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Abstract

Inextricable links between international trade, growth and role of knowledge-creation are well-established in the economics literature. The issues of creation of technology, its diffusion and actual adoption have been discussed on both theoretical and empirical planes. Effective assimilation of advanced technologies hinges on the 'Absorptive Capacity' and the 'Structural Congruence' between source vis-à-vis the destinations; role of public policies for actual implementation of these new ideas is extremely crucial. This paper offers a synoptic overview of current research and sketch a possible extension of the analytical framework on an operationally feasible plane within the Computable General Equilibrium framework. The survey highlights that analysis of the issue of technology-induced growth in a knowledge-based society must further the analysis by highlighting the role of factors for capturing the benefits. It has been identified that the factors propelling the acquisition depend, *inter alia*, on human capital, infrastructures, learning effects, and indigenous inventive activity.

Key Words—Absorptive Capacity, Structural Congruence, Endogenous Growth, Total Factor Productivity, Computable General Equilibrium, Trade, Human Capital, Technology.

JEL Classification: C8; F4; O3; O4.

1. Introduction

Of late, the importance of knowledge capital and inventive activity in production has attracted considerable attention. The inextricable links between international trade, growth and invention are well established in the economics literature. Many less developed or developing countries (LDCs) have pursued liberal trade and technology policies and have depended for their growth and development on foreign technologies originating in the industrialised, developed countries (DCs) of the world. The LDCs' growth and development in the long-term has depended not only on the extent and nature of the technology which has become available to them, but also on their competence, or capabilities, for effectively absorbing and applying the state-of- the-art.

The important issues of creation of new technology, its diffusion and actual adoption have been discussed on both theoretical and empirical planes. As will become clear, the roles of research and development (R&D) and of trade in high technology in promoting growth and development in LDCs need further study, as does the role of public policies in facilitating (or perhaps hindering) the transfer and diffusion of technology.

Theoretical as well as empirical attempts to explore these interlinkages are briefly reviewed below. In this paper, we confine our attention to the crucial role that absorptive capacity and structural congruence play in determining the conditions for applicability and effective assimilation of the transferred technology. In the subsequent sections, we survey the research and attempt to provide a synthesis. Section 2 describes the objectives and scope of my study. Section 3 reviews the relevant literature in brief. Structure of the proposed refinements is outlined in Section 4. Section 5 concludes. The entire discussion is situated in the context of embodied technology flows from the leaders to the technology followers, especially the less developed countries.

2. Motivation of the Study: Role of Absorptive Capacity and Structural Congruence in Technology Acquisition.

Given the fact that new, superior technologies are researched, developed and located predominantly in the developed, industrialised nations, and also the fact that these technologies cannot be readily, *effectively* utilised, we highlight the important role of public policies for actual implementation of these new ideas. We relate this to the notion of the 'Absorptive Capacity' (henceforth, AC) of an economy and the 'Structural Similarity' (or Structural Congruence—henceforth, SS) between the source of technology creation and the destinations. It has been argued that the *maximum* potential for productivity enhancement attainable with a given stock of ideas can be achieved only if absorptive capacity is optimal and the source and destinations are more or less structurally similar. AC and SS conjointly determine the extent to which a region succeeds in capturing foreign technology.

It has been postulated that the scope of the lagging countries to attain a higher rate of growth and productivity depends on the constellation of AC and SS (see for example, van Meijl and van Tongeren (1997, 1998), Keller (1996)). In the literature, to the best of my knowledge, the earliest authors to discuss this explicitly were Cohen and Levinthal (1989, 1990) and Nelson (1990);[1] unlike the discussion of van Meijl and van Tongeren, however, their treatment lacks an explicit model of technology diffusion.

According to Cohen and Levinthal, AC can be defined as "the ability to identify, assimilate, and exploit knowledge from the environment" (1989, p.569) and also "the ability.... to apply it to commercial ends" (1990, p.128). Notwithstanding the fact that the LDCs carry out little R&D activity, substantial technological development is a prerequisite for experiencing growth and development.

As Pack and Westphal (1986, p.105) argued,

> "effort is required in using technological information and accumulating technological knowledge...to create new technology. This takes the form of investments in.….effective use of knowledge."

Development of AC is important for *effective* diffusion of technology as it encompasses the "ability to imitate new process of product innovations,....[and] to exploit basic research." (Cohen and Levinthal, 1989, p.569).

Nelson (1990, pp.78-9) defines AC as

> "the ability to learn and implement the technologies and associated practices of… ...developed countries.".

Nelson and Pack (1999, p. 418) argues that

> "to learn to use new technologies and to function effectively in new sectors required the development of new sets of skills, new ways of organising economic activity, and …. [becoming] competent in new markets" [and also] "to be sure, adopting

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[1] Abramovitz (1994) has used the term 'social capability' in almost the same sense as AC.

> technologies of the advanced countries required, among other things, high rates of investment in physical and human capital..."

We attribute the absorptive capacity of individuals to the human capital embodied in them. In fact, according to *Human Capital Investment: An International Comparison* (OECD, 1998), human capital is defined as the knowledge, skills, competence and other attributes embodied in individuals that are required for undertaking economic activity.

Structural similarity (SS) relates to the similarity of factor proportions in the source and destination countries. The idea is that the more similar are the proportional factor endowments in the origin of technology creation and the clients, the more likely are the clients to benefit from technology transfer. This has been emphasized in a slightly different context from ours in the discussion of appropriateness of technology being transferred from DCs to LDCs (see Basu and Weil (1998); Temple (1998)). The similarity of factor proportions purports to measure the 'structural' and 'technological congruence' between the donor and the recipients (see Hayami and Ruttan (1970, 1985); Fagerberg (1994)). In case of agriculture, the land/labour ratio is used as a proxy measure of SS whereas capital per unit of labour is also a candidate element for an index of SS. AC, together with SS, determines the magnitude of embodied technology captured by the clients. The capture parameter determined by AC and SS is essential for facilitating effective adoption of technology.

According to the *World Development Report* (World Bank 1991, 1995 and 1999) (henceforth, WDR) trade is one of the primary vehicles for technology flows. WDR (1999) has documented the relevant country experiences in acquiring the knowledge capital with particular emphasis on the role of absorption capacity for diffused knowledge flows. In fact, WDR (1999) reports that

> "even a follower country needs a labour force with a relatively high level of technical education, especially when technologies are changing rapidly" (see p.42, ibid.)

It also categorizes three main tasks for closing 'knowledge gaps' between the source of technology creation and the recipient countries as [see p.25]:

> (i) "Acquiring and adapting global knowledge—and creating knowledge locally
>
> (ii) "Investing in human capital to increase the ability to absorb and use knowledge, and

(iii) "Investing in technologies to facilitate both the acquisition and the absorption of knowledge."

It also regards that these three tasks are complementary and 'mutually reinforcing' in nature in the sense that effective absorption of advanced technology acquired from the origin requires an educated, skilled work force.

From an operational point of view, one can attribute AC to the skill intensity of the work force. Typically, skilled labour embodies higher human capital which can be proxied by educational attainment. Whilst satisfactory AC is essential for harnessing new technology, AC need not be treated as an exogenous endowment. Since the new technology requires a skilled labour force, the opportunities created by it may stimulate changes in the skill composition of employment so as to enhance AC (see Wolff (1995); Wood (1995, 1999); Tyres et al. (1997); Haskel (1998); Galor et al. (1999), Krugman (1997)).

There is evidence that knowledge spills over from the sources of innovation to the destinations through different channels. Two principal channels through which such transmission of advanced knowledge-capital occurs are (a) International Trade in goods and services and (b) Foreign Direct Investment (of which Joint-Ventures are a special case). The literature has highlighted the role of trade in technology spillovers from North to South [for example, Coe, Helpman and Hoffmaister (1995, 1997); Connolly (1997); Keller (1997, 1999), Edwards (1993, 1997), Hall and Jones (1998), Padoan (1996), Eaton and Kortum (1994, 1996, 1999)—to name a few]. As will be evident from below, the literature documents the role of foreign trade in ferrying the benefits of technical progress in a global, interdependent knowledge-driven economy.

