "satisficing" and prefers the stability of "the quiet life". In successful LDCs, it is in small- and medium-scale firms in relatively competitive industries that most significant R&D activity takes place. Institutional innovations, including the establishment of R&D institutes, providing access to smaller entrepreneurs on a temporary basis, have been very helpful to such firms which can't afford major organized R&D efforts in the most successful countries, e.g. ITRI in Taiwan. The more competitive environment faced by these firms usually encourages them to find appropriate adaptive responses. The existence of the utility model patent can also be very helpful in this regard since much R&D may be carried out in the form of "tinkering," i.e. blue collar or informal activities on factory floors and in repair shops, including "reverse engineering," all of which is not captured in the official formal R&D statistics. For example, an LDC may reap a higher payoff from an imported machine if it is tested, used, and redesigned by workers on the factory floor to suit the special needs of the local environment.

The emphasis should clearly be on *adaptive* rather than *basic* R&D. Julian Engel sees "little justification [in developing countries] for basic research except for sustaining a viable teaching effort and keeping your best brains at home."[28] Most observers agree that the biggest

[28] In Ranis (1978).

waste of all is second-rate basic research and instead advocate flexible economic environments plus science and technical education focused on indigenous improvements and adaptations. However, to neglect basic science-focused R&D entirely may be going *too* far, particularly in agriculture and health. Without such research on a country or regional basis, Green Revolution technology in agriculture, for example, would not have had the necessary sustaining power and the necessary defense against specific local problems (such as pests and disease). Similarly, in the field of health, few people would argue that one transnational science can really be equally responsive to the very different conditions around the globe. Even in some industries, some attention to science-based R&D may be helpful, e.g. in footwear production, depending on different cowhide tanning procedures, or in textile industry, depending on different humidity requirements. In such areas, minimal scientific literacy is necessary to respond to technological problems, even as an LDC is ill-advised to "show the flag" in an array of frontier science endeavors.

The benefits of investment in educating and retaining adaptively-motivated science and technology (S&T) personnel domestically, rather than risk losing such individuals to developed nations with strong programs and more formal education and research structures, are substantial. In the East Asian countries that have experienced success the building up of S&T personnel was a priority. Japan stands as an example of technical education put to good use, noted for its mastery of reverse engineering, for achieving appropriate adaptation by carefully analyzing imported machinery's structure, function, and operation, and changing key elements in consonance with local factor and institutional endowments. Some contemporary LDCs, e.g. in Latin America, typify some of the impediments in this area, e.g. by their relative emphasis on academic over vocational education at the secondary level and on the humanities over science and engineering at the tertiary level.

III. Summary and Some Conclusions for Policy

Our six country comparison in its various dimensions indicated that while the world is grey, rather than black and white, there are marked differences in the extent to which East Asia, in contrast to Latin America – with South Asia in an intermediate position – took advantage of technological opportunities and reduced some of the obstacles. While most economists agree that R&D is the major source of technology change because it permits adaptation to take place, it is clearly subject to perceptible underinvestment, especially in Latin America, when compared to Asia. With increased cheap flows of information and technology now possible across borders, it has become much easier for new technologies to be both imported and exported across the globe. Thus, opportunities are mushrooming but are not being sufficiently utilized. Some progress has clearly been made, i.e. basic research and development has given way to increased emphasis on adaptive research and development, with the need for country-specific R&D clearly evident. Frances Stewart has rightly maintained from the beginning that R&D is "the dominant source of innovation today," and that adaptive R&D in particular is critical for LDCs to develop their own appropriate technologies and avoid over-reliance on inappropriate imports from the developed world.[29]

Yet we should recognize that impediments continue to exist to repairing the current LDC underinvestment in R&D even if we could account for the "blue collar" R&D not reflected in the available data. Most economists agree that current tax code-embedded R&D programs tend

[29] Stewart (1981)

to benefit larger firms. Moreover, there has been a lack of institutional commitment to R&D among bilateral and multilateral aid agencies. When and where successful R&D programs do exist, the dissemination of relevant knowledge remains problematic. Complementary human capital investments are required to take full advantage of the potential for adaptive technology change. To remedy this, Stewart offers a few suggestions for R&D policy, including the promotion of "appropriate" technology choices by aid agencies, as well as the creation of new R&D partnerships incentivized by tax credits and public grants. In this way, she argues that *basic* (or "old-style") R&D will no longer be effective, and considerable investment in adaptive R&D should be undertaken. In a similar vein, Ranis suggests that government support of R&D institutions that cater to S&M firms be set on a long-term, gradually-declining subsidy basis in order to ensure their focus on private sector "appropriate adaptation" activity rather than the pursuit of international academic or scientific interests.

