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Ability-Biased Technical Change and Productivity Bonus in a Nested Production Structure: A Theoretical Model with Endogenous Hicks-Neutral Technology Spillover

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Abstract

This paper develops a model of endogenous trade-mediated productivity spillover in which jointly trade-intensity, capital-intensity of production, and skill-intensity for adoption of technology from an exogenously available stock of world knowledge determine firm's productivity. The representative firm, in the process of maximising profit (or minimising costs), takes into account the benefits of technological improvements embodied in imported intermediates. Sectors with higher skilled labour intensity will have an advantage in extracting the 'bonuses' from spillovers. The framework is useful for exploring technology adoption, considering wage premium, investigating innovative changes in sectors, and analysing productivity differences.

Keywords: productivity bonus; technology spillovers; absorption; congruence; trade; skill; CGE nesting.

JEL classification: D58; O47; O33.

"What is it about modern capitalist economies that allows them, in contrast to all earlier societies, to generate sustained growth in productivity and living standards? What is central, I believe, is the fact that the industrial revolution involved the emergence (or rapid expansion) of a class of educated people, thousands – now many millions – of people who spend entire careers exchanging ideas, solving work-related problems, generating new knowledge." – Robert E. Lucas Jr. (2009a, p. 1)

1. PROLOGUE AND LACUNAE IN THE LITERATURE

With the ongoing process of globalization and rapid technological change, empirical evidence shows an upsurge in global trade, especially in new manufactured products and services intensive in technology and skill requirements. There are evidences that propensity to trade affects technological diffusion and with demand for human capital for its adoption, industrial demand for skill rises whereas structural factors determine patterns of comparative advantage. Human capital-induced skill formation and technological progress can be

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conceived as a mutually reinforcing joint process creating persistence in innovation, and productivity bonus (Acemoglu, 2009; Aghion and Howitt, 2009; Galor, 2011; Maddison, 2001, 2008). Eapen (2012) links absorptive capacity (AC) of the recipients to cohesive social structure based on social network or ties for facilitating transfer and search for foreign technologies. Additionally, Che (2012) finds that the extent to which a country's industrial structure aligns with her factor-endowments and factor accumulation fundamentals (such as, human, ICT, or physical capital) – *i.e.*, *structural coherence* –positively affects economic growth and hence, could explain inter-country growth differentials. Drawing on them, this paper formulates *a decision-making process* to integrate these elements where trade-link proxies external exposure, resource-endowment differentials encapsulate the structural features, and skill-intensity represents inherent capabilities. Ours value-addition lies in formalising technology capture as an amalgam of trade-led technology diffusion, structural features, and skills in a model with nested production. We investigate: *How does a firm with given characteristics, when faced with an advanced foreign technology causing changes in economic environment, consider the skill-content of the labour and structural factors for coping with the technology diffusing globally?* The framework demonstrates that productivity differentials could be attributed to differences in structural factors and AC.

Stylized facts based on Global Trade Analysis Projects (GTAP) global database show that for each region, at the micro or *sectoral level*, the share of skilled labour in the wage bill for a sector is positively associated with that sector's trade share in total regional trade and also positively associated across regions with total factor productivity (TFP) improvement (Das, 2002; Jones and Romer, 2010). Starting from Coe and Helpman (1995), the interest in exploring the North-South trade-mediated 'indirect' spillover has culminated into a series of papers analysing the relative merits of technology flows via trade-embodiment, FDI and 'direct' disembodied flows *via technological proximity*. Mahlich and Pascha (2007, p. 2), in the context of 'newly advanced economy' of South Korea, has mentioned that: "for the period 2003-2012 about two-fifths of growth will have to be achieved through productivity increases. Another 0.6 percentage point may be realised through raising quality of labour in terms of human capital increases." Jones and Romer (2010) offer vistas of research exploring the interactions between increased market integration and four state variables, namely: ideas, human capital, population and institutions for explaining cross-country growth rates.

In a dynamic model, Acemoglu and Zilibotti (2001) attributed productivity differences between relatively skill-abundant developed countries (DCs) and unskilled-labour abundant less developed ones (LDCs) to technology-skill mismatch when technology is imported in LDCs. Acemoglu *et al.* (2006) offer a model with selection of high-skill entrepreneurs for innovation and adoption of frontier technology rather than over-indulgence in investment strategy. Benhabib and Spiegel (2005) model interaction between distances of 27 LDCs from the technology frontier of the DC (USA), where it is shown that with logistic pattern of technology diffusion, lack of human capital causes divergences in productivity as it slows down TFP growth. However, Basu and Weil (1998) highlighted the importance of DC-LDC differences in factor proportions (capital-labour ratios). Considering a panel dataset of 19 DCs, Vandenbussche *et al.* (2006) models endogenous allocation of labour across adoption and innovation tasks, and empirically verifies that skill is instrumental for approaching the technology frontier. Galor (2011, p. 6) says: "variation in rates of technological progress has reinforced the differential pace of the emergence of demand for human capital."[1]

Now, the complementarity between skills and technology is evident at the micro/firm level and has often been attributed to skill-biased technical change (SBTC). The underlying assumption is that workers differ in the appropriateness of their skills to achieve any given productivity level with a particular vintage of technology. Importance of developing capabilities, indigenous skills and technological competence in solidifying the requisite skill base has been dealt at length (Jones and Romer, 2010; Lucas, 2009b, 2009a). Cunha and Heckman (2007) have shown that 'ability differences' could explain differences in socioeconomic successes and implementation of technology. Cosar (2011) models a skill-augmented technology adoption function via intermediate to account for income differences. As latest technology requires for its effective utilization a labour force with adequate human capital, the demand for and relative wage of skilled labour are expected to increase with the technological bonus taken into account. According to Acemoglu (2002) as supply of skilled-labor increases, *directed technical change* leads to induced invention of skilled-labour-complementing capital goods and generates skill premium. This paper adds value by offering an insight for cross-country productivity differences in a general equilibrium framework where technical, generic and '*soft*' skills (i.e., skills for social interaction or receptiveness) help firms to augment productivity via technology adoption. For the adoption process of the domestic firms, importance of network ties, interface with external environment (via trade and FDI) and information exchange via networks are crucial (Eapen, 2012).

For technology diffusion, the usual suspect is trade and FDI: trade ferries technology and technology facilitates trade. Jones and Romer (2010) has discussed the role of trade in increasing the extent of the market through increased flows of good and ideas facilitated by globalization. Plethora of papers have discussed about technology transmission, spillover of invention and its absorption (Das, 2002; Hoekman and Javorcik, 2006; Keller, 2004). Although there are diverse findings, overall, imports contribute to technology transfer via intermediates and capital goods embodying superior technologies (Schiff and Winters, 2003; Falvey *et al.*, 2004). OECD (2010) has documented the growth and importance of traded intermediates (80% and 50% for goods and services respectively). For imported intermediates as vehicle of knowledge transfer, empirical evidences abound. For example, Tang and Koveos (2008) has shown that IT cluster and trade, as compared to FDI, has larger impact on technology spillover from G7 to destinations. Papaconstantinou *et al.* (1996) has provided evidence that smaller countries source more than 50% of their acquired technology via imported intermediates and capital equipment with ICT cluster being the dominant source among the high-technology manufacturing sectors and services. By constructing imports and exports weighted foreign R&D-stock, Falvey *et al.* (2004) has shown in the context of the OECD that imports are dominant diffusion channel apart from exports. In fact, there are empirical evidences supporting the role of trade reforms on productivity via import competition and input effects. Generally, tariff reductions on both competing final goods and imported intermediate inputs enhance productivity; however, in case of the former import competition boosts productivity whereas in case of intermediate inputs, the mechanism occurs via learning, quality-effects, and variety. For Indonesian manufacturing during 1991-2001, Amiti and Konings (2007) has shown that 10 percentage point fall in tariffs on inputs caused 12% productivity gains (more than output tariffs) for firms inputting intermediates via foreign technology embodied in inputs.[2] Similarly, for Chile, Kasahara and Rodriguez (2005) has shown that imported inputs increased productivity by 2.3%. Using firm-level data for Hungary, Halpern *et al.* (2013) show that both capital imports and intermediate input imports are vehicles for cross-border technology diffusion with positive effect on productivity across and within firms by more than 2%. In case of R&D spillovers from developed to developing nations, also evidence exists that import of machinery and equipment contributes to R&D spillovers (Coe, Helpman and Hoffmaister 2009, 1997). In the same vein, Goldberg *et al.* (2010) has shown that for India in post economic reform after 1990s, increasing access to better quality foreign intermediate and capital goods enabled her to manufacturing output growth by 200% during 1989-2003 with greater variety. Presenting evidences from French firms, Bas and Strauss-Kahn (2014) mentioned channels such as complementarity of inputs, input cost savings, foreign technology transfer, and quality transfer through which imported inputs function, and showed that more varieties of imported intermediate inputs over 1995-2005 have caused 2.5% productivity gains and more export scope of varieties.

As trade reform causes more trade in imported inputs, it affects Value-added Trade (VAT) via effective rate of protection and hence, price of material inputs change causing more supply chain activities to flourish via outsourcing of material inputs.[3] Therefore, supply-chain trade encompassing three modes such as, importing to produce, importing to export and VAT, causes vertical specialization, and enables technology diffusion to the firms via globalization’s second unbundling thanks to information and communication technology (ICT) (Baldwin and Lopez-Gonzalez, 2014).[4] Robust findings of the effect of such modes of supply-chain on intensity of knowledge diffusion are discussed for a sample of 29 countries covering production networks in Asia, North-America, and Central-Eastern Europe for 2000-2008 in Piermartini and Rubinova (2014). they make use of database of international input-output tables for geographical distribution of foreign inputs.

Lucas (2009b) has modelled the role of trade in ‘ideas’ and its internalization or absorption via skill. By adopting a supply-demand-institution approach, Chusseau *et al.* (2008) show that both trade and (endogenous) SBTC interactively impact on inequalities. In a novel framework integrating multinational production and trade, Burstein and Vogel (2010) shows that with differences in Hicks-Neutral technology, extent of globalization has strong effects on skill premium for the sectors with production efficiency. Newer technology embodied in traded goods demands its own types of skills, and could cause wage inequality (Acemoglu, 2009). As mentioned by Lucas (2009b), the pattern and magnitude of these trans-border flows can be discerned via constellation of conducive parameters that enable superseding the ‘barriers to riches’ (Parente and Prescott 2002). As will be evident in Section 2, in our model the similarities/differences in skill-intensity and factor proportions implicitly encapsulate the (structural) propinquity/distance factor.

According to Galor (2011), the neoclassical exogenous and endogenous growth literature – focusing on centrality of factor accumulation, technical progress, and non-decreasing returns to scale – represents rather limited non-unified approach without unveiling the intricate growth patterns and underlying forces.[5] ‘Major methodological and conceptual innovations in the construction of a unified microeconomic framework’ is necessary for ‘*orchestrating*’ endogenous evolution of human capital, scope for trade and the extent of technology adoption while taking into account the structural characteristics (pp. 142-147, ibid.). Along this line, we consider structural congruence of two sectors – a binary measure involving comparison of structural characteristics of a sector in the source and the destinations – judged by the similarity of their capital intensities (physical capital per unit of effective labour force); the idea is that the technical knowledge in the advanced economies will be most ‘appropriate’ to the clients closest in terms of their primary factor intensities. Unified growth theory postulates that 'since the educated individuals have a comparative advantage in adapting to the new technological environment', altered economic environment, thanks to technological progress, raises demand for human capital (p.148, ibid.). As scope of expanded gains from trade looms large in general equilibrium adjustment in the wake of trade-led technology transmission, this is the starting point of this paper—to unravel the interlinkages in a Global Trade Model (GTAP) with intersectoral and inter-regional linkages via input-output relationships, which exemplifies the fundamental reason to formally model the quintessential ingredients. We assume that the share of skilled labour in total labour payment for a region and/or sector is an index of *AC*. At the macro level, given the *overall* human capital stock of a region and structural congruence with the trading partners, apart from the motives of comparative advantage, the regions participate in trade to reap the *technological bonus (TB)* out of trade flows. At the level of a sector, the question is to find out the "optimal" level of skilled labour for a sector so as to make the best use of the 'TB' obtainable from harnessing the technology. Technical progress in the foreign source is *exogenous*. This induces a *sectoral bias* into technical change in the sense that sectors with higher skilled labour intensity will have an advantage in extracting the 'bonus' from spillovers.

