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TRADE-INDUCED TECHNOLOGY SPILLOVER AND ADOPTION: A QUANTITATIVE GENERAL EQUILIBRIUM APPLICATION

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This paper investigates the impact of a 4% Hicks-neutral technical progress in heavy manufacturing in the United States and its trans-border spillover via intermediates. A three-region, six-traded-commodity computable general equilibrium model is numerically simulated to show that differentials in regional productivity improvements depend on their absorptive capacity and structural similarity. This determines the extent of technology capture. The model results show that the productivity improvement and transmission result in productivity growth in sectors intensively using heavy manufacturing. Returns to skilled labour depend on technology spillover and capture parameter. The results have implications for the role of human capital in assimilating advanced technology.

Keywords: Absorptive Capacity, Structural Similarity, Capture Parameter, Trade, Technology
JEL classification: D58, F16, O4

1. INTRODUCTION

This paper offers an analysis of the impact of embodied technology transmission and its potential capture by the recipients in a computable general equilibrium (henceforth, CGE) model. In our model, international trade flows are the primary conduits for trans-border technology spillover that occurs via the traded intermediate inputs in which it is embedded. In the model, destination country's ability to use the foreign technology depends on its capacity to identify, procure and use the diffused state-of-the-art (i.e., on *Absorptive Capacity* - *AC*) and the technological or *Structural Congruence or Similarity* (*SS*). The improved technology transferred via traded inputs into production determines

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total factor productivity (TFP) of the client regions endogenously. These ideas are implemented using a modified Global Trade Analysis Project's (GTAP)[1] computable general equilibrium model and its database. Section 2 spells out the conceptual framework. To implement the technology transmission equations, we made the necessary modifications in the extant GTAP theory as documented in Section 3. Based on econometric estimation of the substitution elasticity between two skill categories, we introduced a Constant Elasticity of Substitution (CES) labour nesting in the standard value-added nest of the production function. Higher endowment of skilled labor aids assimilation of technology ferried via trade (see Das (2002)). Since AC depends, *inter alia*, on the human capital and skill content of the work force, it is worthwhile to explore the impacts on productivity growth contingent on skill-intensity of the labor force.

The underlying database is the GTAP database with split of labour payments between two skill categories. For implementation, we aggregate the 30 regions × 37 traded-sectors Version 3 of the GTAP database into 6 traded sectors and 3 regions viz., USA, European Union (EU) and Rest of the World (ROW).[2] This aggregation is motivated primarily by computational tractability.[3] Section 4 discusses the sectoral and endowment mapping. Section 5 documents the simulation exercise. Simulation results are reported in Section 6 and concluding remarks are offered in Section 7.

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[1] The GTAP model is a multi-sectoral, multi-regional global trade model with a broad database being developed at the Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA. See Hertel (ed.), 1997.

[2] In alternative scenarios, one could consider single developed regions like Japan, Australia or Canada (relatively proficient in harnessing superior technologies) and study the consequential diverse impacts. Since our primary focus is to numerically implement the transborder technology flows in other regions from the U.S. and studying comparative impacts of technological spillovers in general, we do not consider countries/regions separately in our present study. Higher dimensional issues with multiplicity of regions are beyond the scope of this paper. In our simulation, we focus on relatively more amorphous group in geographical composition. The rest of the world is a composite of all foreign economies that are trade partners of the U.S. and EU. Each of the regions participates in trade in commodities with the U.S. and the ROW region. Since the sole objective of this paper is to study the 'regional' impacts of 'potential' technology capture, we believe that the simplified presentation of foreign trade helps facilitating the main thrust of our theoretical premise on differential inter-regional impacts. The author thanks the referee for useful comments on this issue.

[3] Recently in the Version 5 of the GTAP Database, it is updated to incorporate 57 sectors and 66 regions (see Dimaranan, B.V., and R.A. McDougall (March, 2002), *Global Trade, Assistance, and Production: The GTAP 5 Data Base*, Center for Global Trade Analysis, Purdue University). It was not available during the time the research was undertaken. Because our primary emphasis is on elucidating the transmission of trade-induced technology flows and its effective assimilation, the different version with more disaggregation does not make difference in the directionality of the results. However, the simulation incorporating relatively recent data can be mounted easily without undermining the flavor of our results.