Some of the models in the literature assume investments occur in knowledge-capital and create scope for spillovers across firms and industries within a country, or across national boundaries. Coe and Helpman (1995, 1997) have examined the extent of spillover benefits derived by other countries—both DCs and LDCs—from the R&D undertaken by their trade partners. Coe, et al. (1997) have found substantial spillovers accruing to the LDCs with their total factor productivity responding positively to a larger foreign stock of R&D, as well as to liberalised imports of manufactured products and a higher level of education for the labour force.

All these above arguments suggest that it is important to incorporate AC within any attempt to model technology diffusion. Public policy for allocation of resources and investment has a role to play in the acquisition of AC. In this context, policy interventions such as investments in scientific and technological infrastructure and in education and provision of incentives for firms to adopt newer technologies are important issues. However, it must be admitted that none of the quotations above offer guidance about how best to define AC from an operational viewpoint. Our primary motivation is to investigate the role of the AC and SS in fostering technology acquisition via "embodied" spillovers of knowledge through *international trade* in commodities.

3. A Brief Overview of Relevant Literature

The research in this area typically has a developed country focus. Among the plethora of papers on the determinants of technological innovation and flows of technology, the bulk has been in the context of DCs. However, we do not attempt a detailed critical review of the extant literature in this area. Rather, we provide a synoptic overview of sparsely selected articles of direct relevance to the literature on embodied technology transfer and its effective adoption.

Broadly speaking, in the subsections below we highlight four strands of research in the burgeoning literature emphasizing the nexus between international trade, technology transmission and assimilation. It is to be noted that not all of them do consider the role of AC and SS (and hence the role of the capture parameter) explicitly in their formulations; the importance of AC, however, has been acknowledged in different models via their emphasis on human capital.

3.1 Previous research on technology, trade, human capital and growth

At the theoretical level, the importance of the appropriability of new technology in determining R&D activity has received considerable attention. Most of the literature is situated in an Industrial Organisation (IO) or game-theoretic framework, addressing issues of market structure, firm size, optimal length and breadth of patent protection, strategic interactions, and decision-making in the face of uncertainty in innovation. Authors have derived welfare implications of alternative patent arrangements. Some of them are De Bondt (1995), Goel (1995), Aoki (1991), Taylor (1994) and Chang (1995). Diwan and Rodrik (1991) modelled North-South trade in technology by taking into account differences in needs and tastes over a spectrum of available technologies, but they did not discuss what governs the accretion of ideas and their assimilation. On the empirical front, patent statistics and R&D statistics are used as proxies for investment in technology and technological competence for a strand of literature in econometrics. This literature provides estimates of the R&D spillovers between firms and industries and measures of returns to R&D investment, focusing on the role of intellectual property rights protection (IPRs) as a determinant of technology transfer and analysing their impact on economic variables like productivity and output—see Griliches (1992, 1995), Mansfield et al. (1977, 1985, 1986, 1988, 1993), Ferrantino (1993), Raut (1995), Deolalikar and Evenson (1989), Maskus and Penubarti (1995), Jones (1995), to name a few. However, the authors do not consider the role of AC and SS in their models; rather, they focus on patent statistics as proxies of R&D and the R&D creation activities.

The role of trade in transmission of technology has been well-established in both the theoretical and empirical literature [see for example, Sjöholm (1996), Coe et al. (1997), Lichtenberg and Potterie (1998)]. The renewed interest in the determinants of economic growth and development in a more liberal global trade environment has resulted in new strands of research exploring the interaction between trade and industrial policies and macroeconomic performance [see Temple (1999) for a comprehensive survey on this issue]. On the empirical plane, this literature focuses on the relationship between the outward-orientation of an economy and its economic growth—especially for the LDCs [see Dollar (1992); WDR (1991, 1999)].

International differences in technological competence are a fundamental factor in explaining the relative growth performances among economies. In the presence of trans-border flows of goods embodying technological improvements, the focus of research is on the determinants of different national capabilities to innovate and to appropriate the benefits; the adjustment mechanism within and between regions following such *technological shocks*; the relationship between sectoral performance and general equilibrium factors linked to relative price movements and intersectoral factor mobility. Grossman and Helpman (1995) summarise the various modelling approaches in the area of the trade-technology nexus and offer ‘a unified and synthetic framework’ of the models which we do not reproduce here.

In the first wave of the models in current (endogenous) growth literature (the models of Romer (1986, 1990, 1993), Grossman and Helpman (1990, 1991), Aghion and Howitt (1992), Helpman (1997)—to name a few, the interlinkage between trade-induced technology spillover and growth, patterns of international trade in intermediates and disparate innovative capabilities across nations have been researched. In these models, openness to international trade facilitates technology flows via advanced technology-bearing inputs and augments the size of the market facing the producers. These flows also affect the specialization in R&D-intensive sectors. Therefore, trade policy has implications for long-run growth via the induced technical change.

Most of the relevant papers in the new growth literature deal with non-convexities in production and dynamic gains from trade between trade partners.[2] The integration of new growth theory and trade theory à la Grossman and Helpman (1991) and other researchers (mentioned above) places the emphasis on induced endogenous technical change and scale economies. Typically, most of the models assign a more prominent role to 'technological change' as an explanator for varying growth episodes across nations.

Lucas (1988, 1993), however, is a *tour de force* in this genre of growth models in the sense that the role of human capital in driving growth—modelled via schooling and formal education as well as learning by doing and on-the-job-training—has been given due importance. In fact, Lucas (1988, p.15) argues

> "By assigning so great a role to 'technology' as a source of growth, the theory is obliged to assign correspondingly minor roles to everything else, and so has very little ability to account for the wide diversity in growth rates that we observe".

Lucas (1993, p.270) argued that, although they started from almost entirely comparable bases, South Korea experienced a 'growth miracle' whilst the Philippines had an episode of 'growth failure' between 1960 and 1988; according to him,

> "The main engine of growth is the access to human capital—of knowledge—and the main source of difference in living standards among nations is the difference in human capital. Physical capital accumulation plays an essential but decidedly subsidiary role".

Romer (1990) incorporates Lucas's (1988) ideas and develops a formal model emphasizing the importance of human capital in the development of new technology.

Note that absorptive capacity can essentially be related to human capital formation via schooling. However, unlike the strands of literature mentioned in the earlier section, one can also do so in a perfectly competitive world with constant returns to scale with no endogenous knowledge creation (i.e., in the Solow tradition of exogenous technological change in the source region). The initial *exogenous* innovations, however, spill over to the trade partners to induce endogenous total factor productivity changes in them. Also, the models mentioned above are theoretical general equilibrium in nature whereas explorations in an applied general equilibrium framework would be more appealing so far as the operational definitions of AC and SS are concerned.

So far as the issues of empirical measurement of technology transfer is concerned, in the literature the flows of technology have been identified through intersectoral input-output transactions. This strand of empirical literature attempts to quantify the technology spillover via the construction of technology flow matrices based on the R&D intensity of sectors. For example, Verspagen (1997) constructs such matrices using patent citations as an indicator of R&D creation and purports to measure intersectoral spillovers in manufacturing sectors over time and also the changes in the sectoral structure of spillovers over time. Also, using the Yale Technology Concordance (YTC) [Evenson (1995)], Keller (1997, 1999) constructs the technology transmission matrix via 'international inter-industry and intra-industry trade' adjusted for R&D conducted in the different sectors. The approach of Verspagen and Keller has been primarily driven by the explicit treatment of R&D-driven growth in their model structures. However, in a much simpler theoretical exposition one can assume knowledge creation as exogenous and trace its diffusion between sectors and nations via trade in commodities in which the technological 'know-how' is embedded.