Ours is an attempt to assess these issues in a Global Computable General Equilibrium (CGE) model – GTAP. This paper fills the void by encompassing skill, structural symmetry, technology and trade and by furnishing that the interactions between relative wage and TFP changes as main vectors of impacts. Section 2 analyses the rationale. Section 3 models and Section 4 offers numerical illustrations. Section 5 concludes.

2. A MODEL OF BONUS EMBODIED SPILLOVER OF TECHNOLOGY (BEST)

In order to model the technology diffusion, we adopt a comparative static modelling framework based on CGE model. As we do not model the technology creation, human capital or skill acquisition process, we do not need to consider dynamics of R&D, investment in human capital for knowledge accumulation. Das (2005) has adopted a dynamic CGE model for technology transfer and assimilation for simulation of productivity shocks and its transmission. Hong *et al.* (2014) discusses that in case of R&D-based CGE models, for understanding endogenous TFP impacts it is necessary to incorporate R&D as an element in a dynamic framework; otherwise, exogenous factor-augmenting productivity is analysed usually in comparative analysis of baseline and policy-shock scenarios. Ours is a semi-endogenous model to decipher the mechanism where trade-induced technology embedded in foreign intermediates change the input-mix and the accrual of benefits from imported sophisticated inputs depends on skill-induced absorptive capacity. As our model does not model endogenous growth process and assumes exogenous technological change, adopting a comparative static mechanism does not undermine our objective of modelling the complementarities of skill constraints, structural coherence, and technological factors. This is supported in the literature; in fact, Lakatos (2011) developed a model with knowledge capital based product differentiation in the comparative static CGE model that we pursue in this paper and Batabyal and Beladi (2014) adopts a comparative static analysis. In this thesis we have not attempted to handle dynamic aspects of technology diffusion: hence its focus tends to be static, long run and partial in nature. Partial because the process of knowledge creation is exogenous; long-run because prices adjust fully to clear markets. A first pre-requisite for a more dynamic treatment of the subject is to establish a data base 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. However, intuitively speaking adopting a dynamic framework would enable us to understand the skill acquisition and technology assimilation process via human capital accumulation over time. In other words, in a dynamic model with endogenous technological progress and a spectrum of quality-ladder of imported intermediates, the firm's skill mix composition would change in a continuum and the model would offer intertemporal and spatial dimensions of technology diffusion embodied in trade.

The production technology tree in the 'CGE' model uses a *nested* production function (Hertel, 1997). To analyse the influence of the technological bonus motive on sectoral trade and skill intensities, we use a '*bottoms-up*' approach. Our starting point is a representative firm for a given sector located in a given region. We focus not only on the firm's attainment of a *least-cost* combination of inputs as in a conventional micro production function, but also on *endogenous changes in productivity* brought via technology transfer. The vital elements in the latter are skilled labour intensity (because it measures *absorptive capacity - AC*), physical capital intensity (because it measures *structural congruence - SS*), and the relevant index of trade intensity - *TR* (because it measures the *opportunities for capturing a technological bonus - TB*). Following the evidence discussed before, we infer that traded inputs could increase productivity via knowledge spillover, learning effects, higher quality, and induced innovation. Das (2010, 2014) has incorporated the aspects of trade-induced productivity enrichment in a separate modelling framework to highlight the joint roles of these factors. In fact, Alvarez *et al.* (2013) has shown that trade has a 'selection effect' when idea flows occur via learning through trade-interactions. Absorptive capacity of the destination is crucial for determining the input mix or technological improvement-bearing imported intermediates (Navaretti and Tarr, 2000). Along similar line, in the context of Uruguayan manufacturing firm Peluffo and Zaclicever (2013) has given evidence that imported intermediates affect productivity of the firms with a facilitating role of absorptive capacity proxied by skilled labor.

The higher is a sector's import trade intensity, for a particular degree of structural congruence between the source and the recipient, the higher is the *potential* endogenous technology transfer and, contingent on the skill intensity, and the higher should be the sectoral capture of the technology. The sectoral capture parameter is an amalgam of *skill intensity*, *structural congruence* and *trade intensity* defined at the level of the representative firm. Capture-parameter is an *endogenous* outcome of the firm-level decision-making process. The incentive of reaping 'TB' from embodied technology spillovers modifies the representative firm's choice of an optimal occupational mix of both categories of labour, capital, and material inputs. Thus, *the representative firm, in the process of maximising profit (or minimising costs), takes into account the benefits of technological improvements embodied in imported intermediate inputs. Capturing these benefits requires an appropriate mix of skilled and unskilled labour, which is recognized by the representative firm in its production decisions. Technological improvement in the source region and sector is exogenous in this theory which is restricted to the propagation of technology.*

We *assume* that 'TB' for a sector is achieved in three successive stages in consonance with the representative firm's static optimization exercise: [1] sectoral skill intensity, structural congruence and trade intensity in production of the sector combine to produce a scalar, binary sectoral capture-parameter; [2] this is scaled via a logistic transformation so as to lie within the unit interval, yielding the '*scaled magnitude of capture* (SMC)' for sector j;

[3] this 'SMC' subsequently transforms the potential productivity improvement in the origin of invention into an actual productivity bonus, accrued by a sector in the client region via the intermediates.

2.1 Specification of Production Technology

Assume the existence of a representative firm in each of the single-product sectors producing the n traded goods and use the terms 'sector' and 'firm' synonymously. Consider the set of industries indexed by j where j = 1, 2, …, n. Following is the list of notation used:

Y_j : Output of firm j

A_j : Hicks-Neutral Technology Progress (HNTP) Shifter in production function of firm j

K_j : Physical capital stock in use by firm j

L_j^h : Skilled labour in use by firm j

L_j^u : Unskilled labour in use by firm j

E_j : Effective (quality-adjusted) units of labour in use by firm j

T_j : Land used by firm j

V_j^c : Conventionally measured real primary factor composite in use by firm j

P_Y^j : Price of output Y_j

M_i^j : Intermediate input demand for i^{th} (top-level) Armington composite material used by sector j for current production where i = 1,…,n

M_j: Leontief composite of n Armington composite inputs M_1^j , M_2^j , …, M_n^j .

W_j^h : Wage rate of skilled labour in use by sector j

W_j^u : Wage rate of unskilled labour in use by sector j

W_j^E : Wage of composite labour unit in use by sector j

R_j^K : Rental price of capital in use by sector j

R_j^T : Rental price of land in use by sector j

P_i^{Mj} : Price of M_i^j going into the production of Y_j ,$\forall$ i=1, 2, …, n

P_i^{Dj} : Price of domestic good (D_i^j) going into production of M_i^j

P_i^{Fj} : Price of (lower level) Armington composite of imported goods (F_i^j) used in production of M_i^j

D_i^j : Domestically sourced intermediate input i demanded by firms in sector j.

F_i^j : Armington composite of imported inputs i demanded by firms in sector j.

CES_t^j be the Constant Elasticity of Substitution (CES) aggregator for sector 'j' of specific input types 't' in each nesting. r, s : regional subscripts where REG is the set of all regions, r, s $\in$REG.

TRAD_COMM: Set of traded commodities, s: Complementary set of Regions whose members are non-members of Set ‘r’.

Here, we have suppressed the regional affix for relevant sector ‘j’. In any region r, at the top level each ‘j’ combines a composite of primary factors viz., physical capital (K_j), land (T_j), skilled labour (L_j^h) and unskilled labour (L_j^u) with a Leontief composite of material inputs (M_j) to produce Y_j using fixed coefficient production technology where $j \in \{1, 2, \ldots, n\}$ belongs to the set of all produced commodities. Following *ex post* rationalisation of GTAP’s disaggregation of labour payment by skill level in Das (2002), we model two types of labour as substitutes in satisfying sector j’s labour requirements and propose a Constant Elasticity of Substitution (CES) aggregator so that *effective* (i.e., quality-adjusted) units of labour E_j for sector j are formed by aggregating labour-hours provided by skilled (L_j^h) and unskilled (L_j^u) labor categories. Thus,

$$E_j = \Gamma_E [\delta_h (L_j^h)^{-\rho_E} + \delta_u (L_j^u)^{-\rho_E}]^{-1/\rho_E} \tag{1}$$

where δ_h and δ_u are the distribution parameters in the CES aggregator so that δ_h+δ_u =1. Γ_E is the technical progress shifter for the effective labour composite. Recently, Mello (2008) has also proposed such nesting of skill types as imperfect substitutes to explain relative income variations. The substitution elasticity between L_j^h and L_j^u is $\sigma_E = \frac{1}{1+\rho_E}$, where $\rho_E > -1$. σ_E is assumed to be identical across uses and regions. The conventional primary factor composite V_j^c is produced combining land (T_j), effective labour (E_j) and capital (K_j). N_j is the demand for the primary factors in producing V_j^c where $N_j \in \{ T_j, E_j, K_j\}$. The production technology at this second level of Figure no. 2 is a CES value added function as given below:

$${}^{c}_{j} = A_V\{ \sum_{\forall N_j} \delta_{N_j} (N_j)^{-\rho_V} \}^{-1/\rho_V} \tag{2}$$

where δ_{N_j}'s are the distribution parameters (positive constants with sum equal to unity). The elasticity of substitution between the components of value-added for sector j is $\sigma_V = \frac{1}{1+\rho_V}$ which is assumed to be the same across all uses and regions.

The Armington composite indexes of material inputs of types i (i= 1, …, n) into j, M_i^j, are combined using Leontief technology to produce M_j; i.e., the composite of n material inputs going into the production of sector j's output. As regards the vector of (n) (top-level) Armington composite material inputs M_i^j, these are obtained *à la* Armington (1969) specification (Figure no. 3 below). Each composite element in the vector is determined by a CES aggregation function of domestically sourced intermediate input i demanded by firms in sector j (D_i^j) and a (lower level) Armington composite of imported varieties sourced from the other trading regions (F_i^j). Hence, each M_i^j is produced using D_i^j and F_i^j which are imperfect substitutes so that we write the nested CES Armington production structure for the M_i^j-nest as below:

$$M_i^j = A_M \left[\delta_F (F_i^j)^{-\rho_M} + \delta_D (D_i^j)^{-\rho_M}\right]^{-1/\rho_M}, \quad \forall\ i = 1, 2, \ldots, n \tag{3}$$

where $\sigma_M = \frac{1}{(1+\rho_M)}$ is the elasticity of substitution between F_i^j and D_i^j and $\rho_M > -1$. δ_F and δ_D are distribution parameters adding to unity.

2.2 Capture Parameter and Technology Bonus [TB]

2.2(a) Production Function for Capture Parameter

Here we direct attention to the determinants of TFP – HNTP parameter. We emphasize the role of sectoral skill intensity $\left(\frac{L_j^h}{L_j^u}\right)$ proxying human capital induced absorption capacity, physical capital intensity $\left(\frac{K_j}{E_j}\right)$ proxying the relevant structural characteristics of a sector j and sectoral trade intensity $\left(\frac{F_i^j}{M_i^j}\right)$ measuring the potential extent of embodied technology spillover.

In our formulation, the productivity of primary factors is affected by the technology embodied in traded inputs. V_j^c indicates the primary factor composite measured in conventional units, while $V_j^{effective}$ stands for the primary factor composite measured in constant-efficiency units.

Following our theoretical premise, the capture parameter for sector j is an amalgam of proxies for AC, SS and TR. AC for sector j is destination-specific whereas structural congruence SS retains both source and destination affixes. We have selected the capital-labour ratio as the most relevant characteristic for structural congruence (Acemoglu, 2009, pp. 623-625; Basu and Weil, 1998). Hence, structural congruence between source r and destination s for sector j, X^{C}_{jrs} (where r≠s), is measured by: $X^{C}_{jrs} = \exp\left(-\left[\frac{\left|X^{C}_{jr}-X^{C}_{js}\right|}{X^{C}_{jr}}\right]\right)$ where the X^{C}_{jq} ($X^{C}_{jq}>0\ \forall$ j, q) are the ratios of physical capital to quality-adjusted labour in region q (q = r, s). Note that $0 \le X^{C}_{jrs} \le 1$ with $X^{C}_{jrs}=1$ implying perfect structural congruence between r and s.