2. THEORETICAL PREMISE: EMBODIED SPILLOVER HYPOTHESIS[4]

The state-of-the-art technologies are developed in the developed countries (DCs). The less-developed countries (LDCs) have depended for their growth and development on foreign technologies originating in the DCs. Their growth and development depend not only on the extent and nature of the technology which is available to them, but also on their competence for effectively absorbing the diffused state-of-the-art. Current state-of-the-art technologies created by concerted research efforts are embodied in the commodities produced using the new 'ideas'. The 'ideas' generated at the sources of inventions, spill over to the destinations through bilateral trade linkages. Thus, international trade in commodities entails trans-border flows of superior 'technologies' embodied in traded goods and services (see for example, Coe *et al*. (1995, 1997), World Development Report (World Bank (1999)), Dietzenbacher (2000), Keller (2001) for empirical evidences). It is pertinent to note that the creation of 'ideas' occurs exogenously to the system, manifest as an exogenous TFP shock.

It is not necessarily true that the technology transferred through cross-border flows of commodities will be readily and effectively adopted in the destination LDCs. The adaptability and domestic usability of the diffused technologies depends on the *Absorptive Capacity* (Cohen and Levinthal (1989, 1990)) of the destinations and the *Structural Similarity* (e.g., Hayami and Ruttan (1985)) between the trading nations.[5] Using the GTAP model, van Meijl and van Tongeren (1998) have analysed the issues of technology transfer. Productivity growth rates of countries are related through international trade linkages and associated trade-mediated knowledge-spillovers. Their model incorporates the essential elements of 'AC' and 'SS' factors in determining the domestic usability of foreign technologies. Together with trade volume, these two indexes conjointly determine the 'productive efficiency' parameter. It is argued that domestic usability of the transmitted foreign technology depends mainly on the recipient's capability to utilise the diffused technology. This treatment of AC is motivated by the desire to keep the model simple by concentrating on first-order effects. Thus, the AC factor is made destination-specific only. However, unlike Das and Powell (2001), as will become evident from Section 4, we have incorporated a CES nesting of skilled and unskilled labours. The basic spillover equations are developed in the next section.

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[4] Unlike Eaton and Kortum (1996a & b) (henceforth, EK), Grossman and Helpman (1991a & b) and Connolly (1997) considering empirical dynamic general equilibrium model of technology-diffusion based on a "quality-ladder" approach, we adopt a static general equilibrium framework where creation of R&D is beyond the scope of the paper.

[5] This aspect of "*effective* absorption" has not been studied by the authors cited above. The role of such factors in assimilating the foreign technology was first emphasised in the literature by Cohen and Levinthal. Based on their notion of absorption capacity and its importance, some authors like Keller (1997), Lall (1982), Nelson (1990), to name a few, have extended the discussion initiated by them.

3. TECHNOLOGY SPILLOVER HYPOTHESIS

Technology embodied in traded and domestic intermediate inputs spills over to *all* other sectors and affects their TFP. That is, following an exogenous technological improvement in one sector of one region, all other sectors in the source region, and all sectors in other regions experience *endogenous* TFP improvement. Thus, the technology transmission equations apply for the *trade-induced spillover* between client regions and the source of innovation as well as, we consider endogenous *domestic spillover* to the sectors in the source itself from the sector experiencing exogenous technological change.

A. Definition of Embodiment Index

The amount of trade-induced knowledge spillover from a source sector in the donor region to a particular sector in the client regions via traded intermediates depends on the input-specific trade intensity of production of that sector. Hence the embodiment index is defined in terms of trade intensities for different specific material inputs; i.e., source and using sector-specific trade-embodiment index. We define this index $[E_{ijrs}]$ as the flow of imported intermediate produced in sector 'i' in source region 'r' that is exported to firms in sector 'j' in recipient region 's' $[F_{irjs}]$ per unit of composite intermediate input of 'i' used by sector 'j' in destination 's' $[M_{ijs}]$. The latter - M_{ijs} - is a simple aggregate of nominal values and is the total (i.e., domestically sourced as well as composite imported inputs) usage of intermediate input 'i' by sector 'j' in region 's'. Thus, it is expressed as

$$E_{ijrs} = F_{irjs} / M_{ijs} \,, \tag{1}$$

where F_{irjs} is the imports of 'i' from source 'r' used by sector 'j' in recipient 's'. In GTAP notation, M_{ijs} is the value of purchases of tradeable intermediate i by firms in industry j of region r. It is to be noted that the definition for the spillover coefficient bears an additional subscript for source sector 'i' so that we write it as