The co-movement between human capital (proxied by educational attainment) and growth is evidenced in the literature [see e.g., Temple (1998, 1999), Romer (1990)]. The attribution of the principal role to human capital in some of the research in *endogenous growth* is due to its primary role in facilitating innovative activities, technical progress and skill formation. However, all the models discussed so far have little to say about the wage gap across skill categories in the wake of technological shocks. In fact, in a somewhat related literature of recent vintage we find discussions on the issues of trade, technology and the labour market. Section 3.2 introduces this literature synoptically.

3.2 Prior research on trade, technology and the labour market

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[2] See for example, Grossman and Helpman (1990), Evenson and Westphal (1995).

In the early 1990s, there was an outpouring of research seeking to explain the considerable empirical evidence relating to wage inequality prevalent in USA and other OECD countries. Research concentrated on the positive relationship between introduction of new technologies and the returns to skill. For example, Berman et al. (1994) and Kosters (1994) find that in USA manufacturing, the industries that invested more in R&D creation in the 1970's paid a higher skill premium in the 1980's. Borjas and Ramey (1995), Bartel and Sicherman (1999), Revenga (1992), Murphy and Welch (1992), Katz and Murphy (1992), Doms et al. (1997)—to name a few—have also concentrated on the changes in the wage structure especially in the context of USA and some other industrial countries belonging to the OECD block. They ascribe the trend in wage gaps to the skill-biased technical change and revolution in information technology, and also to changing trade patterns. Another camp, mainly in the subdiscipline of labour economics, focused on 'deunionization' of the US economy, immigration and the decline in the real minimum wage over the 1980's [see Freeman (1993); Blackburn, Bloom and Freeman (1990); Borjas, Freeman and Katz (1992)].

Since our exploration in this study considers trade-induced technology flows, we confine ourselves to a brief review of studies that touch on the trade-technology nexus. The influential researchers in this line are Wood (1994, 1995), Wood and Ridao-Cano (1999), Krugman and Lawrence (1993), Krugman (1997), Lawrence and Slaughter (1993). Of them, Krugman (1997) presents a stylized 'semi-realistic' CGE model and found in his numerical simulation that trade has shifted the distribution of income from less to more skilled labour—the effect, however, being of modest magnitude i.e., wage inequality in the North has risen by about 3% over the last two decades as a result of North-South trade.

Wood (1995) argues that growth of manufacturing exports from newly industrializing countries in Asia explains most of the rise in the earnings gap throughout most of the DCs. Wood (1999) covers the analysis for the LDCs in South Asia and finds evidence of rises in inequality in earnings there. His conclusion was that erosion of unskilled to skilled relative wages could be attributed to North-South trade in its entirety. However, Bhagwati and Kosters (1994) find that rising wage dispersion in the USA and other DCs is mainly accounted for by technological change; and is not due to the effect of foreign competition as such. As Feenstra and Hanson (1996, p. 240) argue,

> "….the current trade-versus-technology debate obscures a more fundamental question about how firms respond to import competition and how these responses, in turn, are transmitted to the labour market."

They consider a model incorporating outsourcing of production into 'discrete activities allocated across countries' and its effect on occupational types. Haskel and Slaughter (1998) find that rising skill premia during the 1980's in the USA and UK correlate strongly with sector-bias in technological change favouring skilled-labour intensive sectors. Galor and Moav (1999, p.1) observe that this type of technical improvement can be called 'ability-biased technological transition'.

Because increased openness to trade involves flows of new technologies via imported goods embodying superior state-of-the-art, it is to be noted that trade and technology arguments are hard to disentangle. The present critique enters the fray at this point. We argue that human capital induced AC and skill formation facilitate adaptation of technological improvement embodied in imported intermediate inputs. As will become evident, in our proposed synthesis the interaction between technology spillover and the labour market (including wage differentials) is via the channels of AC and SS. However, technical change can be skill-biased as well.

So far we have given a broad overview of the literature on the nexus between technology and growth with special emphasis on human capital. In this discussion, we have not considered ongoing research on knowledge creation aspects of economic growth. Although there are some overlaps between the paradigms identified above and the literature related to innovation, we give a separate brief review of a representative model of such genre. This is owing to the fact, as will be seen below, that this model considers technology creation, its diffusion via trade and measurement in a dynamic general equilibrium framework.

3.3 Dynamic general equilibrium models of invention and growth

The models developed by Grossman and Helpman (1991a, 1991b), Young (1991), Jones(1995) have explored the possible interlinkages between invention, technology diffusion, learning and growth and productivity. Models of this genre also have focussed primarily on the advanced countries. Amongst those models of recent vintage, the ones developed by Eaton and his co-workers have also an empirical dimension. Eaton and Kortum (1999) model world growth where innovation is fully endogenous depending on the factors affecting R&D and diffusion. In another version of the model, technology creation is insulated from factors affecting research. This is *'semi-endogenous'* as opposed to the fully endogenous growth models. In the semi-endogenous growth models, there is room for technical change to occur exogenously. In fact, in Section 4 below we propose an analytical framework which belongs to the latter paradigm of models of new growth theory.

Eaton and Kortum (1994, 1996a&b, 1999) have analysed international technology diffusion and productivity differences across countries in multi-country, empirical, dynamic general-equilibrium models incorporating the elements of innovation and growth. Using data on international patenting and on productivity and research effort (for identifying diffusion patterns), they explored the forces underlying the process and concluded that, in the steady-state, all countries' growth rates 'eventually' converge. With a view to identifying the sources, destinations and benefits of diffusion of inventions, all three of the models cited are based on the same unifying conceptual framework of productivity, growth and patenting of R&D activities, or research efforts. We concentrate on their *empirical* dynamic general equilibrium model. Because it is operational, this model helps identify the underlying basic mechanisms of the paradigm. This research has focussed on the five leading innovative economies of the OECD and the diffusion of technology between them, and to the rest of the OECD. We discuss below the fundamental mechanism in brief.

In Eaton and Kortum (1996a, 1999), each country n (n=1,.....,N) produces a single output Y_{nt} at time t. This output may be traded internationally. Intermediate inputs are treated as a continuum, rather than as a discrete set, and are defined on the same interval [0, J] in every country. The variable ω locates a position on this spectrum and defines the "type" of intermediate input under consideration. Intermediate inputs cannot be traded internationally in this model. The nominal quantity of an intermediate input located at ω on the spectrum of inputs is denoted by $X_{nt}(\omega)$ and the quality of this input is $Z_{nt}(\omega)$, so that in units of constant-quality, the usage of intermediate input ω is $X_{nt}(\omega)Z_{nt}(\omega)$ in country n at time t.

The production function is the continuous analogue of Cobb-Douglas with constant returns to scale (CRTS) and may be written as

$$\ln Y_{nt} = F[Z_t(\omega), X_t(\omega)] = \int_0^{\omega} \ln X_t(\omega) Z_t(\omega) d\omega \qquad (1.1)$$

It is assumed that the only technology used at ‘t’ in ‘n’ is the ‘state-of-the-art’ then current in that country; thus below $Z_{nt}(\omega)$ indicates state-of-the-art (rather than an arbitrary) level of technology then available.

The intermediate inputs $X_{nt}(\omega)$ are produced according to a conventional (discrete) CRTS production function which is identical across all values of ω, n and t. It is via the impact of the stock of available ideas on the values of $Z_{nt}(\omega)$ that the effects of technological diffusion are evidenced in the output of any given country. A country can affect this stock by choosing the proportion of the workforce employed in knowledge producing activity. Of course, to varying extents, such knowledge flows (with a lag τ_{ni} from source ‘i’ to ‘n’) to other countries, and also affects their productivity. This transborder diffusion of ideas occurs through the conduit of foreign trade.