However, even with same SS mismatch between skill-intensity and requirements of advanced technology might cause reversal of fortune. Thus, skills of the workforce for clients along with capital-labor endowment ratios are important. Let r be any source of invention. Thus, AC for sector j in destination s (r≠s) is denoted as X^{A}_{js}. According to our definition, $X^{A}_{js} = \left(\frac{L^{h}_{j}}{L^{u}_{j}}\right)_{s}$.

TR is defined as the foreign composite intermediate input i used per unit of composite intermediate input i demanded by sector j in any region s. Thus, $X^{A}_{ijs} = \left(\frac{F^{j}_{i}}{M^{j}_{i}}\right)_{s}$, calculated for a fixed i for each using sector j in s, measures the commodity-i-specific trade intensity.

We define a binary, scalar capture-parameter (θ_{ijrs}) for sector j in destination s. Thus, the production function for θ_{ijrs} involves three components; viz., human capital-induced absorption capacity (X^{A}_{js}), structural congruence (X^{C}_{jrs}) and trade intensity (X^{T}_{ijs}) so that we write the production function for θ_{ijrs} as:

$$\theta_{ijrs} = Z\,(X^{A}_{js}, X^{C}_{jrs}, X^{T}_{ijs}) \tag{4}$$

For the first stage—the determination of θ_{ijrs} (before scaling into unit interval)—we choose a *Constant Ratios of Elasticities of Substitution, Homothetic* (CRESH) function (Hanoch, 1975) which combines the determinants X^{A}_{js}, X^{C}_{jrs} and X^{T}_{ijs} to yield a scalar index of technology capture (θ_{ijrs}). This functional form was chosen because it is *more flexible* than the Cobb-Douglas function (with all partial substitution elasticities set to unity) and the CES (with all such elasticities sharing a common value differing from one); on the other hand, it is relatively thrifty in its use of parameters. We adopted CRESH in order to leave open the possibility that the three substitution elasticities among the pairs of determinants of θ_{ijrs} take different values[6]. In the present context, different substitution elasticities among trade intensity, human capital intensity, and structural congruence is plausible and adopting CRESH form as the underlying specification for an empirical model (in a CGE framework) allows elasticities to differ from each other and from 1 (see Hertel *et al.*, 1991 and Dixon *et al.*, 1982). Particularly, the implicitly additive functional form is useful in nonlinear CGE models like GTAP. Under the CRESH specification, there is no *closed-form* representation of Equation (4); i.e., we cannot write an explicit functional form for Z. Assuming non-inferiority of components and constant returns to scale [CRTS] to

X^A_{js}, X^C_{jrs} and X^T_{ijs}, we write the implicitly additive CRESH production function for the capture parameter (θ_{ijrs}) below:

$$\sum_n \left(\frac{\nu_n}{\omega_n}\right)\left(\frac{X^n}{\theta_{ijrs}}\right)^{\omega_n} = \tau \tag{5a}$$

where $X^n \in \{X^A_{js}, X^C_{jrs}, X^T_{ijs}\}$ and ν_n, ω_n and τ are parameters with $\nu_n \geq 0$ and $0 < \omega_n < 1$, $\forall$ n = A, C, T. We also assume that ν_n and τ are normalised so that $\sum_n \nu_n = 1$. Z is homogeneous of degree zero in the *scale* of input levels and homogeneous of degree one in the *intensities*. This leaves the overall production structure homogeneous of first degree, but with *TFP dependent via θ_{ijrs}* on the three intensities. Also, we note that the *marginal rate of technical substitution* between any pair of determinants say, X^n and X^m (n≠m) (keeping the remaining factor and θ_{ijrs} constant) decreases as we increase $\frac{X^n}{X^m}$. The logarithmic differential form of Equation (5a) is written as:

$$\bar{\theta} = \sum_n \frac{\nu_n\left(\frac{X^n}{\theta_{ijrs}}\right)^{\omega_n}}{\sum_m \nu_m\left(\frac{X^m}{\theta_{ijrs}}\right)^{\omega_m}} \times x^n \tag{5b}$$

where $\bar{\theta}$ denotes the *logarithmic differential* in θ_{ijrs} i.e., $\bar{\theta} = d\ln\theta_{ijrs}$ and x^n is the logarithmic differential in X^n. The expression on the right hand side of Equation (5b) is the '*Divisia quantity index*' for θ_{ijrs}. The second stage simply transforms the capture-parameter θ_{ijrs} into a variable Ω_{ijrs} that is bounded in the *unit* interval:

$$\Omega_{ijrs} = G(\theta_{ijrs}) = \frac{a\theta^{\kappa}_{ijrs}}{a\theta^{\kappa}_{ijrs} + 1}; \quad \theta_{ijrs} > 0,\ a > 0 \text{ and } \kappa > 0 \tag{6}$$

with the property that $\frac{\partial G}{\partial \theta} > 0$, *globally*, and $\frac{\partial^2 G}{\partial \theta^2} > 0$ for low values of θ, then $\frac{\partial^2 G}{\partial \theta^2} = 0$; while finally $\frac{\partial^2 G}{\partial \theta^2} < 0$ for high values of θ_{ijrs}. The value of Ω_{ijrs} will be referred to as the *scaled magnitude of capture (SMC)* for technological improvement occurring in sector j of region s as a result of that sector's use of intermediate input i imported from region r. When $\theta_{ijrs} \to \infty$ (i.e., an indefinitely large magnitude), $\Omega_{ijrs} \to 1$ implying fully realised technological bonus; when $\theta_{ijrs} \to 0$ (i.e. a very small number), $\Omega_{ijrs} \to 0$ implying no absorption. The constant '*a*' in Equation (6) does not have any economic interpretation as such; however, for a given set of values of κ and θ_{ijrs}, higher values of 'a' lead to a larger magnitude of Ω_{ijrs}. Given the same magnitude of *a* and θ, the higher is κ, the higher is the firm's efficiency in harnessing the productivity 'bonus' via the capture parameter[7]. In the next stage, Ω_{ijrs} transforms the embodied productivity spillover into an actual productivity bonus (Ξ_{ijrs}). Subsequently the values of Ξ_{ijrs} are aggregated over the source sectors i and source regions r to derive the overall sectoral bonus for recipient j in any destination s ($\Xi_{\bullet j \bullet s}$).

The logistic function Ω_{ijrs} is depicted below in Figure no. 1.

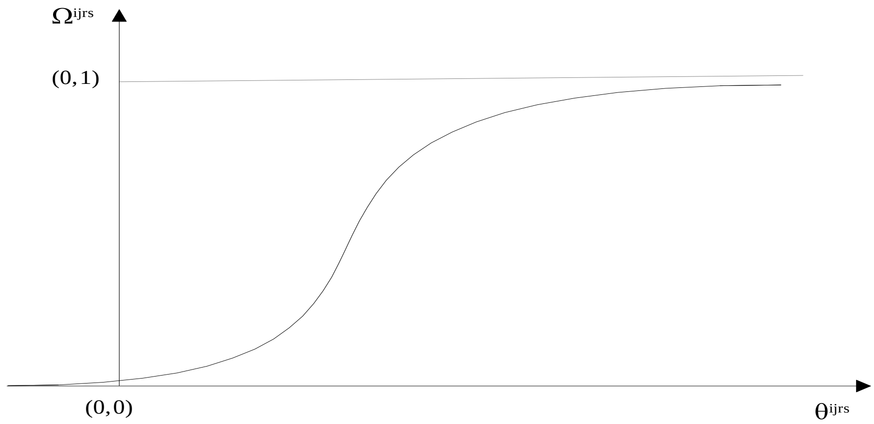

Figure no. 1 – Logistic transformation of capture parameter for SMC bounded in unit interval.

2.2(b) Nature of Technological Change-led Bonus

Technical progress occurring in the source is *exogenous*.[8] Let A_{ir} be the exogenous HNTP coefficient in source r.[9] Now $A_{ir} \in [0, A_{ir}^{max}]$ where A_{ir}^{max} is the *maximum* potential productivity level deliverable to the recipients. Depending on the extent of technological improvements, the source will have whole array of productivity augmentation. Sector j in recipient s (r≠s) has, in principle, access to the technology A_{ir}^{max}; however, the actual productivity bonus for sector j in s will depend on the magnitude of its scaled capture-parameter Ω_{ijrs} as not all of this panoply of technological improvements is realized by the recipients. The productivity bonus in the recipient is actual realization of the potential productivity levels depending on capture-parameter and its components.

Let Ξ_{ijrs} be the technological bonus reaped by sector j in s from traded intermediate i sourced in r via the SMC (Ω_{ijrs}). Then, we can write the equation for technology transmission from i in source r to recipient j in s as

$$\Xi_{ijrs} = \Omega_{ijrs} \times A_{ir} \quad , 0 \leq \Omega_{ijrs} \leq 1 \tag{7}$$

Given $A_{ir} \in [0, A_{ir}^{max}]$ and given regional shares of imported inputs, as SMC (Ω_{ijrs}) goes up, so does the actual productivity bonus (Ξ_{ijrs}). However, determination of the productivity bonus realized by sector j in s from *all* sources is obtained in two successive stages: firstly, the bonus due to imports of commodity i by sector j (i≠j) in a destination region s ($TB_{ij \bullet s}$) is expressed as a weighted geometric mean over all source regions as:

$$\Xi_{ij \bullet s} = \prod_{r \in REG\_NOT\_s} \Xi_{ijrs}^{m_{irs}} \tag{7a}$$

where m_{irs} is the market share of source r in the aggregate imports of tradeable i in recipient s evaluated at market prices; subsequently, a weighted geometric mean of $BEST_{ij \bullet s}$ ($\Xi_{ij \bullet s}$) is taken across all imported intermediate inputs to deduce sector-specific $BEST_{\bullet j \bullet s}$ ($\Xi_{\bullet j \bullet s}$) for j in region s. Hence, we can write

$$\Xi_{\bullet j \bullet s} = \prod_{i \in TRAD\_COMM} \Xi_{ij \bullet s}^{b_{ijs}} = \prod_{i \in TRAD\_COMM} \Big(\prod_{r \in REG\_NOT\_s} \Xi_{ijrs}^{m_{irs}} \Big)^{b_{ijs}} \tag{7b}$$

where the weights b_{ijs} are the shares of aggregate imports of tradeable commodity i used by sector j in s in total imports by j in s.

2.2(c) A Modified Production Structure incorporating TB

Figure no. 2 depicts the production structure. In what follows we will write $TB_{\bullet j \bullet s} \equiv \Xi_{\bullet j \bullet s}$ simply as $TB_j \equiv \Xi_j$. Following our discussion in Section 2.2(a), primary factor composite (measured in efficiency units) $V_j^{effective}$ available for production of final output Y_j, is a product of the productivity bonus component ($BEST_j$) and the input of the conventional primary factor composite (V_j^c):

$$V_j^{effective} = V_j^c \times TB_j \tag{8}$$

Therefore, the production function for sector j, a Leontief combination of inputs of composite materials (M_j) and effective inputs of primary factors composite ($V_j^{effective}$), is written as:

$$Y_j = A_j \min \left[A_j^M M_j, V_j^{effective}\right] \tag{9}$$

where A_j^M is a technological coefficient associated with M_j.