$$g_{ijrs}\left(E_{ijrs}, q_s\right) = E_{ijrs}^{1-q_s} \,, \tag{2}$$

where g_{ijrs} is the spillover coefficient between 'i' in source 'r' and 'j' in destination 's' and q_s is "capture parameter". q_s is the product of the recipient-specific AC-index AC_s (where $0 \le AC_s \le 1$) and the binary structural similarity index SS_{rs} (where $0 \le SS_{rs} \le 1$); it measures the efficiency with which the knowledge embodied in bilateral trade flows from source 'r' is *captured* by the recipients 's' so that:

$$q_s = AC_s \cdot SS_{rs} \ . \tag{2a}$$

The realised productivity level from the potential streams of ‘latest technology’ is dependent on $q_s \in [0,1]$ with $q_s = 1$ implying full capture of the transmitted technology. For any specific constellation of ‘*i*’ and ‘*j*’, to avoid notational clutters, we suppress the industry subscripts and denote (simplistically) the embodiment index between source ‘*r*’ and region ‘*s*’ by E_{rs}. Thus, for any fixed ‘*i*’ and ‘*j*’, q_s and E_{rs} conjointly determine the value of the ‘*Spillover Coefficient*’ $g_s(E_{rs}, q_s)$ for the destination ‘*s*’. More specifically,

$$g_s(E_{rs}, q_s) = E_{rs}^{1-q_s} \ , \quad 0 \le q_s \le 1 \ . \tag{2b}$$

$g_s(.)$ is a strictly concave function of E_{rs} with the properties that

$$g_s(0) = 0 \, , \quad g_s(1) = 1 \, , \quad g_s' = (1-q_s)E_{rs}^{-q_s} > 0 \, , \quad g_s'' = -q_s(1-q_s)/E_{rs}^{1+q_s} < 0 \, ,$$

where primes indicate the first () and the second (′) derivatives with respect to E_{rs}. Given the functional form, for $0 < q_s < 1$ and $0 \le E_{rs} \le 1$, $\dfrac{dg_s'}{dq_s} = -E_{rs}^{-q_s}[1 + \ln g_s]$ and is less than zero. It can also be shown that g_s is a convex function of q_s such that $\dfrac{\P g_s}{\P q_s} = [-g_s(E_{rs}) \cdot \ln E_{rs}] > 0$ and $\dfrac{\P^2 g_s}{\P q_s^2} = [\ln(E_{rs})^2 \cdot E_{rs}^{1-q_s}] > 0$.

It is to be noted that trade intensity is treated as a *binary* variable indexed both for the recipient sector ‘*j*’ in a given region ‘*s*’ and for the source sector ‘*i*’ and region ‘*r*’ of the intermediate products that it uses as inputs. The database, however, does not allow this degree of disaggregation: while we know by source region the total imports of the composite intermediate good used by any given sector in any given region (i.e., $F_{ij\bullet s}$), we do not know the regional composition of imports for individual using sectors in *s*. To accommodate the definition of the embodiment index, we make a pro-rata *assumption* based on import proportionality.[6] In particular, we assume that an imported input is proportionally distributed across all user sectors; that is, the share of imported input ‘*i*’ from source ‘*r*’ in receiving region ‘*s*’ holds for all industries in ‘*s*’ using imported ‘*i*’. Thus, if F_{irjs} indicates usage in region ‘*s*’ by industry *j* of imported intermediate *i* from source *r*, we assume that

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[6] This particular assumption is driven by limitations of data availability. However, in the literature on embodied international technology diffusion, this is a common assumption. See OECD (1997), *Science and Technology Indicators Scoreboard*, p. 105.