It is not the fact that all new diffused ideas will be actually implemented. But better quality ideas $q(\omega)$ would always be used by displacing the current ‘state-of-the-art’ $Z_{nt}(\omega)$ provided $q(\omega) > Z_{nt}(\omega)$. For any discussion involving LDCs, it would be interesting to explore the relationship between quality of ideas $q(\omega)$, diffusion lags τ_{ni} and the *actual adoption* of a new technology. This interest is motivated by the fact that country-specific factors (e.g. level of skills, competence, and hence ability to adopt ideas) influence the speed of diffusion ε_{ni}. This has been set aside in this model.

Now, the workforce L_{it} in any country ‘i’ at time t consists of people of heterogeneous research acumen although they are equally productive in production of inputs. Researchers generate a flow of new ideas $\alpha_{it} s^{\beta}{}_{it} L_{it}$ where α_{it}, s_{it} and β respectively are the overall productivity of research effort, research intensity (the fraction of L_{it} engaged in research) and an adjustment factor to account for declining productivity with the use of less talented labour as less able workers are progressively drawn into the research establishment. The diffusion of ideas at the rate $\dot{I}_{nt}$ from all sources of research i=1,...,N augment the stock of ideas I_{nt} in country ‘n’ at time ‘t’. Thus, we can write

$$I_{nt} = \int_{-\infty}^{t} \dot{I}_{ns} ds \qquad (1.2)$$

I_{nt} determines the "technology frontier" $H_n(Z_{nt};t) = H_n(I_{nt})$ for any country 'n'.

The producers of intermediate inputs of various qualities act as price-setting oligopolists with Bertrand conjecture. Faced with the same wage rate w_{nt} and cost of capital r_{nt} in country 'n', and hence the same unit cost of production c_{nt} for producing inputs, they charge different prices p_{nt} for different new ideas $q_{nt}(\omega)$ varying across the spectrum $\omega \in [0,J]$. The producer of each "type" charges a quality-adjusted price $[q_{nt}(\omega)/Z_{nt}(\omega)]c_{nt}, \forall n \in (1,\ldots,N)$ which is less than the marginal cost (MC) of its closest rival producing the prevalent (i.e., about to be replaced) state-of-the-art (whereas the rival charges its marginal cost). Thus, in every country at each point of time there is a single producer of a quality 'type' capturing the entire industry market as a monopoly.

The price varies as does (q/Z) across the spectrum $\omega \in [0,J]$. However, this type of competition implies a mark-up M(ω) over *c* depending on the extent of quality improvement. M(ω) varies proportionately across input ranges as (q/Z) varies for each $\omega \in [0,J]$. Now, $p(\omega) = M(\omega).c$. With unitary expenditure elasticity of demand in the input market (a consequence of the homothetic production relationship), and identical expenditure on each input, the supplier of this input will neither increase, nor decrease the price. It is to be noted that 'each input' means the collection of input 'types' on an interval of arbitrary length (say Ξ), where Ξ is chosen such that [J/Ξ] is the number of equal-length segments into which the input spectrum is broken. It is a property of the production function that cost minimization with Y and prices of the X(ω)'s exogenous leads to each interval on the input spectrum having an equal share in cost. The inputs with minor quality upgradation have lower $M(\omega) = p(\omega)/c$ than those with substantial improvements. Thus, with low M(ω) and hence low p(ω) for those inputs, such inputs, being used in greater quantity, will attract larger inputs of labour and capital.

In the face of potential risks of imitation, the inventor of an idea will seek patent protection. Of course, he has to bear costs of patenting f_{nit} in destination 'n' at time 't'. The originator, having no idea about either the quality of competing inputs elsewhere, or τ_{ni}, calculates the expected discounted value of the right to use the idea with and without patenting as given respectively by $V_{nit}^{patent}(q,Z)$ and $V_{nit}^{notpatent}(q,Z)$. Thus, if $V_{nit}^{patent}(.) \geq V_{nit}^{notpatent}(.)$, a patent is demanded with the "cut-off" quality level $\bar{q}_{nit}$ being determined by the condition

$$V_{nit}^{patent}(q,Z) - V_{nit}^{notpatent}(q,Z) = f_{nit} \qquad (1.3)$$

V_{nit} depends on profits accrued using q>Z, on the degree of patent protection and on the probability of diffusion. The number of patents P_{nit}, however, depends on the rate of diffusion of ideas from 'i' to 'n', and on $\overline{q}_{nit}$. The inventor country also considers all the expected returns across all n=1,...,N over the possible competing qualities q in recipient n to evaluate expected return as

$$V_{it} = \sum_{n=1}^{N} V_{nit} \qquad (1.4)$$

Equilibrium in the labour market determines the research intensity in any 'i' where workers equate their wages earned in producing $X_{it}(\omega)$ with the value marginal product (VMP) of labour involved in research i.e.

$$w_{it} = \beta\alpha_{it} s_{it}^{\beta-1} V_{it} \qquad (1.5)$$

This, in turn, determines corresponding level of R&D in that country.

With the same w_{it} and r, the producers employ the same $(K/L) = k$ ratio and the aggregate output in country 'i' is given by equation (1.6) below

$$V_{it} = F[K,L,t] = A_{it}.F[K,L] = A_{it}k_{it}^{\phi}L_{it}(1-s_{it}).\kappa_1(\theta)/\kappa_2(\theta), \qquad \dot{A}_{it} \geq 0 \qquad (1.6)$$

where total factor productivity (TFP) is proportional to productivity growth and $\kappa_1(\theta), \kappa_2(\theta)$ are respectively constants relating a productivity index to the wage rate and the average value of the inverse of M(ω). The equation system (1.2), (1.3) and (1.5) describes the dynamic equilibrium of the model and evolution of the technology state variable I_{nt} in any n.

Such an economy 'n' will move along a steady-state path when the stock of ideas I_{nt} determining that country's frontier of technology grows at a constant rate $g = \dot{I}_n / I_n$. As all ideas are not necessarily potentially adaptable or suitable to 'n' and sometimes as a rapid rate of growth compared to the rate of diffusion makes them vulnerable to obsolescence, the ideas that are actually used after diffusion is a fraction $\left({\varepsilon_{ni}}\big/{\varepsilon_{ni} + g}\right)$ of those available ideas. The world stock of knowledge at time ‘t’ is given by $\bar{I}_t = \sum_i I_{it}$ whilst country ‘i’s own stock of knowledge is I_{it}.

We present a general taxonomy and flow chart à la Eaton and his co-workers in Figure 1.1 below.