2.2(d) Optimization Exercise: Underlying Rationale

Following our specification, interdependencies between conventional generic inputs and the Ξ_j component entering into the production function are crucial in determining the level of Y_j. Under the conventional production structure, let $Y_j^* = A_j \min [A_j^M M_j, V_j^c]$ which implies

$Y_j^* = A_j\, A_j^M\, M_j = A_j\, V_j^c$. Under the modified production structure, Ξ_j is independent of changes in scale of all inputs and hence, the production technology is also Constant Returns to Scale (CRTS) in all the composite input types. Thus, the final output Y_j in the *modified* production structure is:

$$Y_j = Y_j^* \times \Xi_j = \gamma\,(L_j^h, L_j^u, E_j, K_j, T_j, M_j) \tag{10}$$

where γ is *homogeneous of degree one* in all the conventional inputs. Taking total logarithmic differentials of (10), we get

$$d \ln Y_j = d \ln Y_j^* + d \ln \Xi_j \tag{11}$$

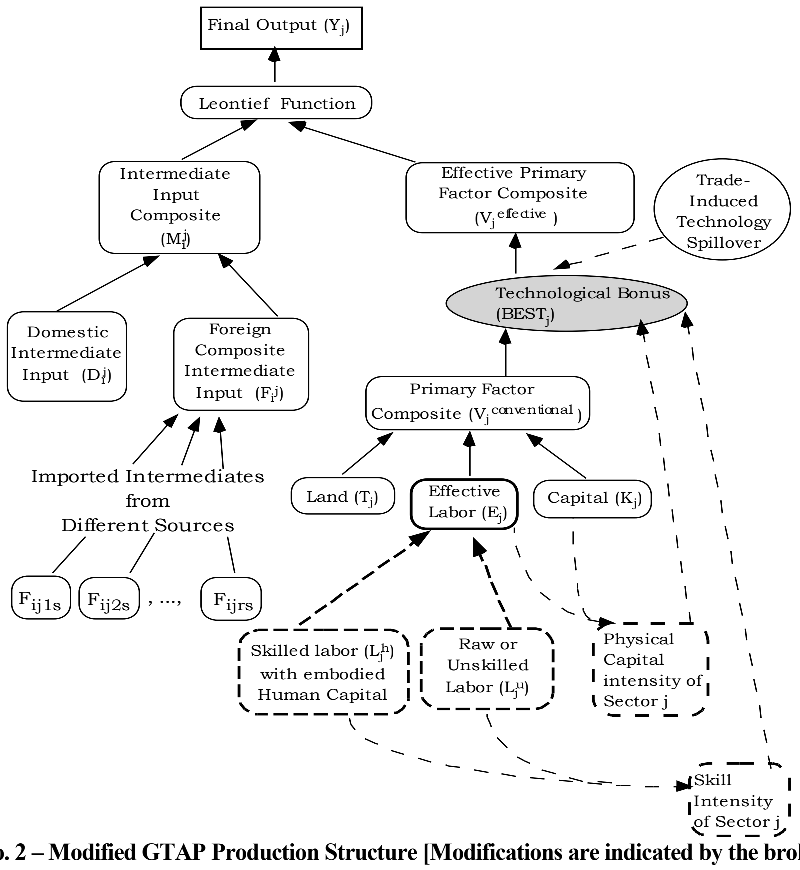

Figure no. 2 – Modified GTAP Production Structure [Modifications are indicated by the broken lines]

Thus,

$$d \ln Y_j = \sum_i \left(\frac{\partial \ln Y_i^*}{\partial X_i}\right) dX_i + \sum_i \left(\frac{\partial \ln \Xi_i}{\partial X_i}\right) dX_i \tag{12}$$

where X_i is i-th generic input and $X_i \in \{ L_j^h, L_j^u, E_j, K_j, T_j, M_j\}$. For the Leontief fixed proportions production function, necessary condition for cost minimization is dictated by technologically fixed coefficients and it yields[10].

$$Y_j = A_j A_j^M M_j \tag{23}$$

and

$$Y_j = A_j V_j^{effective} \tag{34}$$

Although at the top level the input composition is determined by fixed technological coefficients, the firm decides the composition of the aggregate inputs M_j and V_j^c. In this extension of GTAP, however, there is *interdependency*[11] between the effective primary factor composite and material input composite via the term Ξ_j.

2.2(e) Optimization in Composite Intermediates Nest

The optimization problem faced by firm j is to choose a particular combination of foreign-composite intermediate (F_i^j) and domestic intermediate (D_i^j) for a specified level of M_i^j in keeping with a stipulated level of Y_j. Note that there is a 1:1 mapping between M_i^j and Y_j because of the Leontief assumption ($\bar{Y}_j = A_j A_j^M M_j$). Thus, the firm seeks to minimize the cost of producing composite material inputs in the light of given prices of D_i^j and F_i^j.

Now, any movement in the relative prices of D_i^j and F_i^j will trigger substitution between them. This will entail changes in the trade intensities and hence will result in a change in the magnitude of the capture parameter. Suppose that the price of imported composite intermediates rises. Despite the relative price movement against F_i^j, the incentive of reaping a technological bonus through imported intermediates means that the price change will not cause as much substitution in favour of D_i^j as it would have in the conventional case. This is because primary factor productivity declines as the trade intensity of intermediate inputs falls. In order to compensate for this lower productivity, more primary factors must be used if output is to remain steady at a specified level. We illustrate the argument in Figure no. 3.

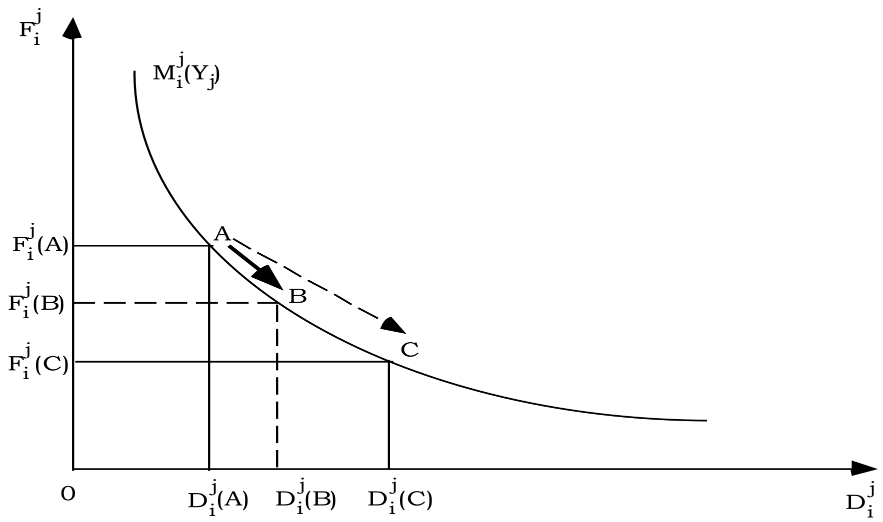

Figure no. 3 – Cost-minimization in twin cases: with and without the trade-induced technology bonus

First consider the case of a conventional technology without trade-induced technological bonus. Let A $[D_i^j(A), F_i^j(A)]$ be the initial choice of input combination for producing M_i^j consistent with a pre-determined final output level Y_j. At point A, the trade intensity for this specific level of Y_j is given by $\left(\frac{F_i^j(A)}{M_i^j}\right)$. Suppose following the impingement of some external shock, the price of F_i^j goes up (relative to the price of D_i^j). Assume that this leads the firm to substitute D_i^j for F_i^j so that it reaches the new position at C $[D_i^j(C), F_i^j(C)]$ whilst remaining on the same isoquant. With fixed M_i^j, this implies a decline in $\left(\frac{F_i^j(C)}{D_i^j}\right)$ and hence, in trade intensity $\left(\frac{F_i^j(C)}{M_i^j}\right)$.

According to the technological bonus hypothesis, a movement along the isoquant from point A to point C entails a reduction in trade-induced technology spillover. Here, although firm j uses the *same* level of M_i^j, trade intensity falls and hence, Ω_{ij} will also fall. This will diminish the 'bonus' Ξ_j and the consequent fall in $V_j^{effective}$ will lead to a diminution in the final output level Y_j unless more primary factors are used. With due cognizance of this 'trade-off', the firm will not substitute the relatively cheaper D_i^j for the dearer F_i^j to the same extent as it would have in the conventional case. *Thus, the firm would not move as far as point C in the diagram; rather, it would choose a point in between A and C, say B.* Given the fixity of Y_j at $\bar{Y}_j$, B $[D_i^j(B), F_i^j(B)]$ is the firm's cost-minimizing position. Clearly, at the intermediate position 'B', the firm reaps a higher 'bonus' than that at C because trade-intensity at 'B' $\left[\text{i.e.,}\ \frac{F_i^j(B)}{M_i^j}\right]$ is higher than that at 'C'.

Suppose by moving along the isoquant from A to C the firm saves dF_i^j and purchases an additional dD_i^j units of domestic intermediates. This saves $(dF_i^j.PF_i^j)$ dollars but costs the firm $(dD_i^j.PD_i^j)$ dollars. But, to maintain fixed Y_j $(\bar{Y}_j)$, the firm has to purchase additional value-added composite (say, dV_j^c) to compensate for the fall in primary factor productivity. Assume that firms are price-takers in the markets of primary factor inputs so that there is no change in the prices of the constituents of V_j^c and hence that dV_j^c is contributed by equi-proportional changes in K_j, E_j (hence in L_j^h and L_j^u) and in T_j. If PV_j^c is the price of composite V_j^c, additional expense borne is $(dV_j^c.PV_j^c)$. Hence, we can rewrite the following as the condition for remaining on a given *iso-cost plane*:

$$-dF_i^j.\ PF_i^j = dD_i^j.\ PD_i^j + dV_j^c.\ PV_j^c \qquad \text{(i)}$$

With the movement in relative prices as shown in Figure no. 3, $dF_i^j<0$, while dD_i^j and $dV_j^c>0$.

From (13) and (14), we can write:

$$\bar{Y}_j = A_j\ A_j^M\ M_j\ = A_j\ V_j^c \times \Xi_j \qquad \text{(ii)}$$

From (ii), taking total differentials, we obtain (on the isoquant)

$$d\bar{Y}_j = 0 = A_j.(\Xi_j\ dV_j^c + V_j^c d\Xi_j) \qquad \text{(iii)}$$

Because M_i^j is fixed, we can write:

$$dM_i^j = 0 = S_D\ dD_i^j + S_F\ dF_i^j \qquad \text{(iv)}$$

where S_D and S_F are respectively the value shares of D_i^j and F_i^j in M_i^j and $S_D+S_F = 1.$[12]

Now, from (i), we obtain after rearrangement of terms,

$$\frac{dF_i^j}{dD_i^j} = -\left[\ \frac{PD_i^j}{PF_i^j} + \frac{PV_j^c}{PF_i^j}\frac{dV_j^c}{dD_i^j}\ \right] \qquad \text{(v)}$$

where for the moment we regard the differentials d(•) as finite and generated in an environment in which M_i^j remains fixed. We observe that $dV_j^c = -\frac{V_j^c d\Xi_j}{\Xi_j}$ which leads us to write equation (v) as

$$\left.\frac{dF_i^j}{dD_i^j}\right\rfloor_{\bar{Y}_j} = -\frac{PD_i^j}{PF_i^j} + \left[\frac{d\Xi_j}{dD_i^j}\frac{PV_j^c}{PF_i^j}\frac{V_j^c}{\Xi_j}\right] \tag{vi}$$

We now take the limit of (vi) as dD_i^j becomes infinitesimally small, obtaining

$$\left.\frac{\partial F_i^j}{\partial D_i^j}\right\rfloor_{\bar{Y}_j} = -\frac{PD_i^j}{PF_i^j} + \frac{\delta\Xi_j}{\delta D_i^j}\frac{PV_j^c}{PF_i^j}\frac{V_j^c}{\Xi_j} \tag{vi-a}$$

where $\frac{\delta\Xi_j}{\delta\Xi_i^j}$ is the limiting quotient of the incremental change in TB_j when D_i^j moves from A to B in Figure no. 3. The left-hand side of equation (vi-a) is the limiting value of the slope of the isoquant at point B in Figure no. 3. The additional term in the bracket (which reflects the movement from C to B) can be attributed to the dependence of primary factor productivity on trade intensity. Since domestically sourced intermediates do not embody the foreign improvement of technology, the 'bonus' per unit increment of D_i^j diminishes as D_i^j increases so that the sign of the differential quotient $\left(\frac{\delta\Xi_j}{\delta\Xi_i^j}\right)$ is negative. For simplicity we consider the case in which there is a unique source of such improvement, namely, industry i in region r (r≠s). Thus, (7) is written as

$$\Xi_{js} = \left(A_{ir} \times \Omega_{ijs}\right)^{b_{ijs} \cdot m_{irs}}$$

where r and s denote relevant fixed source r and destination s respectively.[13]

3. FIRM'S STATIC OPTIMIZATION PROBLEM

Assume that the representative firm j is perfectly competitive in factor input markets. The production function is assumed to be *strictly quasi-concave* with non-negative input and output levels. Because imported material inputs can change the productivity of (conventionally measured) primary factors, the technology used becomes *endogenous*. Thus, to minimize the cost of producing a given output, the representative firm must take into account changes in the position and slope of the isoquant map brought about by changes in the input mix which it selects.