$$F_{irjs} / F_{ij\bullet s} = F_{ir\bullet s} / F_{i\bullet\bullet s}\,, \tag{3}$$

where $F_{i\bullet\bullet s}$ is the aggregate imports of tradeable commodity ‘*i*’ in region ‘*s*’ from all source regions. The left-hand ratio in (3) is the quantity share of source *r* in the imports of *i* by sector *j* in its total imports of *i*. The right-hand ratio in (3) is the market share of source ‘*r*’ in the aggregate imports of tradeable ‘*i*’ in region ‘*s*’ evaluated at market prices. In the source region, the benefits of a technological change (exogenous) in a particular sector is reaped *directly* by the other sectors via the *locally* produced material inputs embodying advanced technology and *indirectly* via the changes in relative prices of *imported* intermediates from foreign sources (i.e., the basic premise here is: the latest state-of-the-art technology embodied in the intermediate inputs produced by a sector experiencing technological progress diffuses to other sectors using that material input/s sourced in its own regional market (directly) and via trade from abroad (indirectly). Hence, the exogenous TFP improvement in the source sector in the origin endogenises the TFP improvement in the receiving sectors via a *domestic* spillover effect. Therefore, the relevant sectoral embodiment index $[E_{ijr}]$ for the sectors in the source region is given by

$$E_{ijr} = D_{ijr} / M_{ijr} \qquad (i \neq j)\,, \tag{4}$$

where D_{ijr} is the quantity of domestic tradeable commodity ‘*i*’ used by firms in sector ‘*j*’ of source region ‘*r*’ and M_{ijr} is composite intermediate inputs of ‘*i*’ (from all sources) used by sector ‘*j*’ in ‘*r*’. However, for the source country the relevant capture parameter is defined in terms of the human capital-induced absorption capacity (AC) only. Thus, we assume that the higher is AC in ‘*r*’, the higher will be the domestic sectoral spillover such that the spillover coefficient for source region is written as

$$g_{ijr}(E_{ijr}, q_r) = E_{ijr}^{1-a_r}\,, \tag{5}$$

where $a_r \in [0,1]$ is the human capital (HK) induced capture-parameter for source ‘*r*’. In conformity with our notation for the capture-parameter, q_r maps one-to-one with a_r (where r is the source region).

B. Spillover Equation and Productivity Shock

Following our discussion above, the productivity transmission equation for the client regions can be written as

$$ava(j,s) = E_{ijrs}^{1-q_s} \cdot ava(i,r)\,, \tag{6}$$

where $ava(i,r)$ and $ava(j,s)$ are respectively the percentage changes in TFP levels in source and destinations (where $i \neq j$, $r \neq s$). For the source region ‘r’, the transmission equation (where i and j $(i \neq j)$ are the innovating sector and the receiving sectors respectively) is given by

$$ava(j,r) = E_{ijr}^{1-a_r} \cdot ava(i,r)\,. \tag{7}$$

Moreover, we incorporate a Constant Elasticity of Substitution (CES) nesting of the two types of labour so that skilled and unskilled labours are combined in a CES-nest to form an effective labour composite.[7] However, we do not provide the algebraic derivations and the computer codes for the equations here.

4. METHODOLOGY AND DATABASE

A reduced dimension involving three regions-six sectors aggregation of the GTAP database is calibrated. Version 3 of the GTAP database (i.e., GTAP Sectoral Classification, revision 1 (GSC1)) distinguishes 30 regions and 37 sectors.[8] We take the proportions of skilled and unskilled labour from the GTAP database and use them to derive the skilled and unskilled labour proportions for the GTAP Version 3 sectors. Table 1 presents the sectoral aggregation.

Also, the estimated elasticity of substitution between skilled and unskilled labour in a sector ‘j’ is added in a parameter file. The value (0.83) is taken from econometric estimation. In Das (1999), we considered educational data that can be used as a proxy for human capital endowment. The analysis reveals that the available alternative educational attainment data sets all conform with the share of aggregate labor payments accruing to the skilled labor categories incorporated in the Version 4 of GTAP database.

[7] A diagrammatic exposition of the modified production nest in GTAP is given in Das (1999). Typically, the optimization problem involved in this sub-nest is: minimize total cost of skilled and unskilled labour subject to a pre-specified level of output of effective labour composite. All the Coefficients and Variables declared in the TABLO source file for this particular simulation are not reported here. All the equations (in the GTAP notation) are coded in the TABLO language. TABLO is the algebraic language used by the GEMPACK software suite and is used to solve large economic models. GTAP is a large model focusing on global linkages with sectoral details. See Harrison and Pearson (1996) for a brief introduction. The source TABLO Code for the model is detailed and is available from the author upon request.