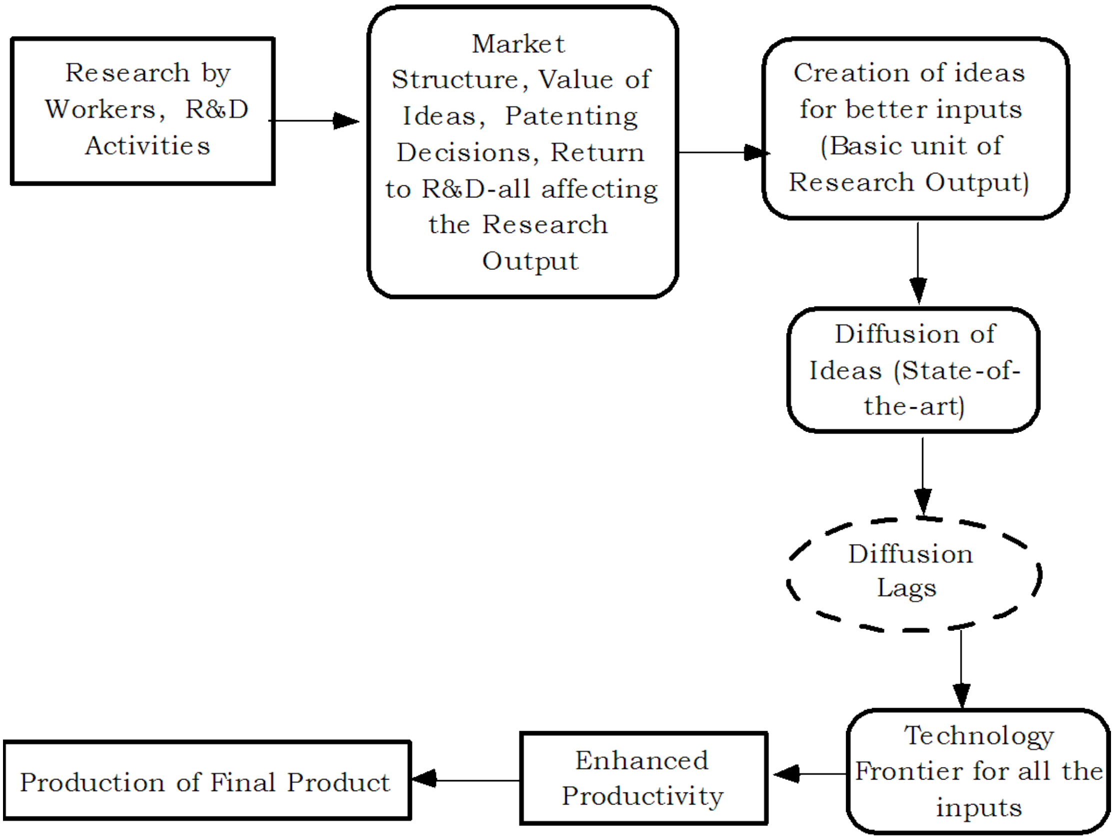

Figure 1.1: Flow chart for basic Eaton and Kortum framework

Assuming that relative productivity of researchers in any ‘n’ is proportional to the level of technology there relative to technology in a given benchmark country N, and to the global knowledge-stock, it can be shown that this relative productivity is proportional to country n’s stock of ideas relative to that of the benchmark country; i.e. $A_{nt} / A_{Nt} = (I_{nt} / I_{Nt})^{\eta}$ where η is a parameter of the quality distribution. Growth of productivity is proportional to the diffused stock of ideas. In the steady-state, when s_{it} and g are constants, the ratio of patented ideas to those adopted is also constant and is determined by the threshold quality level for patenting and I_{nt} at time ‘t’. Although research produces a huge pool of ideas, the imperfect diffusion due to patenting, lags and technology gaps hindering the capability of adopting them, may lead to cross-country differences in productivity levels. Nonetheless, the multiplicity of unexploited ideas of high quality gives scope for the relatively lagging countries to utilise them. The other two papers develop the same ideas with minor variations. The authors' 1994 paper was a first attempt towards empirical general equilibrium modelling of technology diffusion and the later two papers draw heavily on it. In Eaton and Kortum (1996), they developed an analogous model and concluded that relative productivity levels rather than their growth rates indicate a country's ability to innovate or to imitate new ideas. This model differs from the former in its "specifications of diffusion" where they postulated a linear relationship between the adoption of the diffused ideas and distance between source and destinations, own stock of ideas, trade patterns, and level of human capital. They inferred that for DCs diffusion occurs more within than between countries with distance and human capital affecting its absorption.

The idea of adoption of diffused technology is intricately related to the capacity to assimilate it which has been treated *exogenously* in these models and this is particularly important for any discussion involving LDCs. In the following subsection, I describe the underlying mechanism of a model of relatively recent vintage where attempts have been made to capture some of these factors. The model is based on a work by Hans van Meijl and Frank van Tongeren [henceforth, referred to as MT (April 1997, 1998)]. In fact, this will relate to the scope of further extension of the framework. The following section elaborates the overall analytical framework.

To implement ideas about the potential importance of AC and SS empirically, we need a suitable model of international trade flows. Van Meijl and Van Tongeren (1997, 1998) give the lead here; they chose the Global Trade Analysis Project (GTAP) [3] model for their analysis of trade-embodied diffusion of technology. GTAP is a comparative-static, multi-sectoral, multi-regional computable general equilibrium (CGE) trade model which provides a suitable framework to analyse the issue of embodied technology transmission via traded material inputs in a global context.

3.4 Comparative Static Computable General Equilibrium Modelling (CGE) Framework:

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[3] GTAP is a multi-regional, multi-sectoral global CGE model [see Hertel ed. (1997)].

In the strands of CGE modelling, the paper by MT is a stepping-stone for modelling issues of technology transfer from the innovating countries at the frontiers of technology creation to the relatively laggard recipient countries within the multi-regional CGE framework of the Global Trade Analysis Project (GTAP) model. To quote them, "[it] is perhaps best regarded as an *initial* step" (p.39, ibid.) in operationalizing the issues of endogenous embodied technology spillovers. The basic idea is that knowledge about improved production technologies or current state-of-the-art is embodied in traded goods. Technology spills over to the receiving countries through the bilateral trade linkages. MT postulate a 'technology spillover function' envisaging a functional relationship between the factor productivity growth rates in innovating country 'r' and in innovation-receiving destination 's'. Focussing on agricultural innovation, this functional specification relates factor productivity growth rates to traded agricultural inputs (intermediates). The technological innovation in agriculture, by its very nature, introduces some primary factor biases- viz. land-saving innovations via the innovations in chemical inputs and labour-saving innovations via the innovations in transport equipment and agricultural machinery. This primary factor bias is crucial in 'economizing' on a country's relatively scarce factors of production because, given the situation that technology flows from 'r' to 's', the accrual of potential gains owing to the spillovers depends on the recipient's ability to *effectively* use them in increasing the outputs with the same or lower costs of production. The effective utilisation of the ideas generated abroad and embodied in traded agricultural inputs hinges crucially on human capital related *absorption capacity* (AC) and on structural characteristics in land-use patterns; i.e., land/labour ratios in 'r' and 's'. It is argued that "local" or domestic usability of the foreign technology depends on the destination's capacity to identify, procure and use the diffused state-of-the-art. This is captured by MT's human capital induced AC-index which carries both a source and a destination affix.

Since the focus of MT's analysis is primarily on agriculture, structural features like land/labour ratios, endowments, climate, soil, ecological conditions of countries, to list a few, are also important for effective assimilation of the diffused technologies via bilateral trade. For convenience, the term *structural similarity (or congruence)* (SS) will be used to describe MT's measure of similarity between source and destination countries. Thus, MT identify two apparently different sets of factors influencing acquisition of foreign technologies. For effective utilisation of the latest state-of-the-art, both of these factors should enter into the ‘technology spillover function’. They jointly determine the productive efficiency of foreign technology transmitted from ‘r’ to ‘s’.

As in the EK model, in MT, trade acts as a conduit of technology flows. They make use of global data on bilateral trade flows available in the GTAP database. But unlike EK, MT incorporate essential elements of AC and SS factors in determining domestic usability of foreign technologies. Denoting productivity growth rates of ‘r’ and ‘s’ as a_r and a_s respectively, MT’s spillover hypothesis is captured by a technology spillover function given below

$$a_s / a_r = \gamma (E_{rs}) \qquad (1.6)$$

where $0 \le E_{rs} \le 1$ is the index of received amount of embodied knowledge in bilateral trade linkages between ‘r’ and ‘s’, and γ (.) is the knowledge spillover coefficient.