For a given P_Y^j and Y_j, the revenue $R_j = P_Y^j Y_j$ is fixed. Cost of production for firm j is given by

$$C_j = W_j^h \,.\, L_j^h + W_j^u \,.\, L_j^u + R_j^K .K_j + R_j^T .T_j + \sum_{i=1}^{n} PM_i^j .M_i^j \tag{45}$$

Therefore, profit is given by:

$$\Pi_j = R_j - C_j \tag{15a}$$

The problem facing the firm j is:

$$\text{Maximize } \Pi_j \text{ subject to } Y_j = A_j \min [A_j^M M_j, V_j^{effective}]$$

This formulation captures the idea that profit-maximization implies cost-minimization at the profit maximizing level of output. If the profit-maximization is conceived to be achieved in two stages, then the underlying model of optimal behaviour can be formulated in terms of the following *nested* optimization problem:

$$H_j = \max_{\{Y_j\}} \Big(P_Y^j . Y_j - \min_{\{L^h, L^u, K, T, M_1, \dots, M_n\}} \Big\{ \big[W_j^h . L_j^h + W_j^u . L_j^u + R_j^K .K_j + R_j^T .T_j + \sum_{i=1}^{n} PM_i^j .M_i^j \big] \;\; \textit{subject to } Y_j = A_j \min (A_j^M M_j, V_j^{effective}) \Big\} \Big) \tag{15b}$$

Thus, at any given level of output, cost is minimized; the output level (Y_j) in principle would then be selected to give the highest profit once the minimum cost is determined parametrically as a function of the output level. That is, in the inner nest, minimum cost $\hat{C}_j$ is determined as a function of output [$\hat{C}_j = \hat{C}_j(Y_j)$] with exogenous prices of inputs and output. In the outer nest, Y_j would be varied to maximize Π_j. $\hat{C}_j$ obviously depends on the output level Y_j as it does in the standard theory of the firm under CRTS.[14] The value of Y_j will subsequently be determined in the general equilibrium. The one-period constrained cost-minimization problem faced by the representative firm j in a typical year is formalised as: choose D_i^j and F_i^j (i.e., the component inputs of composite commodities M_i^j, ∀ i= 1,2,…, n), E_j, T_j, K_j and inputs of labour classified by skill categories (i.e., L_j^h and L_j^u) to minimize total cost of production of j (C_j). That is, we wish to minimize

$$C_j = W_j^h L_j^h + W_j^u L_j^u + R_j^K K_j + R_j^T T_j + \sum_{i=1}^{n} (P_i^{Dj} .D_i^j + P_i^{Fj} . F_i^j) \tag{16}$$

with respect to L_j^h , L_j^u , K_j, T_j, F_i^j and D_i^j (i = 1, …, n)

subject to a fixed activity level

$$Y_j = A_j \min [A_j^M M_j, V_j^{effective}] \tag{17}$$

Because the Leontief form of the production function (17) is non-analytic, on the assumption that inputs are not costless, the optima must be located at the corners of isoquants; that is

$$Y_j = A_j A_j^M M_j = A_j \Xi_j V_j^c \tag{18}$$

We will use $A_j A_j^M M_j$ for Y_j in the objective function, and enforce $\{A_j A_j^M M_j = A_j \Xi_j V_j^c\}$ via side-constraints. But first, all these expressions must be written in terms of the choice variables $\{L_j^h, L_j^u, K_j, T_j; F_i^j, D_i^j \ (i = 1, ..., n)\}$. Let CES_t^j be the Constant Elasticity of Substitution (CES) aggregator for sector 'j' of specific input types 't' in each nesting where 't' refers to labor, primary factor composite and intermediate inputs nest. Using CES_E^j to indicate the labour aggregator (1), CES_{PF}^j to indicate the primary factor (PF) aggregator (2), and CES_{Mj}^i to indicate the Armington aggregator of imported and domestic material inputs i (i = 1, ..., n), we write the input decision problem as follows:

Maximize $$Y_j = A_j A_j^M \ CES_{Mj}^1 (F_1^j, D_1^j) \tag{19}$$

subject to:

$$A_j A_j^M \ CES_{Mj}^1 (F_1^j, D_1^j) = A_j \Xi_j CES_{PF}^j (CES_E^j (L_j^h, L_j^u), K_j, T_j) \tag{20}$$

$$CES_{Mj}^q (F_q^j, D_q^j) = k_q CES_{Mj}^1 (F_1^j, D_1^j) \quad (q = 2, ..., n) \tag{20a}$$

and

$$C_j = \sum_{i=1}^{n} (P_i^{Fj} \bullet F_i^j + P_i^{Dj} \bullet D_i^j) + L_j^h \bullet W_j^h + L_j^u \bullet W_j^u + K_j \bullet R_j^K + T_j \bullet R_j^T \tag{21}$$

where Y_j and all prices are exogenously given. The $k_2, ..., k_n$ are ratios of input-output coefficients.

The Lagrangean for this problem is:

$$\begin{aligned} L = {} & A_j A_j^M \ CES_{Mj}^1 (F_1^j, D_1^j) + \zeta_j \{A_j A_j^M \ CES_{Mj}^1 (F_1^j, D_1^j) \\ & - A_j \Xi_j CES_{PF}^j (CES_E^j (L_j^h, L_j^u), K_j, T_j) \} \end{aligned} \tag{22}$$

$$\begin{aligned} & + \sum_{q=2}^{n} \lambda_{qj} \{CES_{Mj}^q (F_q^j, D_q^j) - k_q CES_{Mj}^1 (F_1^j, D_1^j) \} \\ & + \Lambda_j \{C_j - (\sum_{i=1}^{n} (P_i^{Fj} \bullet F_i^j + P_i^{Dj} \bullet D_i^j) + L_j^h \bullet W_j^h + L_j^u \bullet W_j^u \\ & + K_j \bullet R_j^K + T_j \bullet R_j^T)\} \end{aligned} \tag{23}$$

To solve for the Lagrange multipliers, ζ_j, λ_{2j}, ..., λ_{nj}, Λ_j, we will exploit the first degree homogeneity of each of the CES functions, and the zero degree homogeneity of Ξ_j in each of the three sub-vectors of input pairs determining intensities of trade, skill, and capital. Thus, we solve for λ_q, obtaining:

$$\lambda_q = \frac{A_j \Xi_j V_j^C P_q^{Mj}}{C_j} \qquad (q = 2, ..., n) \tag{24}$$

Having determined all Lagrange multipliers, the demand functions may be found explicitly by substituting their values into first order conditions: see equations (AI-1) – (AI-8) in Annex AI. To facilitate an understanding of the economics of the system, we offer below an explanation of the direction of change in Ξ_j with respect to its components. We must evaluate the terms $\frac{\partial \Xi_j}{\partial X_i}$ where X_i is the i-th generic input [$X_i \in \{L_j^h, L_j^u, E_j, K_j, T_j, M_j\}$]. As the technological change (A_i) occurring in any sector i of the overseas source region is assumed to be exogenous, we can therefore write,

$$\left.\frac{\partial \Xi_j}{\partial D_i^j}\right|_{F_i^j, \bar{Y}_j} = \left.\frac{\partial (\Omega_{ij})^{\beta_{ij}}}{\partial D_i^j}\right|_{F_i^j, \bar{Y}_j} \times (A_i)^{\beta_{ij}} \tag{25}$$

and

$$\left.\frac{\partial \Xi_j}{\partial F_i^j}\right|_{D_i^j, \bar{Y}_j} = \left.\frac{\partial (\Omega_{ij})^{\beta_{ij}}}{\partial F_i^j}\right|_{D_i^j, \bar{Y}_j} \times (A_i)^{\beta_{ij}} \tag{26}$$

where $X_{ij}^{T} = \frac{F_i^j}{M_i^j}$ is input-specific trade intensity for sector j. The first derivative on the right-hand side (RHS) of the last two equations is the slope of the logistic function given by (5) so that

$$\frac{d\Omega_{ij}}{d\theta_{ij}} = \frac{\kappa\Omega_{ij}}{\theta_{ij}(1+aq^{\kappa}_{ij})} \tag{27}$$

In the next step, we calculate the change in the input-specific trade intensity with respect to the change in domestic and foreign-composite intermediates separately so that

$$\left.\frac{\partial X_{ij}^{T}}{\partial D_i^j}\right\rfloor_{F_i^j} = -\frac{F_i^j}{(M_i^j)^2}\left.\frac{\partial M_i^j}{\partial D_i^j}\right\rfloor_{F_i^j} \tag{28}$$

Evaluating $\left.\frac{\partial M_i^j}{\partial D_i^j}\right\rfloor_{F_i^j}$ and substitution into (28) after simplification yields

$$\left.\frac{\partial X_{ij}^{T}}{\partial D_i^j}\right\rfloor_{F_i^j} = -\frac{\delta_D}{(A_M)^{\rho_M}}\frac{F_i^j}{D_i^j}\frac{(M_i^j)^{\rho_M-1}}{(D_i^j)^{\rho_M}} \tag{29}$$

where $\rho_M > -1$ and $\sigma_M = \frac{1}{(1+\rho_M)}$ is the elasticity of substitution between F_i^j and M_i^j. Similarly,

$$\left.\frac{\partial X_{ij}^{T}}{\partial F_i^j}\right\rfloor_{D_i^j} = \frac{\delta_D}{(A_M)^{\rho_M}}\frac{(M_i^j)^{\rho_M-1}}{(D_i^j)^{\rho_M}} \tag{30}$$

Based on the above derivations, we can infer:[15]

Proposition I: *With the foreign-composite input held fixed, a unit increment of domestically sourced intermediate input reduces the captured productivity bonus (Ξ_{ij}); on the other hand, with a fixed level of domestic intermediate inputs, Ξ_{ij} is augmented by an increment of foreign-sourced intermediates due to a higher capture of the foreign-sourced technological improvement.*

Proof: Having derived the mathematical expressions, we substitute (27), (28) and (29) in both the equations (25) and (26) and rearrange them; we use (7c) to replace $(A_i\Omega_{ij})^{\beta ij}$ with Ξ_j, obtaining:

$$\left.\frac{\partial \Xi_j}{\partial D_i^j}\right\rfloor_{F_i^j,\bar{Y}_j} = -\beta_{ij}\frac{\kappa\Xi_j}{\theta_{ij}(1+a\theta^{\kappa}_{ij})}\frac{\nu_T[X_{ij}^{T}/\theta_{ij}]^{\omega_T-1}}{\sum_n \nu_n[X^n/\theta_{ij}]^{\omega_n}}\frac{\delta_D}{(A_M)^{\rho_M}D_i^j}\frac{F_i^j(M_i^j)^{\rho_M-1}}{(D_i^j)^{\rho_M}} \tag{31}$$

$$\left.\frac{\partial \Xi_j}{\partial F_i^j}\right]_{D^j,\bar{Y}_j} = \beta_{ij} \frac{\kappa \Xi_j}{\theta_{ij}(1+a\theta_{ij}^{\kappa})} \frac{\nu_T [X_{ij}^T/\theta_{ij}]^{\omega_T - 1}}{\sum_n \nu_n [X^n/\theta_{ij}]^{\omega_n}} \frac{\delta_D}{(A_M)^{\rho_M}} \frac{(M_i^j)^{\rho_M - 1}}{(D_i^j)^{\rho_M}} \tag{32}$$

The negative sign of (31) implies diminution of technological bonus with incremental domestic intermediates given fixed imported intermediates; and the positive sign of (32) signifies that with given domestic intermediates, higher doses of imported intermediates augment the bonus.