[8] See Robert A. McDougall (ed.) (Jan., 1997), *Global Trade Assistance and Protection: The GTAP 3 Data Base*, Center for Global Trade Analysis, Purdue University. As mentioned in Footnote 3, the latest version of GTAP database is Version 5 with much more sectoral and regional disaggregation in details. However, given the sole focus of our analysis consideration of such details is beyond the scope of this paper.

Table 1. GTAP Sectors and GSC1 Identifiers used in the Present Implementation

GTAP Version 3 Sectors	Constituents	GSC1 Identifier
HeavyManuf (Heavy Manufacturing)	Electronic equipment	ele
	Machinery and equipment nec	ome
	Motor vehicles and parts	mvh
	Transport equipment nec	otn
	Paper products, publishing	ppp
	Petroleum, coal products	p_c
	Chemical, rubber, plastic products	crp
	Ferrous metals	i_s
	Metals nec	nfm
PrimaryInds (Primary Industries)	Paddy rice	pdr
	Wheat	wht
	Cereal grains nec	gro
	Vegetables, fruit, nuts	v_f
	Oil seeds	osd
	Sugar cane, sugar beet	c_b
	Crops nec	ocr
	Fishing	fsh
	Wool silk-worm cocoons	wol
	Forestry	for
	Coal	col
	Oil	oil
	Gas	gas
	Plant-based fibers	pfb
	Minerals nec	omn
FoodProds (Food Products)	Bovine cattle, sheeps, goats, horses	ctl
	Animal products nec	oap
	Raw milk	rmk
	Bovine cattle, sheep and goat, horse meat prods	cmt
	Meat products nec	omt
	Vegetable oils and fats	vol
	Dairy products	mil
	Processed rice	pcr
	Sugar	sgr
	Food products nec	ofd
	Beverages and tobacco products	b_t
Textl_Lmfg (Textiles and Light Manufacturing)	Metal products	fmp
	Manufactures nec	omf
	Textiles	tex
	Wearing apparel	wap
	Leather products	lea
	Mineral Products nec	nmm
	Wood Products	lum
Services	Electricity	ely
	Gas manufacture, distribution	gdt
	Water	wtr
	Construction	cns
	Trade, transport	t_t
	Financial, business, recreational services	osp
	Public admin, defence, education, health	osg
Dwellings	Dwellings	dwe

This comes as no surprise, since the GTAP labor split is based on one of these educational data sources. The derivation by Liu *et al*. (1998) of the shares of skilled and unskilled labor in the work force of the 45 GTAP regions from data on educational attainment follows an *ad hoc* regression approach. In this paper, the GTAP data on such shares have been taken as given, although it might have been preferable if the shares had been derived within a production-theoretic framework. Given the shares, an *ex post* rationalization of them within such a framework is offered in Das (1999), thereby deriving estimates of the elasticity of substitution between skilled and unskilled labor. This relies on the inter-regional covariation in the GTAP shares and in measures of educational attainment. The resulting point estimates is in the range of 0.83 (±0.03) depending on the educational data used. These point estimates differ significantly from zero and from unity at a high level of significance. Due to limitations on availability of data on schooling years at detailed sectoral and regional levels as consistent with the database (see Das (1999)), we assume that the substitution elasticities are the same across all the firms in all sectors in all three regions. This does not necessarily undermine our purpose.

5. SIMULATION EXPERIMENT

In the current experiment the source of TFP improvement is assume to be *uniquely* in sector ‘*i*’ in the single donor region ‘*r*’. That is, we consider one unique source sector of innovation ‘*i*’. USA is assumed as the only source of technology creation. As regards the absorption capacity parameter for USA [AC_{USA}], we assign a high value for a_r proxying AC_{USA}. The rationale behind choosing such a high value for skill induced absorptive capacity parameter is governed by the assumption that USA and EU are more similar in terms of the skill intensity of their laborforce than ROW. In particular, we assume $AC_{USA} > AC_{EU} > AC_{ROW}$. It is pertinent to note that for the destination-specific capture parameter, we can calculate the skill-unskilled labor payment shares for the regions and use those skill-intensity ratios as proxying AC. As per our calculation in Das (2003, *forthcoming*), a_r proxying AC_{USA} is highest of all the regions and calculated AC-values are such that $AC_{USA} > AC_{EU} > AC_{ROW}$. On the basis of these observations, we validly assume that USA and EU are more similar structurally as opposed to relatively less amorphous composite region ROW. Hence, this leads us to assign higher parameter values for USA and EU whereas for the rest we choose lower magnitude. The economic model includes structural equation, key technology transmission equations viz., (6) and (7), some additional coefficients and parameters for AC and SS.