Determining appropriate responses to R&D underinvestment and designing effective R&D programs requires an understanding of where the individual developing country's basic research needs end, and where the caveats against a wasteful buckshot approach begin to take hold. While this is not an easy matter on which to pontificate, the burden of proof must be on those who would like to initiate advanced university training and basic research, including some obligation to demonstrate a flexible, time-phased relevance to sustained technology change. This may seem like the typical hardheaded, narrow economist's prescription. What about the importance of those many possible interconnections, decades apart, that may flow, in some entirely unpredictable way, from what looks like an unconnected intellectual pursuit? Without disparaging these possibilities, we should be offended by the spectacle of open-heart surgery research in countries where malnutrition is prevalent and insist that basic research should not expect to be outside the realm of some flexible, sophisticated version of cost/benefit analysis. Such analysis must try to balance the potential benefits against the possible alternative allocations of scarce financial and, undoubtedly even more important, human resources. The higher risks of science, due partly to the uncertainty of predicting future two-way interactions between science and technology, and partly to the likely inappropriability on a national scale of any such "returns," render this task unusually difficult. But analysis must still be done; an act of faith does not suffice.

In addition to placing the burden of proof on those who would like to have developing countries pay the "price of admission" in a given field of basic R&D, it might be possible, although admittedly difficult, to encourage much more specialization within, and possibly also among, countries on a regional basis. This type of agreement has been reached, for example, in European atomic energy and ballistics research and in African efforts to combat yellow fever and rinderpest regionally – that is, where the required scale and the need to avoid expensive duplication were sufficient to overcome nationalistic jealousies. Although the record on similar agreements among developing countries in the field of common market investment allocations, for instance, has not been very encouraging, it has been somewhat better with respect to the use of regional training institutes and research organizations, i.e. whenever regionalism is not forced but flows from the recognition of a mutual self-interest.

If we agree that no developing country can really afford to be either a full-time borrower of science or an across-the-board contributor to it, the same holds for the hamlet of our piece, domestic human development as expressed in terms of appropriate education levels. When we speak about a society's national capacity to utilize and modify basic science creatively, we are really referring to a human capacity to make appropriate adaptations to a different environment.

Contributions to human knowledge that break new ground and provide scope for major new technological breakthroughs will, with few exceptions, probably remain the province of the North for the time being.

What can we say about the direction that new science-intensive and engineering-intensive frontier technology is likely to take? The two elements that seem most responsible for this direction are changing resource endowments and changing public policy. The very different historical behavior of the natural resources-rich, labor-scarce United States relative to a relatively capital-scarce England and a Germany that felt cramped for natural resources should be instructive in this respect. Engineering-intensive technology took a different, more capital-intensive path in the wide-open spaces of the United States than in England. And in Germany, metallurgical science responded to the demands of an iron ore with high phosphorous content; official encouragement of the entire chemical industry was based on the felt need to overcome, by artificial and synthetic shortcuts, the relative unkindness of nature. Japan, after first exploring its abundant labor resources – and taking an engineering-intensive route analogous to that of the United States - has, with the disappearance of its labor surplus, tended to place more of its eggs in electronics and other high-technology baskets.

While government policies cannot legislate away the basic endowment of a society, they can, if flexible and able to overcome national sectional interests, provide important assistance to the transition effort of a developing economy as its resource endowment and institutional capacity change over time. Analogously, if dominated by narrow vested interests and/or lacking in historical perspective, such policies can attempt to draw a veil over the endowment and lead the system into expensive scientific/technological dead ends and economic stagnation. While there is no rigid unidirectional sequence of phases that every developing country must follow on the path to mature growth, some attention to the changing roles of science and technology in terms of a changing resource endowment and, especially, changing human capabilities is essential in all but the most unusual cases.

At the micro and institution-building levels, the appropriate role of government in the mixed economy context is not unrelated to the appropriability or nonappropriability of the new knowledge acquired. Investment in basic science carries a high risk, in part because of its, at best, indirect and long-term relationship with technology and growth, but also partly because it is generally an international good not even appropriable by a country, not to speak of any private party within a country. As we move from basic international science to changes in technology, risks are reduced and private appropriability becomes much more important. As the extent of appropriability rises, so, normally, does the level of private R&D expenditures.