Proposition II: *For positive values of the parameters Γ_E, δ_h and with $MPX_j^A > 0$ (and even if $MPX_j^C = 0$) 'TB' per unit of increment of composite labour input E_j will go up when skill-intensity increases. Thus, higher absorptive capacity proxied by skill-intensity augments the technological bonus as higher skill endowments enable effective assimilation of fruits of transmitted technology.*

Proof: As before, for the value-added nest we evaluate the relevant derivatives (treating A_i exogenous) as below:

$$\left.\frac{\partial \Xi_j}{\partial E_j}\right]_{\bar{Y}_j, K_j, T_j} = \left.\frac{\partial (\Omega_{ij})^{\beta_{ij}}}{\partial E_j}\right]_{\bar{Y}_j, K_j, T_j} \times (A_i)^{\beta_{ij}} \tag{33}$$

Also,
$$\left.\frac{\partial \Xi_j}{\partial K_j}\right]_{\bar{Y}_j, E_j, T_j} = \left.\frac{\partial (\Omega_{ij})^{\beta_{ij}}}{\partial K_j}\right]_{\bar{Y}_j, E_j, T_j} \times (A_i)^{\beta_{ij}} \tag{34}$$

and
$$\left.\frac{\partial \Xi_j}{\partial T_j}\right]_{\bar{Y}_j, E_j, K_j} = \left.\frac{\partial (\Omega_{ij})^{\beta_{ij}}}{\partial T_j}\right]_{\bar{Y}_j, E_j, K_j} \times (A_i)^{\beta_{ij}} \tag{35}$$

Combining the Eqs., after some manipulations, we derive a more tractable expression:

$$\begin{aligned} \frac{\partial \Xi_j}{\partial E_j} &= \frac{\kappa \beta_{ij} (A_i \Omega_{ij})^{\beta_{ij}}}{\theta_{ij}(1+a\theta_{ij}^{\kappa})} \left[MPX_j^A \left\{ \frac{(\Gamma_E)^{\rho_E}}{\delta_h} \left(\frac{L_j^h}{E_j}\right)^{(1+\rho_E)} \left(\frac{1}{L_j^u}\right) \right\} - MPX_j^C \frac{X_j^C}{E_j} \right] \\ &= \frac{\kappa \beta_{ij} \Xi_j}{\theta_{ij}(1+a\theta_{ij}^{\kappa})} \frac{1}{E_j} \left[MPX_j^A \left\{ \frac{(\Gamma_E)^{\rho_E}}{\delta_h} \left(\frac{L_j^h}{E_j}\right)^{\rho_E} X_j^A \right\} - MPX_j^C \cdot X_j^C \right] \end{aligned} \tag{36}$$

and

$$\frac{\partial \Xi j}{\partial K j} = \beta ij \frac{\kappa \Xi j}{\theta ij(1+aq^{\kappa}_{ij})} MPX^{C}_{j} \frac{1}{E_j} \tag{37}$$

$$\text{where } MPX^{A}_{j} = \frac{\nu_A[X^{A}_{j}/\theta ij]^{\omega_A - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}} \text{ and } MPX^{C}_{j} = \frac{\nu_C[X^{C}_{j}/\theta ij]^{\omega_C - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}}.$$

This leads to:

Proposition III: *Since $MPX^{C}_{j}>0$ and since all the other terms are positive in (37), the sign of the derivative is positive; that is, a higher dose of physical capital in use by sector j will stimulate accrual of higher productivity bonus. Thus, higher capital intensity translates into higher appropriation of technological bonus in any region. As long as the destination's capital intensity is lower than that in the source region (i.e., if capital intensity increases in the destination but not as rapidly as that of the source so that the client region's capital-intensity does not overshoot the source's capital-intensity), then higher dose of physical capital in the recipient region translates into larger value of structural congruence resulting in amplification of productivity bonus.*

The composite labour input is produced in a CES nest by aggregating the physical units of skilled and unskilled labour. Following derivations as before, we can write that

$$\left.\frac{\partial \Xi_j}{\partial L^{t}_{j}}\right|_{L_j^{p}(p = h,u;\ t \neq p)} = \left.\frac{\partial (\Omega_{ij})^{\beta ij}}{\partial L^{t}_{j}}\right|_{L_j^{p}(p = h,u;\ t \neq p)} \times (A_j)^{\beta_{ij}} \tag{38}$$

Proposition IV: *An increment of unskilled labor, L^{u}_{j} (keeping skilled labor, L^{h}_{j} fixed) reduces Ξ_j owing to lower absorption of technology. An increment in skilled labour going into the composite labour pool inflates the value of Ξ_j, whereas an augmentation of unskilled labour acts conversely on Ξ_j.*

Proof: Based on earlier derivations, we evaluate the implied derivatives, finding: Substitution of Equations, simplification and using the expression for Ξj via (7c), we write:

$$\frac{\partial \Xi j}{\partial L^{h}_{j}} = \frac{\kappa \beta ij \Xi j}{\theta ij(1+a\theta^{\kappa}_{ij})} \frac{1}{L^{h}_{j}} \left[\frac{\nu_A[X^{A}_{j}/\theta ij]^{\omega_A - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}} X^{A}_{j} - \frac{\delta h}{(\Gamma_E)^{\rho E}} \frac{\nu_C[X^{C}_{j}/\theta ij]^{\omega_C - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}} X^{C}_{j} \left(\frac{E j}{L^{h}_{j}}\right)^{\rho E}\right] \tag{39}$$

and analogously we get

$$\frac{\partial \Xi j}{\partial L^{u}_{j}} = -\frac{\kappa \beta ij \Xi j}{\theta ij(1+a\theta^{\kappa}_{ij})} \frac{1}{L^{u}_{j}} \left[\frac{\nu_A[X^{A}_{j}/\theta ij]^{\omega_A - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}} X^{A}_{j} + \frac{\delta u}{(\Gamma_E)^{\rho E}} \frac{\nu_C[X^{C}_{j}/\theta ij]^{\omega_C - 1}}{\sum_n \nu_n[X^n/\theta ij]^{\omega_n}} X^{C}_{j} \left(\frac{E j}{L^{u}_{j}}\right)^{\rho E}\right] \tag{40}$$

It is to be noted that the derivatives in Equation (39) and (40) are of opposite signs. Since apart from the leading minus sign all terms on the right of (40) are positive, it is clear that an increment of unskilled labor, L_j^u (keeping skilled labor, L_j^h fixed) reduces Ξ_j owing to lower absorption of technology. An increment in skilled labour going into the composite labour pool inflates the value of Ξ_j [via the positive sign of (39)], whereas augmentation of unskilled labour acts conversely on Ξ_j.

However, using (39) and (40), with further manipulation, we derive skill-unskilled relative wage as:

$$\frac{W_j^h}{W_j^u}=\frac{E_j\frac{\partial \Xi_j}{\partial L_j^h}+\Xi_j\frac{\partial E_j}{\partial L_j^h}}{E_j\frac{\partial \Xi_j}{\partial L_j^u}+\Xi_j\frac{\partial E_j}{\partial L_j^u}}=\frac{\frac{\delta_h}{(\Gamma_E)^{\rho_E}}\left(\frac{E_j}{L_j^h}\right)^{(1+\rho_E)}+\frac{E_j}{L_j^u}\frac{\kappa\beta_{ij}}{\theta_{ij}(1+a\theta_{ij}^{\kappa})}\frac{\nu_A[X_j^A/\theta_{ij}]^{\omega_A-1}}{\sum_n \nu_n[X^n/\theta_{ij}]^{\omega_n}}}{\frac{\delta_u}{(\Gamma_E)^{\rho_E}}\left(\frac{E_j}{L_j^u}\right)^{(1+\rho_E)}-\frac{E_j}{L_j^u}\frac{\kappa\beta_{ij}}{\theta_{ij}(1+a\theta_{ij}^{\kappa})}X_j^A\frac{\nu_A[X_j^A/\theta_{ij}]^{\omega_A-1}}{\sum_n \nu_n[X^n/\theta_{ij}]^{\omega_n}}} \tag{41}$$

In (41), the second term in the denominator is X_j^A times greater than that in the numerator. Assuming that all the constituent terms are positive, this implies that the numerator is greater than that would have been obtained in the conventional analysis; on the other hand, the denominator is less and falls by more than the increment in the numerator so that it tends to become smaller. This, however, implies that skill-intensity being an important ingredient for harnessing the 'bonus', the higher is the skill-induced absorption capacity, the higher will be the associated capture and hence, the higher is the skill premium.[16]

To check the theoretical consistency of the ideas, a miniature partial equilibrium model was developed. This miniature incorporated in simplified form all of the important ideas about how the GTAP technological specification needs to be altered to capture the endogeneity sketched above.[17]

4. NUMERICAL ASSESSMENT OF THE THEORETICAL MECHANISM

Trade intensity of material inputs is varied parametrically with skill intensity and structural congruence held fixed. We consider a hypothetical data set. The effect of changing trade intensity X_j^T on the capture parameter, and hence on Ξ_j, are computed.

4.1 Covariation of capture parameter and trade intensity

We start with a fixed level of material inputs consistent with the exogenous output level Y_j=900. Table no. 1 shows the initial configuration of values for F_i^j and M_j and the parameters.

Table no. 1 – Initial scenario for the firm with fixed output (conventional structure)

F_i^j	D_i^j	M_j	Y_j	κ	a	β	σ_M	δ_F	δ_D
10	403.8158	900	900	0.41	0.01	0.1	2	0.5	0.5

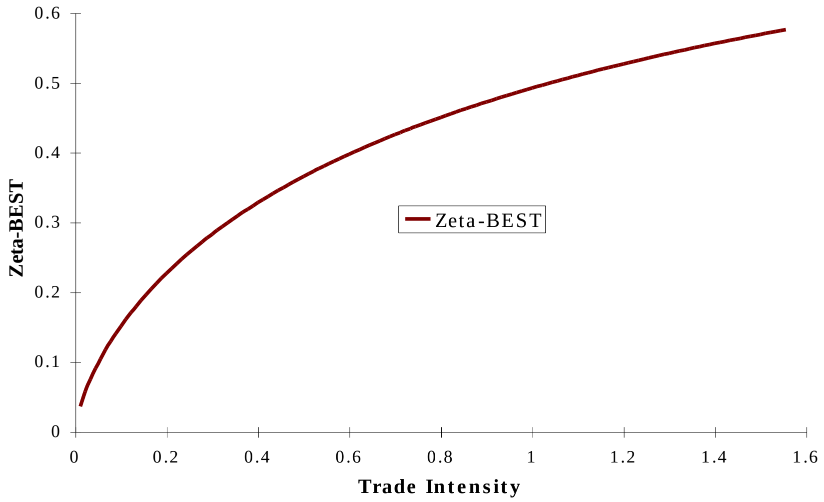

Figure no. 4 – Relationship between trade intensity and trade-induced technology bonus

We choose arbitrary values for a, κ and β and augment F_i^j by equal successive increments of 10. With exogenous technical progress the increase in X_j^T augments the value of θ_j and consequently also increases the value of the bonus Ξ_j. This is shown in Figure no. 4.

However, following Equation (8), for a given level of output (as specified in column 3, Table no. 1), the accrual of TB with an increase in trade intensity diminishes the required *conventionally measured* primary factor input. Given fixed AC and SS, with an increase in X_j^T, θ_j increases. Thus, trade intensity has implications for primary factor productivity. The latter increases with X_j^T and the firm needs less V_j^c to produce the same output – see Figure no. 5.

With the conventional technology depicted in Figures no. 4 and no. 5, M_j is kept fixed while F_i^j is varied parametrically. The least-cost combination of domestic and imported components of M_j would be found using the conventional tangency condition. However, when trade-intensity has implications for primary factor productivity, the firm should consider the locus of isocost combinations of V_j^c, F_i^j and D_i^j to choose the least-cost combination of F_i^j and D_i^j for a particular M_j.

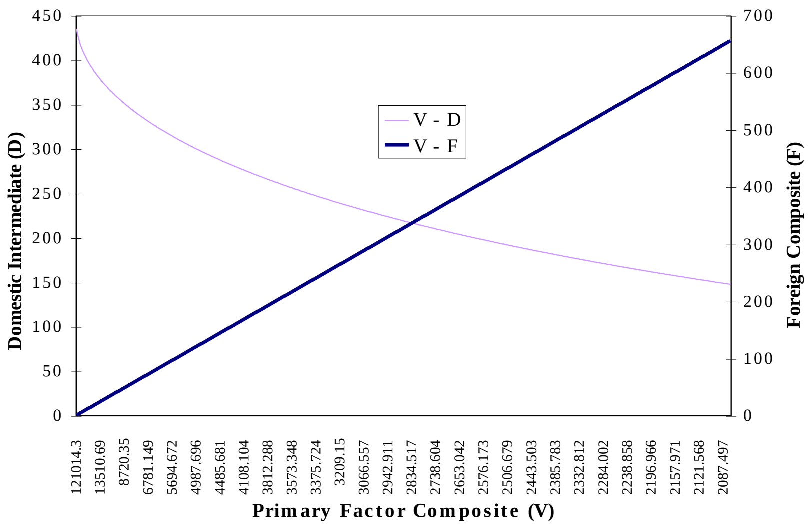

Figure no. 5 – Relationship between conventional primary factor composite, foreign intermediate composite and domestic intermediate with output fixed

4.2 Primary Factor Productivity in the modified structure

Assuming price-taking behaviour in the markets for conventional inputs, the firm faces the following isocost schedule in the generic input space:

$$R_j = F_i^j.PF_i^j + D_i^j.PD_i^j + V_j^c.PV_j^c \qquad \text{(EQ-c)}$$

The additional term $[V_j^c.PV_j^c]$ accounts for the outlay that the firm incurs on conventional primary factor composite. Each point on such an isocost schedule will represent a particular configuration of of F_i^j, D_i^j and V_j^c. We choose identical values (namely, unity) for the exogenously fixed prices of of F_i^j, D_i^j and V_j^c (columns 5, 6 and 7 of Table no. 2). To obtain the base-case scenario, the same values have been assigned to the parameters. This gives the value of initial TB (Ξ_j) via equation (EQ-b) and then using equation (8), we get the value of V_j^c in the base-case (see columns 11 and 3 respectively of Table no. 2). Using equation (EQ-c), we compute initial total cost (R_j) (column 8, Table no. 2).