Empirical studies confirm that heavy manufacturing (including transport equipment) is one among the industries experiencing relatively rapid rates of technological change (see Keller (1997, 1999)). Based on history, we assume policy shock in heavy manufacturing (i.e., the innovating sector) in USA and perturb the Hicks-neutral technological coefficient there by 4 percent (approximately the annual rate of technical change over 1970-91). In the model we attribute particular patterns of technology diffusion (in regions other than the source region) to the *differing intensities* with which sectors use imported material inputs originating in the source sector and region. In what follows, we report the simulation results.

6. ANALYSIS OF SIMULATION RESULTS

A. Regional Macroeconomic Repercussions

Table 2 summarises the impact of such a shock on some selected macroeconomic variables in the three regions. After the TFP improvement in heavy manufacturing in the USA and the associated endogenous TFP changes in all other sectors (both domestically and abroad), the economy-wide index of TFP registers an improvement in all three regions. However, the magnitude of the index differs markedly across the regions (see row 1, Table 2). USA, being the source of innovation, experiences the highest overall technological progress whereas EU and ROW experience a TFP improvement of lower magnitude than USA; more importantly, amongst the two recipients, EU receives higher doses of technology transmission than ROW. As will be evident from Table 3 below, this depends on the magnitudes of the embodiment index and the spillover coefficient at the sectoral level and economy-wide indexes of embodiment and spillover coefficients.[9]

Table 2. Simulated Regional Effects of Technological Change in the USA on Selected Macroeconomic Variables[1)]

Percentage change in:	USA	EU	ROW
1. Region-wide index of TFP growth	3.98	2.30	0.05
2. Real GDP at Factor Cost	3.98	2.30	0.05
3. Region-wide Price index of Value-added	3.24	1.92	0.44
4. Region-wide index of Real Value-added	3.98	2.30	0.05
5. Nominal Wage	3.24	1.90	0.45
6. Real Wage	3.86	2.18	0.16
7. Rental price of Capital	3.26	1.96	0.44

Note: 1) These values are for percentage changes of level variables from their control values (after the shock).

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[9] The aggregate 'Embodiment Index' for source *r* is defined as the share-weighted average of sectoral embodiment indexes - the weights being the share of output of each sector *j* in aggregate output of all sectors in a region *r*. Analogously, for the recipient regions we use the same weights.

The aggregate spillover index gives us an average *overall* magnitude of technology appropriated by all user sectors in the source (i.e., USA) as well as client regions from the heavy manufacturing sector in the USA via traded and/or domestic intermediates. From Table 3, it is evident that the aggregate embodiment index in USA $[E_{ir}]$ is higher than those in the destinations $[E_{irs}(s \neq r)]$ - compare figures in column 3. Since the capture-parameter (q_r) in USA is higher than q_s in both EU and ROW (see column 4, Table 3), from Equations (6) and (7) it is clear that USA reaps the maximum spillover (g_{ir}) (see column 3 of the same Table). For EU and ROW, although the values of E_{irs} are of the same order of magnitude, the aggregate spillover coefficient (g_{irs}) is of much higher magnitude in EU than in ROW. This is because the higher value of the capture parameter $[q_r]$ magnifies the value of the embodiment index and hence enables EU to record a much higher rate of TFP improvement than in ROW. Note that the ordering of the spillover coefficient in column 3 of Table 3 matches the ordering of the real GDP results in row 2 of Table 2.

Table 3. Values of Economy-Wide Embodiment-Indexes, Spillover Coefficients and Capture-Parameters1)

GTAP Regions (1)	Embodiment Index (E_{irs}/E_{ir}) (2)	Spillover Coefficient (g_{irs}/g_{ir}) (3)	Capture-Parameter (q_r) (4)
EU	0.021	0.520	0.855
ROW	0.011	0.012	0.030
USA	0.797	0.912	0.960

Note: 1) Values shown relate to the pre-shock situation.

The above discussion illustrates the fact that whilst traded intermediates in conjunction with AC and SS are crucial for facilitating transfer of technology, the innovating region reaps the maximum productivity growth by sourcing a relatively high proportion of the 'technological improvement bearing' input from the region in which the exogenous improvement occurs; namely, its own region. Of course, with SS by definition equal to unity for intra-regional flows, the dice are loaded in favour of this result.