A perceptible trend has been for the typical LDC, in the early stages of its independence, to rely on import substitution policies in an attempt to assert its post-colonial economic independence by beefing up its domestic industry. However, these policies also often did harm to local industry by making it less competitive and greatly decreased the incentive to innovate, as firms were protected by tariffs, price controls, and foreign exchange rationing. When guaranteed unearned profits, producers have less incentive to find new technologies and innovation is stifled. Firms are content to protect their quasi-monopoly position and adopt "satisficing behavior." While such policies may be necessary at early stages of an LDC's development, there is always the danger that some bad habits persist. For example, some countries still prohibit the importation of second-hand machinery. Ultimately openness to trade and to the transfer of technology via patents and FDI can provide opportunities in the direction of generating appropriate technology change. Stewart has argued that the objectives of a firm can be changed by influencing the environment in which decision-makers operate. By removing the quasi-monopoly protection that import substitution policies provide domestic decision-makers, it is possible to influence performance in an innovative direction.

In order to ensure a successful and mutually beneficial relationship between an LDC and the multinational corporation, the multinational corporation should ideally be disaggregated into its component parts. Most misunderstandings occur because of the mystique of the powerful, footloose MNC, bargaining with the poor, optionless LDC, the latter being pressured to buy what is essentially a "pig in a poke." The capital, technology, management, and entrepreneurship components of any deal should be spelled out as fully as possible and each component priced out. Screening procedures that exist in virtually every LDC should concentrate more on such disaggregation and full disclosure, thus permitting comparative shopping and other than "all or nothing" acceptances or rejections. Fade-out and divestiture agreements can be negotiated much more intelligently *ab initio* which might, for example, provide for a transition from the wholly-owned subsidiary to the joint venture form after ten years, and possibly further reassessments in the direction of licensing or management contracts thereafter.

We must, of course, contend with the argument that it is unlikely that multinational firms will be willing to play this game because, from their point of view, they helped create formidable competition for themselves in return for relatively meager and diminishing returns."[30] Clearly, if offered more at every stage they will seek more. If, however, there is a clear and anticipated transition from one stage (and one bundle) to another within a particular LDC, competitive pressures among the MNCs should assert themselves to dictate a willingness to accept reasonable rates of return. In this we would be safer in relying on the MNC's long-run profit

[30] Ranis (1976), 112

objective rather than on some public spirited impulse. Negotiations should recognize that it is mutually better to plan on living together under changing rules than to attempt to deny the declining value of some major MNC components over time, thus inviting expropriation or other retaliatory actions. The burden of proof would have to be on the side of those, like Raymond Vernon,[31] who claim to see a general tendency for a broadening and deepening relative role for the MNC over time.

LDC screening procedures governing MNC presence could be modified in the direction of greater automaticity, greater predictability and more built-in flexibility over time. Such procedures should reflect a recognition that some of the excesses of the MNC, ranging from transfer pricing to the payment of prematurely high wages, to the inappropriateness of the technology selected, to the underutilization of patents and the overutilization of domestic credit and export prohibition clauses, are clearly related to the overall policy environment of the recipient LDC. The MNC can be effectively forced to put its energies into building better mousetraps and using adaptive (usually labor-intensive) technologies. In that case it is forced to give up the "quiet life" of the satisficing monopolist as the transition to a more liberal policy regime is effected. MNCs are quite capable of coming up with appropriate process and product ideas when they are pressured to "scratch around".

The importance of indigenous human capabilities in determining the rate of technology change is reflected in the importance attached to vocational education and scientific personnel underpinning the nature of domestic R&D at different stages of an economy's development. This very capability will serve a developing country well in determining, most importantly, its

[31] Vernon, Raymond (1992)

domestic policies as well its attitude towards foreign patents, the multi-national company and foreign capital, public and private.

References

Acemoglu, Daron and Fabrizio Zilibotti. 2001. "Productivity differences." *The Quarterly Journal of Economics*, 116(2): pp. 563-606.

Behrman, Jere, 1990. "The Action of Human Resources and Poverty on One Another," Living Standards Measurement Study, Working Paper No. 74, World Bank: Washington, DC.