Table no. 2 – Initial Scenario for firm's behaviour with 'bonus' mechanism

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
F_i^j	D_i^j	V_j^c	M_j	PF_i^j	PD_i^j	PV_j^c	R_j	κ	β	Ξ_j
900	900	1827.85	900	1	1	1	3627.85	0.41	0.1	0.4924

Having set the initial solution, we simulate the impact of altered trade intensity by varying F_i^j parametrically. To do that, a new series of F_i^j is obtained by successive doses of fixed, arbitrary dF_i^j around F_i^j =900 (by increasing and diminishing around that point). Corresponding to each new X_j^T, we get a new set of values for θ_j and Ω_j using equation (EQ-b); however, we keep R_j fixed at the initial level so that

$$0 = dR_j = dF_i^j . PF_i^j + dD_i^j . PD_i^j + dV_j^c . PV_j^c \qquad \text{(EQ-d)}$$

When we vary F_i^j parametrically by choosing an arbitrary dF_i^j, dV_j^c is automatically determined by the BEST mechanism; thus, for arbitrary dF_i^j we can solve for the appropriate values of dV_j^c and dM_j. In this way, equation (EQ-d) is used to trace the isocost schedule as a combination of F_i^j, D_i^j and V_j^c. Figure no. 6 shows that the locus of the isocost schedule is no longer a straight line. Since F_i^j and D_i^j produce a unique value of M_j, the isocost curve can alternatively be represented as a combination of F_i^j, D_i^j and V_j^c. We now find the isoquant for M_j (as shown in Figure no. 7) for a point in the neighbourhood of an initial point (i.e, M_j = 900 on the isocost curve. Figure no. 8 shows the tangency of this isoquant with an isocost at point T in the close neighbourhood of M_j = 900. Following Das (2010), the miniature model developed above is specifically designed to explore the impact of a technology shock on the productivity improvement following TFP shock.[18]

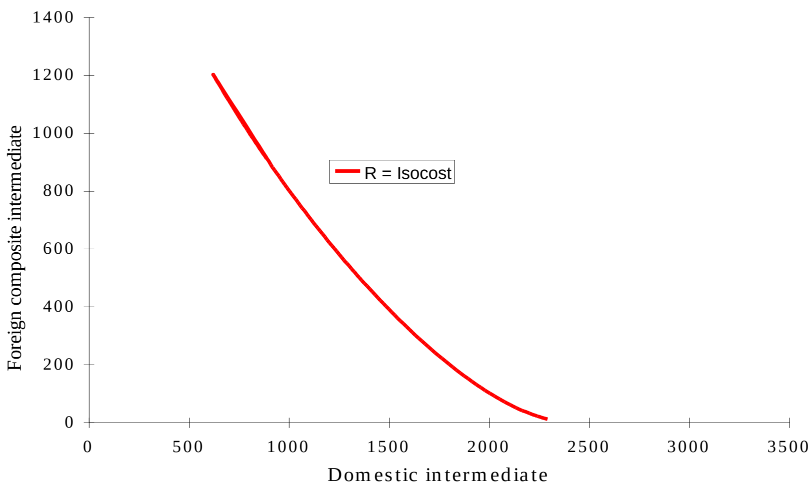

Figure no. 6 – The firm's isocost curve with the trade-induced technology bonus mechanism

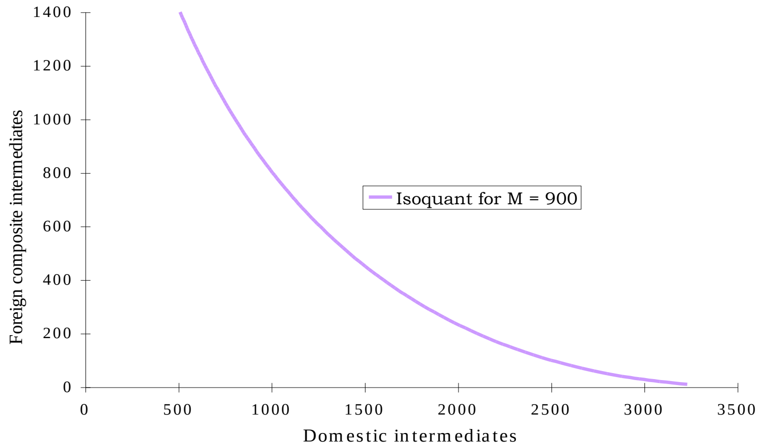

Figure no. 7 – Isoquant for a specific output level on the isocost contour

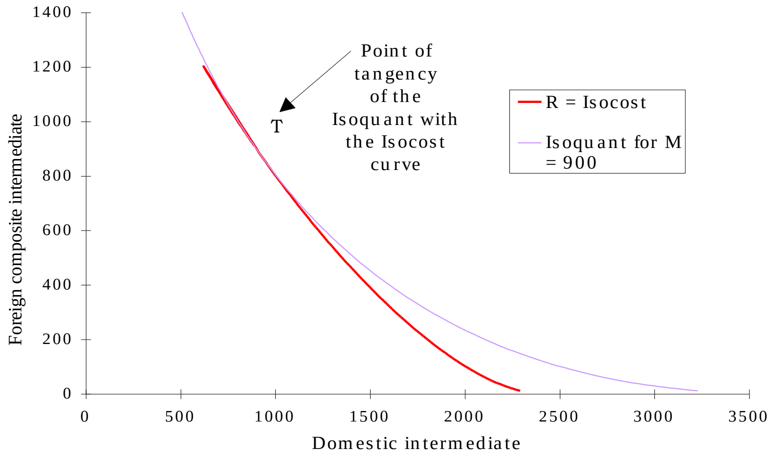

Figure no. 8 – Tangency of the isocost curve with the isoquant for an equilibrium configuration of F_i^j, D_i^j and V_j^c for a particular M_j

The mechanism depicted in Figure no. 8 will only produce well-behaved solutions if the locus of the specified isocost schedule has a unique tangency point with the isoquant contour and the curvature of the isocost is shallower than that of the isoquant. This latter (2nd order) condition rules out the possibility of corner solutions. The tangency at T in Figure no. 8 guarantees unique interior solution.

5. CONCLUSION

Under a mechanism of trade-embodied technology diffusion, in this article a theory which allows for the endogenous capture of foreign technical change has been offered in which the transmitted size of a technology shock originating overseas (but transmitted via imported inputs) becomes endogenous. The underlying assumption is that the workers differ in their skill contents to achieve a productivity level with a particular vintage of technology. Based on the background quantitative evidences, it is postulated that: (i) *AC* increases with the intensity of skilled labour in the input mix; (ii) the amount of technology potentially captured increases with the import intensity of the material inputs; and (iii) *SS* increases with higher capital intensities. The capacity of traded inputs to carry technological improvements changes the factor-mix problem confronting representative firms. The latter takes into account not only the conventionally defined marginal rate of substitution between domestic and foreign inputs of the same generic type, but also the 'bonus' of the superior technology embedded in inputs purchased from a technologically advanced source. The model embeds a mechanics of technology adoption in a global input-output structure based on endowment differences in skill, trade-intensity and capital-intensity. Results confirm that higher skill intensity facilitates adoption of transmitted productivity gains and higher magnitude of capture for the structurally congruent regions via intermediate goods linkages. Further work along these lines would proceed in two parts: (a) elaboration of the model so as to provide it with a general equilibrium closure; and (b) mounting full scale simulations to give an empirical support of the promising results obtained with the model along the lines of Das (2010).

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ANNEX AI

Formalization of Lagrangean Problem in the CES Nesting is presented below:

The first-order conditions are:

$$\frac{\partial L}{\partial F_1^j} = A_j A_j^M \frac{\partial CES_{Mj}^1}{\partial F_1^j} - \frac{\partial CES_{Mj}^1}{\partial F_1^j} \sum_{q=2}^{n} \lambda_q k_q + \zeta_j \{A_j A_j^M \frac{\partial CES_{Mj}^1}{\partial F_1^j} - A_j V_j^c \frac{\partial \Xi_j}{\partial F_1^j}\} - \Lambda_j P_1^{Fj} = 0 \qquad \text{(AI-1)}$$

$$\frac{\partial L}{\partial D_1^j} = A_j A_j^M \frac{\partial CES_{Mj}^1}{\partial D_1^j} - \frac{\partial CES_{Mj}^1}{\partial D_1^j} \sum_{q=2}^{n} \lambda_q k_q + \zeta_j \{A_j A_j^M \frac{\partial CES_{Mj}^1}{\partial D_1^j} - A_j V_j^c \frac{\partial \Xi_j}{\partial D_1^j}\} - \Lambda_j P_1^{Dj} = 0 \qquad \text{(AI-2)}$$

$$\frac{\partial L}{\partial F_q^j} = -\zeta_j A_j V_j^c \frac{\partial \Xi_j}{\partial F_q^j} + \lambda_q \frac{\partial CES_{Mj}^q}{\partial F_q^j} - \Lambda_j P_q^{Fj} = 0 \qquad (\forall q = 2, ..., n) \quad \text{(AI-3)}$$

$$\frac{\partial L}{\partial D_q^j} = -\zeta_j A_j V_j^c \frac{\partial \Xi_j}{\partial D_q^j} + \lambda_q \frac{\partial CES_{Mj}^q}{\partial D_q^j} - \Lambda_j P_q^{Dj} = 0 \qquad (\forall q = 2, ..., n) \quad \text{(AI-4)}$$

$$\frac{\partial L}{\partial L_j^h} = -\zeta_j A_j \Xi_j \frac{\partial CES_{PF}^j}{\partial E_j} \frac{\partial CES_E^j}{\partial L_j^h} - A_j CES_{PF}^j \frac{\partial \Xi_j}{\partial L_j^h} - \Lambda_j W_j^h = 0 \qquad \text{(AI-5)}$$

$$\frac{\partial L}{\partial L_j^u} = -\zeta_j A_j \Xi_j \frac{\partial CES_{PF}^j}{\partial E_j} \frac{\partial CES_E^j}{\partial L_j^u} - A_j CES_{PF}^j \frac{\partial \Xi_j}{\partial L_j^u} - \Lambda_j W_j^u = 0 \qquad \text{(AI-6)}$$

$$\frac{\partial L}{\partial K_j} = -\zeta_j A_j \Xi_j \frac{\partial CES_{PF}^j}{\partial K_j} - A_j CES_{PF}^j \frac{\partial \Xi_j}{\partial K_j} - \Lambda_j R_j^K = 0 \qquad \text{(AI-7)}$$

$$\frac{\partial L}{\partial T_j} = -\zeta_j A_j \Xi_j \frac{\partial CES_{PF}^j}{\partial T_j} - A_j CES_{PF}^j \frac{\partial \Xi_j}{\partial T_j} - \Lambda_j R_j^T = 0 \qquad \text{(AI-8)}$$

To solve for the Lagrange multipliers, ζ_j, λ_{2j}, ..., λ_{nj}, Λ_j, first we multiply (AI-1) through (AI-8) through by F_1^j, D_1^j ; F_q^j, D_q^j (q = 2, ..., n) ; L_j^h, L_j^u, K_j and T_j respectively (and in that order). Adding up the first four of the resultant equations, we obtain

$$A_j A_j^M M_j^1 - M_j^1 \sum_{q=2}^{n} \lambda_q k_q + \sum_{q=2}^{n} \lambda_q M_j^q + \zeta_j A_j A_j^M M_j^1 = \Lambda_j C_j^M \qquad \text{(AI-9)}$$

$$C_j^M = \sum_{q=1}^{n} (P_q^{Fj} \bullet F_q^j + P_q^{Dj} \bullet D_q^j) \qquad \text{(AI-10)}$$