Table 2 shows that, region by region, the overall technical change translates exactly into an equivalent percentage increment of real GDP at factor cost (see row 2). Given the fact that shock is HNTP in nature, with fixity of regional supplies of all the components of value-added (measured in raw physical units), the percentage deviation in real GDP at factor cost in each region is equal to the respective region-wide TFP changes (see rows 1 and 2, Table 2). In the solution period, the index of aggregate real value-added exhibits an increment equal in magnitude to region-wide improvement in TFP growth - compare figures in column 1, row 4 with those in the same column, rows 1 and 2. Similar considerations explain the changes in those variables for EU and ROW.

It is to be noted that the change in the price of value-added is governed by the changes in the prices of its components viz., those of land, labour and capital. But, in fact, land is a sector-specific factor of production used only in the primary industries in each economy. In fact, the share of land in the economy-wide value-added is negligible; but varies between the land-using sector and the other sectors (where land's share is zero). Therefore, while the economy-wide rental prices for capital and wage rate do change by different percentages within a given region, the differences are small. This implies an (almost) equal rise in the respective returns to labour and capital across the user sectors so that for a region we get virtually the same rise in the *nominal* wages and rental to capital in all sectors - see rows 5 and 7, Table 2.[10] Real wage rises most in the USA followed by EU and ROW in the second and third rank respectively. All told, with fixed supplies of factors of production, we observe that the TFP improvement inflates the returns (nominal and real) to the factors of production. Because the changes in price relativities across regions (after the TFP shock) induce changes in regional TOT, the pattern of inter-regional competition is disturbed.

B. Inter-regional Competition

The changes in price relativities coupled with the Armington (1969) specification of commodity substitution lead to inter-regional competition via international trade. For the global economy as a whole, we see that there has been an increase in the quantity index of world trade by 1.11 percent. This is the increase in global real exports (or equivalently, in global real imports). Following the shock, the *aggregate* volume of exports increases in the principal beneficiaries of TFP changes namely, USA and EU whilst for ROW, it declines by small. By contrast, the *aggregate* volume of imports increases in *all* three regions; although not so strongly as the rises in exports in USA and EU - see Table 4. The preceding discussion shows that the TFP shock erodes competitiveness of ROW whereas USA and EU, reaping almost the maximum potential benefits, become more competitive than ROW. A much larger rise in the volume of exports from USA and EU and relatively smaller order of magnitude of fall in the volume of exports from ROW translate into a rise in the volume of global trade. The calculation for this involves multiplying each region's shares of aggregate exports of all commodities in total worldwide exports (at *fob* prices) by the respective percentage increases in *real* (aggregate) regional exports and summation over these products across the three regions.

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[10] The base-period shares of land in the economy-wide endowment of all factors are 0.003, 0.004 and 0.02 for USA, EU and ROW respectively.

Table 4. Simulated Regional Effects on Aggregate Trade Performance of the Regions

Percentage change in:	USA	EU	ROW
1. Terms-of-trade	-0.76	-0.44	+0.39
2. Aggregate export price index	-0.63	-0.34	+0.30
3. Aggregate import price index	+0.13	+0.09	-0.09
4. Real value of exports	3.84	2.50	-0.18
5. Real value of imports	1.78	1.12	0.90
6. Change in trade balance	+7301.1	+7176.2	-14477.3

As the TFP improvements act as an export supply shifter for each generic commodity so that for each commodity the volume of global merchandise exports, as well as imports, increases. A relatively much larger fall in export prices in USA as compared to the falls in these prices in EU translate into a much larger decline in the regional price index of merchandise exports in the USA than in EU - see row 2 in Table 4. On the other hand, the rise in export prices in all traded commodities in ROW leads to a rise in its regional price index for exports. However, the values of the changes in the regional price indexes for exports preserve the same ranking and order of magnitude as the regional quantity indexes of exports. The rationale behind this can be easily explained with reference to Table 6 below. The magnitude and directions of the changes in commodity-specific export price indexes are driven by the changes in regional aggregate export price indexes. These export price indexes for the commodities are share-weighted averages across regions of the aggregate exports price index of each commodity from exporting region - the weights being the shares of regional exports in global exports for that commodity. As expected, we see that this has been governed by the magnitude of the sectoral embodiment indexes and spillover coefficients. In effect, following the TFP shock the supply prices for all the produced commodities fall in USA and EU whereas for ROW they increase (as ROW experiences lesser benefits from transmitted technological spillover).