More specifically, $\gamma(E_{rs}) = E_{rs}^{1-\delta_{rs}}$, $0 \le \delta_{rs} \le 1$ (1.7)

δ_{rs} is the parameter determining the efficiency or productivity of the embodied knowledge transferred via bilateral trade flows from ‘r’ to ‘s’. The innovating country’s source of productivity growth captured by a_r is based on exogenous R&D investments or productivity shocks. The realised productivity level from the potential streams is dependent on $\delta_{rs} \in [0,1]$ with $\delta_{rs} = 1$ implying full realisation of the foreign technology induced productivity growth. The ‘binary’ AC-index H_{rs} and the structural similarity index D_{rs} between pairs of regions ‘r’ and ‘s’ interactively determine the productive efficiency parameter δ_{rs} as below:

$$\delta_{rs} = H_{rs} . D_{rs} \qquad (1.8a)$$

so (1.7) can be written as

$$\gamma(E_{rs}) = E_{rs}^{1-H_{rs}.D_{rs}} . \qquad (1.8b)$$

Therefore, the fundamental equation governing the technological spillover in MT is given by

$$a_s / a_r = E_{rs}^{1-H_{rs}.D_{rs}} . \qquad (1.9a)$$

Empirical implementation of this equation depends on the types of goods considered and the data-base at hand. E_{rs} for sector i's final product is defined as the ratio of bilateral trade flows (X_{irs}) from 'r' to 's' in final product sector 'i' and total flows ($\sum_s X_{irs}$) to *all* destinations 's' from the source 'r'. Hence, we can write (1.9a) as

$$a_s / a_r = \left[X_{irs} / \sum_s X_{irs} \right]^{1-H_{rs}.D_{rs}} \qquad (1.9b)$$

When knowledge is embodied in inputs, assuming that technological progress in sector 'i' in country 's' comes with the inputs produced in sector 'j' that are exported from 'r' to 's', in MT's model

$$E_{irs} = \frac{X_{jrs} / Y_{is}}{Y_{jir}{}^{d} / Y_{ir}} \qquad (1.9c)$$

where X_{jrs} = bilateral trade flows of input 'j' exported from 'r' to 's',

Y_{is} = production of sector 'i' in country 's',

Y_{jir}^{d} = domestic inputs of sector 'j' delivered to sector 'i' in source country 'r',

Y_{ir} = production of sector 'i' in country 'r'.

In (1.9c), the denominator represents domestic input-output coefficient of the inputs from the innovating sector j in the production of activity 'i' in origin 'r' and the numerator is the input-output coefficient of foreign-supplied inputs from the innovating sector in production of activity 'i' in the destination. E_{irs} measures, thus, the relative amount of embodied technologies per unit of output that a sector 'i' in the destination country receives from the innovating foreign input producing sector 'j'. To be precise, it accounts for inter-industry spillovers within a country as well as between countries.

In MT's model, H_{rs} is specified by the function

$$H_{rs} = \min\left[1, \frac{h_s}{h_r}\right] \qquad (1.10)$$

where h_s and h_r are respectively the indices of human capital (HK) in 'r' and 's'. This specification implies that the human capital related AC-index is determined by the shortside of the HK-availability. Structural similarity 'D_{rs}' is based on the difference in the land/labour ratios of agricultural production between 'r' and 's', i.e., it is defined as

$$D_{rs} = \exp\left[-\text{absolutevalue}\left(\frac{l_r - l_s}{d_{max}}\right) \right] \qquad (1.11)$$

where l_r, l_s are respectively the land/labour ratios normalized by the largest absolute difference in such ratios found between all possible pairs 'r' and 's' (d_{max}). For a very large differential between l_r and l_s, D_{rs} tends to zero exponentially. The production technology tree in the GTAP model uses a nested production function. The idea is that at the top level, a Leontief composite output Y is produced with fixed proportion technology using intermediate inputs Q_{ij} and a primary input composite Q_v. At each nesting branch, the production function involves shift parameters A_o, A_e, A_{ij} allowing for Hicks Neutral Technical Progress as well as biased technical change. This allows us to write, the production function for output as

$$Y = A_0 \min\left[A_{i1}Q_{i1}, \ldots. A_{in}Q_{in}; Q_v\right] \qquad (1.12)$$

Q_v is produced using CES technology; i.e.,

$$Q_v = \left[\sum (A_e Q_e)^{-\rho}\right]^{-1/\rho} \qquad (1.13)$$

where $e \in \{\text{land, labour, capital}\}$ and $-1<\rho<\infty$ is the substitution parameter. Each Q_{ij} is a CES composite of domestic and foreign inputs distinguished by country of origin (using the Armington assumption as in standard GTAP model).

Flow Chart 2 depicts the basic M-T model.

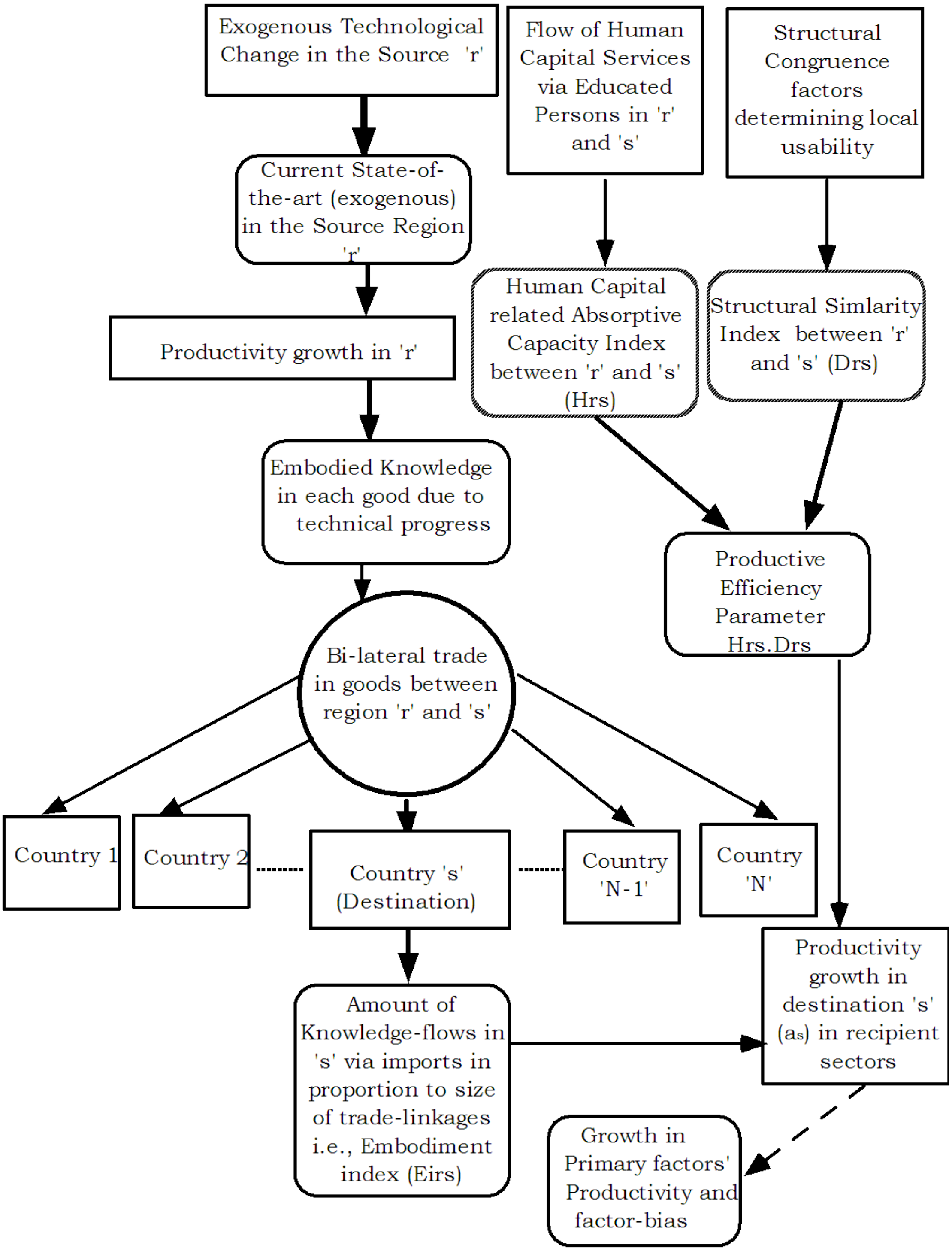

Figure 1.2: Flow chart for schematic presentation of van Meijl and van Tongeren's work

As will be evident from our discussion below, the essential problem of technology absorption hinges on the ‘AC’ of the *recipient* countries. In other words, once the new technologies are generated in the source country, the *effective assimilation* of the technology embodied in imports by the destination depends on its *own* AC so that H_{rs} is not necessarily a 'binary' index. In the following section, we document the extension of the analysis by providing a synthesis of the insights gained from the literature. To summarize: MT take productivity growth in the innovating country as "exogenous" and analyse the effective utilisation and resultant productivity growth in the destination country via transmission of knowledge through bilateral trade linkages, human capital induced AC, and structural congruence.