Adding the second set of resultant equations, we find

$$\zeta_j = -\Lambda_j (C_j - C_j^M) / [A_j \Xi_j V_j^c] \qquad \text{(AI-11)}$$

From the necessary condition of optimization, we invoke the relationship (13), in the text, so that after further simplification equation (AI-10b) yields

$$\Lambda_j = A_j \Xi_j V_j^c / C_j \qquad \text{(AI-12)}$$

ANNEX AII

Derivations related to the Propositions in the Text:

We find the terms in the expressions as follows:

$$\frac{\partial(\Omega_{ij})^{\beta ij}}{\partial E_j}\Big\rfloor_{\bar{Y}_j,K_j,T_j} = \beta ij(\Omega_{ij})^{\beta ij-1}\frac{d\Omega_{ij}}{d\theta_{ij}} \times [\{\frac{\partial\theta_{ij}}{\partial X_j^A}\Big\rfloor_{X_j^n(n=C,T)} \times \frac{\partial X_j^A}{\partial E_j}\} + \{\frac{\partial\theta_{ij}}{\partial X_j^C}\Big\rfloor_{X_j^n(n=A,T)} \times \frac{\partial X_j^C}{\partial E_j}\}] \quad \text{(AII-1)}$$

Also,

$$\frac{\partial(\Omega_{ij})^{\beta ij}}{\partial K_j}\Big\rfloor_{\bar{Y}_j,E_j,T_j} = \beta ij(\Omega_{ij})^{\beta ij-1}\frac{d\Omega_{ij}}{d\theta_{ij}} \times [\frac{\partial\theta_{ij}}{\partial X_j^C}\Big\rfloor_{X_j^n(n=A,T)} \times \frac{\partial X_j^C}{\partial K_j}] \quad \text{(AII-2)}$$

The marginal products of X_j^A (MPX_j^A) and X_j^C (MPX_j^C) in producing θ_{ij} in equations (AII-1) and (AII-2) are evaluated so that we write:

$$\frac{\partial\theta_{ij}}{\partial X_j^A}\Big\rfloor_{X_j^n(n=C,T)} = \frac{\nu_A[X_j^A/\theta_{ij}]^{\omega_A-1}}{\sum_n \nu_n[X^n/\theta_{ij}]^{\omega_n}} \quad \text{(AII-3)}$$

$$\text{and} \quad \frac{\partial\theta_{ij}}{\partial X_j^C}\Big\rfloor_{X_j^n(n=A,T)} = \frac{\nu_C[X_j^C/\theta_{ij}]^{\omega_C-1}}{\sum_n \nu_n[X^n/\theta_{ij}]^{\omega_n}} \quad \text{(AII-4)}$$

For the other terms in (AII-1) and (AII-2), we obtain:

$$\frac{\partial X_j^C}{\partial E_j}\Big\rfloor_{\bar{Y}_j,K_j,T_j} = -\frac{K_j}{(E_j)^2} = -\frac{X_j^C}{E_j} \quad \text{(AII-5)}$$

and

$$\frac{\partial X_j^C}{\partial K_j}\Big\rfloor_{\bar{Y}_j,E_j,T_j} = \frac{1}{E_j} \quad \text{(AII-6)}$$

Also

$$\frac{\partial X_j^A}{\partial E_j}\Big\rfloor_{\bar{Y}_j,K_j,T_j} = \frac{(\Gamma_E)^{\rho_E}}{\delta h}\left(\frac{L_j^h}{E_j}\right)^{(1+\rho_E)}\left(\frac{1}{L_j^u}\right) \quad \text{(AII-7)}$$

Substituting (AII-4), (AII-5), and (AII-6) in equation (AII-1) and subsequently in (36), (37), and (38) in the text, we derive after rearrangement of the terms:

$$\frac{\partial\Xi_j}{\partial E_j} = \frac{\kappa\beta ij\Xi_j}{\theta ij(1+aq_{ij}^{\kappa})}\frac{1}{E_j}[MPX_j^A\{\frac{(\Gamma_E)^{\rho_E}}{\delta h}\left(\frac{L_j^h}{E_j}\right)^{\rho_E} X_j^A\} - MPX_j^C . X_j^C] \quad (39)$$

Substituting (AII-5) and (AII-7) in (AII-2) and subsequently in (37) in the Text leads us to write:

$$\frac{\partial X_j^A}{\partial L_j^h}\Big\rfloor_{L_j^u,\bar{Y}_j} = \frac{\partial(L_j^h/L_j^u)}{\partial L_j^h} = \frac{1}{L_j^u} \quad \text{(AII-8)}$$

and

$$\frac{\partial X_j^C}{\partial L_j^h}\Big\rfloor_{L_j^u,\bar{Y}_j} = \frac{\partial(K_j/E_j)}{\partial L_j^h} = -\frac{K_j}{E_j^2}\frac{\delta h}{(\Gamma_E)^{\rho_E}}\left(\frac{E_j}{L_j^h}\right)^{(1+\rho_E)} \quad \text{(AII-9)}$$

Substitution of Equations (29), (30), (AII-4) and (AII-5) into equations above and (AII-8) yields after simplification and using the expression for Ξ_j via (7c), we write in the text:

$$\frac{\partial \Xi_j}{\partial L_j^h} = \frac{\kappa\beta_{ij}\Xi_j}{\theta_{ij}(1+a\theta_{ij}^{\kappa})} \frac{1}{L_j^h} \left[\frac{\nu_A [X_j^A/\theta_{ij}]^{\omega_A - 1}}{\sum_n \nu_n [X^n/\theta_{ij}]^{\omega_n}} X_j^A - \frac{\delta_h}{(\Gamma_E)^{\rho_E}} \frac{\nu_C [X_j^C/\theta_{ij}]^{\omega_C - 1}}{\sum_n \nu_n [X^n/\theta_{ij}]^{\omega_n}} X_j^C \left(\frac{E_j}{L_j^h}\right)^{\rho_E} \right] \tag{39}$$

and

$$\frac{\partial \Xi_j}{\partial L_j^u} = -\frac{\kappa\beta_{ij}\Xi_j}{\theta_{ij}(1+a\theta_{ij}^{\kappa})} \frac{1}{L_j^u} \left[\frac{\nu_A [X_j^A/\theta_{ij}]^{\omega_A - 1}}{\sum_n \nu_n [X^n/\theta_{ij}]^{\omega_n}} X_j^A + \frac{\delta_u}{(\Gamma_E)^{\rho_E}} \frac{\nu_C [X_j^C/\theta_{ij}]^{\omega_C - 1}}{\sum_n \nu_n [X^n/\theta_{ij}]^{\omega_n}} X_j^C \left(\frac{E_j}{L_j^u}\right)^{\rho_E} \right] \tag{40}$$

Notes

[1] Rise in industrial demand for skill has been attributed to the second phase of industrial revolution with much acceleration in technical progress requiring talent for rapid growth. Other facets of such unified growth theory are: biogeographic factors for historic and prehistoric effects, and emergence of multiple growth regimes or convergence clubs. See Galor (2011, p. 58), footnote 31 for arguments corroborating necessity of a firm's choice taking into account intensities of trade, skill, and capital.

[2] In the context of the North American Free Trade Agreement (NAFTA), the example given is that of use of high-quality compressors from source USA in Mexican refrigerators production in destination, causing higher productivity. In fact, importing intermediates is a mechanism for outsourcing material inputs embodying R&D and thus, could increase proliferation of high quality new products.

[3] VAX ratio is used to measure such trade and is constructed by Johnson and Noguera (2012) is the ratio of value-added trade to gross exports.

[4] As reported by the Economist (January 9th 2013), foreign content of electronic exports, as per OECD and the WTO studies, ranges from 11% (America) to 61% in Mexico, with increasing evidence that exports requiring loads of imports. For China, 40% of US$467 billion electronic goods exports were sourced from imports. There is evidence that China textile exports used cotton imports from overseas to meet surge in demands after lifting of trade quotas in 2005 and fall in domestic production due to less cotton plantation.

[5] See page 145, footnote 4 in Galor (2011).

[6] CRESH allows the substitution elasticities between inputs to vary between different pairs of inputs. In our case of 3 components (namely, X_{js}^A, X_{jrs}^C, and X_{ijs}^T), there are 3 substitution elasticities. For N inputs, there are 0.5×N × (N-1) substitution elasticities --one for every non-diagonal element in the upper triangle of the N×N matrix. With CES, they are the same for every pair of inputs (although it differs from unity). In case N = 2, there is only one pair of inputs, and CES is fine as it beats Cobb-Douglas because the substitution elasticity could be any non-negative number (rather than Cobb-Douglas' value of one). See Hanoch (1971).

[7] κ can be interpreted as a 'catch-all' term involving indigenous adoption capabilities, infrastructural facilities and learning effects determining efficient utilisation of technology captured from overseas.

[8] Because there are no explicit equations modelling technical change, we adopt exogenous treatment of technical change as parametric shift of Hicks-Neutral technological coefficients (Dixon *et al.*, 1982, Chapter 3).

[9] The primary emphasis is the technology transmission from the origin to the recipients. We do not model the mechanism of knowledge creation per se. Note that $A_{ir} = A^{original}{}_{ir}\,(1+a_{ir})$ where a_{ir} is the percentage change in productivity *level* (exogenous perturbations) in industry i in source region r.

[10] The constrained extrema are at the corners of the Leontief isoquant.

[11] This kind of interdependency is the source of reciprocal externality via 'capture parameter' in our model.

[12] Note that (iv) uses the assumption that M_i^j is homogeneous of first degree in D_i^j and F_i^j.
[13] The model is static and explains static differences in productivity across sectors in regions. For technologically stagnant regions, which do not innovate or that are technologically backward the corresponding weights in the aggregations in Equations (7a) and (7b) would be negligible, i.e., set to zero.
[14] This follows from the property of the production functions for θ_{ijrs}, Ω_{ijrs} and Ξ_{ijrs}. As per our construction in Equation (5), if all the elements defining the arguments X_{js}^A, X_{jrs}^C, and X_{ijs}^T of Z are increased equiproportionately, then the value of the function Λ remains unchanged. That is, if E_{js}, K_{js}, L_{js}^h, L_{js}^u, F_{is}^j, M_{is}^j, are increased by the same constant $\upsilon>0$ (a positive scalar), then the value of Λ remains unaltered. Thus, if θ is written as a function χ of E_{js}, K_{js}, L_{js}^h, L_{js}^u, F_{is}^j, M_{is}^j, then χ is homogeneous of degree zero in these arguments. Thus, Ω_{ijrs}—the logistic transformation of θ_{ijrs} — is also homogeneous of degree zero in those variables. Now, we define $\Xi_{ijrs} = \Omega_{ijrs} \times A_{ir}$ [*à la* Equation (7)].
[15] To pin down the important results in the text, we relegate long derivations in the appendices I and II.
[16] Compared to our model, Acemoglu (2009, p. 510 and pp. 516-518, Chapter 15) derives a similar expression for relative wage with different forms, but analogous implications. In a different model (2009, p. 629, Chapter 18) derives an expression for skill premium with similar intuition.
[17] Here we do not mount a full-blown version of the model with a multi-country multi-sectoral simulation for parsimony and beyond the research scope. Given the primary focus of this paper, viz., enunciating a mechanism of skill-biased technical change via imported intermediate inputs and resultant changes in skill-mix in the wake of an exogenous technical change, the numerical assessment offers insight for underlying mechanism without undermining our purpose. It is in our research agenda. However, Das (2010) develops a miniature model alike the flavor of the model.
[18] Although the ideas have been developed with the aim of implementing them within a multi-regional, multi-sectoral applied general equilibrium model, this miniature implementation is a pointer to that. To facilitate interpretation, the miniature model embodying the essential features of the proposed extension has been presented. We show that capture-parameter is the propellant force for assimilation of transmitted technological improvements. Further work along these lines will involve mounting the full scale simulations in a higher dimensional CGE model. However, these are in our research agenda and for parsimony, we avoid repetitions.