Borensztein, E.J., de Gregorio and J.W. Lee, 1998, "How Does Foreign Direct Investment Affect Economic Growth?" *Journal of International Economics*, Vol.45: pp115-135.

Fei, John and Gustav Ranis. 1974. "Technological Transfer: Employment and Development" in *Economic Development and Planning: Essays in honor of Jan Tinbergen*, Willy Sellekaerts (Ed.) International Arts and Sciences Press: New York.

Keller, Wolfgang. 2004. "International Technology Diffusion." *Journal of Economic Literature*, 42(3): pp. 752-782.

Larraín, Felipe, Luis F. López-Calva, and Andrés Rodríguez-Claré. 2001. "Intel: A case study of foreign direct investment in Central America," in Economic Development in Latin America, Vol 1: Growth and Internationalization, Larraín B.Felipe (Ed), Harvard University Press: Boston: pp. 197-250.

Otsuka, K., Ranis, G. and Saxonhouse, G. 1998. Comparative Technology Choice in Development: The Indian and Japanese Cotton Textile Industries, MacMillan Press.

Pack, Howard. 1994. "Endogenous Growth Theory: Intellectual Appeal and Empirical Shortcomings." *The Journal of Economic Perspectives*, 8(1): pp. 55-72.

Pack, Howard and Larry Westphal. 1986. "Industrial strategy and technological change: Theory versus reality." *Journal of Development Economics*, 22(1): pp. 87-128.

Ranis, Gustav, Frances Stewart and Alejandro Ramirez. 2003. "Economic Growth and Human Development," *World Development*, 28(2): pp 197-219.

Ranis, Gustav. 1990. "Science and Technology Policy: Lessons from Japan and the East Asian NICs," in Evenson, Robert and Gustav Ranis (Eds.) Science and technology: Lessons for development policy. Westview Press, Inc: Boulder, Colorado.

—–. 1983. "International and domestic determinants of technology choice by the Less Developed Countries (LDC)," in Lucas, Barbara and Stephen Freedman (Eds.) Technology choice and change in developing countries. Dublin: Tycooly International Publishers.

—–. 1979. "Appropriate technology: Obstacles and opportunities," in Rosenblatt, Samuel (Ed.) Technology and economic development: A realistic perspective. Kapitel 2: Boulder, Colorado.

——. 1978. "Science, technology, and development: A retrospective view," in Beranek, William and Gustav Ranis (Eds), Science, technology, and economic development: a historical and comparative study, New York: Praeger.

——. 1976. "The multinational corporation as an instrument of development," in Apter, David and Louis Wolf Goodman (Eds), The multinational corporation and social change, New York: Praeger.

Rodrik, Dani. 1999. "Where did all the growth go? External shocks, social conflict, and growth collapses." *Journal of Economic Growth* 4(4): pp. 385-412.

Romer, Paul. 1990. "Endogenous Technological Change," *Journal of Political Economy, 98(5)*: Part 2.

Stewart, Frances, 1987, "Overview and Conclusions" in Macro-Policies for Appropriate Technology in Developing countries, Westview.

Stewart, Frances and J. James, (Eds) 1982. "The Economics of New Technology in Developing Countries, Pinter/Westview.

Stewart, Frances. 1981. "Arguments for the generation of technology by less-developed countries." *The ANNALS of the American Academy of Political and Social Science*, Vol. 458: pp. 97-109.

___ 1977. Technology and Underdevelopment, Macmillan: London.

——. 1972. "Choice of technique in developing countries." *Journal of development studies*, 9(1): pp. 99-121.

UNDP, 2001. "Making New Technologies Work for Human Development." in *Human Development Report*, United Nations Development Program: New York.

Vernon, Raymond. 1972. The Economic and Political Consequences of Multinational Enterprise: An Anthology, Boston: Division of Research, Graduate School of Business Administration, Harvard University.

Warren-Rodriguez, Alex. 2007. "Science and technology and the PRSP process: A survey of recent country experiences," in The Least Developed Countries Report 2007: Knowledge, Technological Learning and Innovation for Development, UNCTAD Background paper No. 8

Westphal, Larry. 2002. "Technology strategies for economic development in a fast-changing global economy," in Economics of innovation and new technology, Vol. 11(4-5): pp. 275-320.

Xu, Bin. 2000. "Multinational enterprises, technology diffusion, and host country productivity growth." *Journal of Development Economics*, 62(2): pp. 477-493.