4. Scope for Extension and Refinements: General Taxonomy for A Synthesis

Since we ascribe AC to human capital embodied in skilled personnel, and since the skilled labour share in total labour payments in the GTAP database is positively correlated with educational attainment [see Das (1999)], the skill content of the labour force is a reasonable proxy for AC. Moreover, on this basis one can develop a model where the absorption capacity parameter is an endogenous outcome of the firm-level decision-making process; this implies that the capture of productivity benefits at the sectoral level is contingent on the choice of the appropriate input-mix and trade intensity whilst making the production decisions. This illustrates the fact that trade-technology interaction and AC analysis can have implications for occupational composition in the labour market.

As discussed in Section 3.3, in Eaton and Kortum (1996a), the technology level (A_{nt}) depends on the stock of ideas (I_{nt}) for any 'n' at time 't' given by a proportional relationship involving Euler's constant (≈ 0.5772):

$$A_{nt} = e^{\eta .0.5772} . I^{\eta}{}_{nt} \qquad (1.14)$$

where η is a constant parameter. A_{nt} is a scalar measure of the productivity level (or productive efficiency in a Hicks-Neutral sense).

In Eaton and Kortum, each A_{nt} corresponds [according to (1.14)] to a unique value of the stock of ideas I_{nt}. To introduce *absorptive capacity* into their model, we need to break this 1:1 link, and replace it with one in which the stock of ideas variable I_{nt} only defines the *maximum* productivity level. Different values of A_{nt} will now lie on an interval $\left[0, A_{nt}{}^{\max}\right]$. Each point $\xi \in \left[0, A_{nt}{}^{\max}\right]$ locates a technology level among a range of possible values of which A_{nt}^{max} is the greatest. A_{nt}^{max}, being determined by the diffused 'state of the art', is the most advanced technology that is potentially available to 'n'. Whilst country n in principle has access to the technology which delivers a productivity level of A_{nt}^{max}, only with perfect absorptive capacity would such a result be achieved. In fact, the realised technology level A_{nt}^{actual} from the stream of potentials $A^{max}{}_{nt}$ depends on the absorptive capacity of the destination proxied by the function R(V). V is a vector of variables capturing the constellation of factors influencing AC. Thus, we can replace equation (1.14) by

$$A_{nt}^{max} = e^{\eta .0.5772}.I^{\eta}{}_{nt} \qquad (1.14a)$$

where I_{nt} is the corresponding knowledge-stock accumulated over history at time 't'. It can be postulated that

$$A_{nt}^{actual} = R(V).A_{nt}^{max}, \qquad 0 \le R(V) \le 1 \qquad (1.15)$$

R(V) $\in$ [0, 1] with R(V) = 0 implying no absorption and R(V) = 1 implying perfect absorption. Assuming non-inferiority of the components, we can infer R′(V)>0. The function $R(V)$ becomes more tractable if it is treated in two stages. In the first, the determinants of AC combine to produce a scalar index $R^* = H(V)$. $R^*(.)$ may be a Cobb-Douglas, CES, CRESH, Translog, or other suitable scalar function of the arguments V. The second stage simply transforms R^* to a variable R that is bounded in $(0,1)$. A suitable function is the logistic such that

$$R(R^*) = \frac{1}{ae^{bR^*} + 1} \qquad (1.16)$$

with the property that $\partial R / \partial R^* > 0$, globally, and $\partial^2 R / \partial R^{*2} > 0$, then $\partial^2 R / \partial R^{*2} = 0$; while finally $\partial^2 R / \partial R^{*2} < 0$. Assume that there are n factors affecting R so that

$$V = V(v_1, \ldots, v_n) \Rightarrow R(V) = R(v_1, .., v_n)$$

From the discussion above of the basic structure of the MT model, however, it is evident that their formulation involves the source and destination-specific 'AC' and 'SS' indices, H_{rs} and D_{rs} respectively. H_{rs} takes into account the human capital index in the source as well as in recipient region. The arguments for an interaction between human capital in source and destination countries seem weak. Thus, it is sensible to make AC destination-specific only. The arguments for source specificity are stronger in the case of structural similarity since countries with similar factor proportions will find it easier to use the same technology than will countries with disparate input structures. Therefore, the AC function is specific to the recipient country only so that $R^* = H(V)$ is a destination-specific scalar index. To incorporate into the GTAP framework the notion of *destination-specific* 'absorptive capacity' and to give an operational definition of it, one needs to consider the factors propelling its acquisition.

The question is to identify the candidate elements of 'V' in equation (1.15) above. We postulate that a high level of 'human capital' (HK) makes it easier to absorb newer ideas discovered elsewhere. To increase AC, it may be necessary to increase the general educational level. Success in assimilating foreign technology depends crucially on human capacity to choose and adapt (from the stock of available ideas) in consonance with the local environment. This aspect of human capacity can be proxied by the literacy rate, or the enrolment rate in schools, or by the volume of research undertaken.

Secondly, infrastructural bottlenecks in the LDCs may act as impediments to the development of AC and also make the recipient more structurally dissimilar compared to the source than is nominally the case. In fact, this inadequacy may have been a major disincentive to the technology leaders to supply the latest state of the art to such countries. The necessary infrastructure includes the provision of communications networks, transportation, arrangements at the governmental level designed to reduce the 'geographical and technological' distance between the sources of research and the destinations, the provision of financial facilities for undertaking research and development, to name a few. At any time, the provision of infrastructure generates a flow of services that is important for production. Increasingly sophisticated technology, to be adopted, may demand upgrading and growth of the infrastructure. At a basic level, the infrastructure might be characterized as a function of per capita availability of energy, credit, transport and communications facilities. As well, qualitative differences between available infrastructure in different countries might be captured by dummy variables.

Third, learning via the recent adoption of new technologies enhances AC. Command over technology as a result of technological learning usually involves a relatively large number of people simultaneously working and gaining experience.

Learning effects encompass learning by doing, by which experience in the production of a good, as well as various interactions among the workers in the production process, lead to an improvement in the level of competence of workers and hence, in turn, affect AC. This enhancement of AC through accomplishment of learning and gathering of experience over time contributes to productivity. The learning effect is realised by dint of experience with production using relatively recent technologies. Therefore, we may measure it by a suitable index number which accumulates real output over the last several years with output weighted by a measure of how recent was the technology used.

Fourth, AC is accumulated over past history as well as through present R&D efforts undertaken at the firm/industry level. Effective absorption of spillovers from the sources requires own research efforts to acquire technological capabilities so that one can implement the newer ideas to achieve higher productivity. While there is ample scope for drawing from a large pool of ideas in an integrated world, an importer of technology may need to undertake in-house R&D in order to have sufficient understanding to be able to apply the imported ideas. Sometimes, the knowledge-capital produced by the sources is not particularly suitable for the local conditions. Skills related to exploitation of the ideas, plant operation and maintenance and quality control are normally required for an *effective* implementation of know-how. To meet the local conditions, changes and adjustments are sometimes necessary in order to use locally available inputs in production. Own R&D efforts are important for developing the requisite knowledge, skills and experience within the recipient firms/industries so that it can help in effective utilisation of diffused ideas; or, in other words, own R&D contributes not only to the stock of available ideas, but also directly to absorptive capacity.

Also, M-T do not distinguish between '*stocks*' and '*flows*' dimension of the relevant variables. In order to investigate the role of these four factors in affecting technology absorption, this distinction is important. It is due to the fact that investment in physical as well as research capital generates a 'stock' of the services from which services flow over short, medium, or long- run facilitating the absorption. All these flow variables combine in stage one to yield the AC function $R_j^*\left(V_j\right) = R_j^*$ for any country 'j', $j \in n = 1,2,\ldots.s,\ldots N-1,N$. Then the scaling logistic function transforms R^* to a variable $R \in [0,1]$ in the second stage. This gives the absorptive capacity $R(V)$ in country '*j*'. Technology absorption function $G\left[R(V), A^{\max}{}_{nt}\right]$ determines the realised technological level or technology frontier via equation (1.15) where $R(V)$ defines AC depending on the four factors and structural index encapsulated in V.

Now the increased stock of ideas flows gradually through embodied and/or, disembodied spillovers. From the foregoing discussion, AC is proxied by skill intensity. Each person-hour of effective labour can be conceived of as a combination (vector) of skilled labour and raw labour. We can define composite primary factor inputs of land, capital and effective labour via a suitable production technology. This composite primary input, the composite intermediate inputs (composite of foreign and domestic intermediate in another CES nest), and $\mathrm{A}_{\mathrm{s}}^{\mathrm{actual}}$ combine to yield the Gross output Y_{s} in the destination. At the top level, the production function is Leontief in these composite primary and intermediate inputs yielding Y_{s}. The technology absorption function $\mathrm{R(V).A}_{\mathrm{nt}}^{\max}$ determines the realised technological level or technology frontier via equation (1.16).

All told, we see that meaningful exploration of embodied technology transmission and its absorption can be suitably studied in a general equilibrium framework. Despite differences in approach and methodology, the models developed by EK and MT elicit the underlying mechanism behind technology transfer. Taking MT's study as a starting point, we have offered here a synthesis of our ideas with those studies. As has been noted in Section 3.3, following Eaton and Kortum (1999), the extension sketched in our analysis belongs to the genre of semi-endogenous growth models. The next section spells out the concluding observations following from our analysis.

5. Concluding Remarks

We analyse the issue of technology transmission and its assimilation into the general equilibrium framework. Our analysis draws heavily on methodologically appealing *applied* general equilibrium framework. In particular, we confine our discussion within the issue of technology transfer embodied in traded intermediates, the role of AC and SS in facilitating technology absorption and also the implications of embodied technology transfer in a CGE framework. All of the above ideas relating to absorptive capacity appear in one form or another in the works of Eaton and others; however, they do so at the top of the knowledge creation-diffusion chain. It is better to identify influences that are better handled lower in the chain. This is motivated by the observation that while LDCs may have access to a stock of relatively modern technological ideas, they may not have the capacity to absorb them. By this we mean that even if the ideas could (in principle) be profitably applied at the going relative prices, local firms simply cannot apply them, or cannot apply them at maximum potential. We have sketched above an operational approach (via estimation/calibration of the function V and R) towards measuring absorptive capacity and structural congruence. This differs from (but broadly similar to) the approach adopted in the work by Meijl and Tongeren in both the specification as well as definition of the 'Absorptive Capacity'. In order to gain insights about the policy implications for developing countries, this approach has to be embedded within an empirical general equilibrium framework with necessary modifications

Our exploration is based on some stylized facts on total factor productivity growth, on human capital and on the composition of trade as documented in the published sources. It is simpler and convenient to use a stripped-down version of the GTAP framework and set up a model that investigates the effect of a Hicks-neutral total factor productivity (TFP) shock in a unique source region (for example, in USA) and traces its impact on the other regions. Using a minimally dimensioned version facilitates getting across the underlying mechanisms without the added complexity of commodity disaggregation and of a large number of regions. The regions can be chosen on the basis of their perceived level of growth and development. This will elucidate the role played by *AC* and *SS* in technology assimilation and demonstrate that exogenous technical progress in one region can have very uneven impacts on the productivity of recipient regions.

On the theoretical plane, extension to multi-sectoral analysis involves specification of sectoral indexes of technological embodiment and modification of the structural equation for technology transmission. The source sector for TFP growth in a sector of interest and the magnitude of the TFP shock in this sector has to be taken from history. Experiments can focus on the following: analysing the effects of the exogenous technological shock in the sector with technical progress in the donor country (i) on itself; (ii) on the clients; and (ii) comparison of inter-sectoral differentials in the magnitude of capture-parameter for assimilation of the transferred technology.

As noted earlier, we relate AC to human capital embodied in the labour force. The Version 4 and 5 of the GTAP database provide us with disaggregation of labour payments by two levels of skill. However, the split of labour payments in the GTAP database is made on the basis of the educational attainment of working-age persons. There is no provision for substitution between the two labour types in the GTAP's existing production structure. With technology transfer, there is scope for substitution possibilities between skilled and unskilled labour types (essentially in the longer run). In Das (1999), we reconcile alternative data sources on educational attainment with the GTAP database's [Version 4] disaggregation of labour payments and derive the 'implied' substitution elasticity between skilled and unskilled labour in a production-theoretic framework. In particular, we propose a Constant Elasticity of Substitution (CES) nest of two categories of labour and find the implied substitution elasticity to be in the range 0.67 to 0.83. This estimated elasticity of substitution could be used [see Das (2000)] where GTAP's extant production structure is modified to accommodate the CES nesting of skilled and unskilled labour. More specifically, effective labour is a CES composite of the two categories of labour where the elasticity of substitution is in conformity with our interpretation of Version 4 of the GTAP database.

As a further extension of the analysis suggested before, it can be postulated that the benefits of a higher *AC* may be taken into account by representative firms when choosing their input mix. In particular,: (i) *AC* increases with the intensity of skilled labour in the input mix; and (ii) *SS* increases with higher capital intensities. This, unlike MT's formulation, adds new elements of endogeneity in the model. Thus, major extensions could be determining endogenously a sectoral AC and SS indexes whereby SS (proxied by physical capital per unit of total effective labour) and AC (proxied by skill intensity) combine to deliver the productivity benefits to the representative firms.

Our suggestions are limited to international trade —only one of the conduits through which technology flows from developed to less developed countries. The main other candidate is foreign direct investment (including joint ventures). Also, the adoption of a convention on Intellectual Property Rights (IPRs) as part of the Uruguay Round of GATT has put in place systematic global norms covering (inter alia) patents and copyrights, for almost all fields of technology. Thus, relatively new institutional factors have become an important issue for the study of technology transfer. This is another area for furthering the analysis.

We have noted that the feasibility of sustained growth depends not only on diffusion of newer ideas, but also on the sustained rate of absorption of those ideas. Absorption capacity has been defined as depending on the level of human capital only. Human capital can be proxied by the literacy rate, by the enrolment rate in schools or by more sophisticated attempts to measure the skill content of labour. This may be done by (for example) compiling estimates of highest qualifications attained – with quality adjustment for the program imparting the skills – plus appropriate allowance for on-the-job experience. The availability of such data (for example, Barro-Lee (1993)) should eventually improve substantially our ability to model the role of absorption capacity.

We have not taken stock of the dynamic aspects of technology diffusion and its absorption: hence its focus tends to be static. A first pre-requisite for a more dynamic treatment of the subject is to establish a database on *stocks* (as well as *flows*) of the relevant variables, especially knowledge capital. This would then allow both an endogenous treatment of R & D, and integration of the global trade model with models of educational investment in the various regions. Clearly this is a development which will be beyond the resources of any single researcher (and probably beyond the resources of any one institution). But improved data of the sort mentioned in the previous paragraph will allow a start to be made.

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