The percentage changes of regional TOT can be decomposed into three components (McDougall (1993)) viz., '*W*orld *p*rice *e*ffect' (*Wpe* (*r*)), 'Export *p*rice *e*ffect' (*Xpe* (*r*)) and 'Import *p*rice *e*ffect' (*Mpe* (*r*)). The *net* effect on *tot* (*r*), however, depends on the magnitude of overall changes in *Wpe* and *Xpe* minus the changes in *Mpe*. Table 5 shows the decomposition of regional TOT into three components of which '*Xpe*' dominates the observed changes in *tot*. In an altered trading environment, the changes in commodity-specific world export price indexes manifest themselves as inter-generic commodity competition.

Table 5. Decomposition of Percentage Changes in Regional TOT

GTAP Region	World rice effect (Wpe) (1)	Export price effect (Xpe) (2)	Import price effect (Mpe) (3)	Total TOT effect [tot (r)] (4) = (1)+(2)−(3)
USA	-0.03	-0.60	+0.13	-0.76
EU	-0.04	-0.31	+0.09	-0.44
ROW	+0.02	+0.29	-0.08	+0.39

After the shock, world export price indexes for all the traded commodities, except those for heavy manufacturing and services, increase - see column 4, Table 6. The changes in the regional market prices of each commodity preserve the identical sign, order of magnitude and ranking across regions as the changes in regional aggregate commodity prices received for tradeables produced in a particular region - compare row 6 with other rows for individual columns for the regions in Table 6. The sector whose world export price index rises most is primary industry (0.22%) followed by textiles and light manufacturing (0.1%). Thus, we see that ROW is a *net exporter* of the commodities whose world price indexes rise most (i.e., primary industries and textiles, light manufacturing) and is a *net importer* of heavy manufacturing (whose price index declines) and food products (whose price index increases by small magnitude). These considerations are responsible for the (small) positive world price effect (*Wpe*) for ROW in column 1 of Table 5.

Table 6. Simulated Effect on Export Price Indexes (Regional and Global) of Commodities

GTAP Sectors	Regions			
	USA (1)	EU (2)	ROW (3)	WORLD (4)
1. PrimaryInds	-0.67	-0.19	+0.35	+0.22
2. FoodProds	-0.65	-0.18	+0.32	+0.02
3. Textl_LMfg	-0.63	-0.29	+0.30	+0.10
4. HeavyManuf	-0.61	-0.35	+0.27	-0.05
5. Services	-0.67	-0.38	+0.34	-0.10
6. Simple Average of regional export prices	-0.65	-0.38	+0.32	-

The sectors in which EU is a *net* exporter (namely, in food products, heavy manufacturing and services) experience declines or very small increases in world export price indexes, whereas the world export price indexes for all the goods in which EU is a *net* importer (viz., primary industries and textiles, light manufacturing) inflate. In the case of USA and EU, these co-movements show a weaker (but inverse) relationship. This explains the positive contribution of *Wpe* for ROW and the negative effects for those of USA and EU - see column 1, Table 5. A glance at Table 6 reveals that the impact of the technological improvement is not so uniform across sectors in EU as it is in the other regions. So while this impact has been more or less neutral across sectors in USA and ROW, primary industries and food products in EU experience lower falls in costs than the other three sectors. For USA and EU, regional aggregate export price indexes fall in *all* industries whereas it increases in *all* the industries in ROW - see Table 6. In case of USA, the fall in these prices in all the traded goods is almost double the rise in export price index in ROW; in EU, *except* for heavy manufacturing and services, the falls in these price indexes are relatively smaller in magnitude than the increase in price of exports in ROW. From the last row of Table 6, we observe that compared to the USA, the relative price changes in ROW are more pronounced than in EU. In other words, the average price index across sectors of tradeable commodities produced in ROW inflates relative to both EU and USA. The relative rises in the average price of ROW commodities compared to those in USA and EU are equal to $0.9\,[=-(-0.61-0.29)]$ and $0.63[=-(-0.34-0.29)$ percent respectively. The change in the regional price index received for tradeables produced in EU relative to that in USA is $0.27\,[=-(-0.61+0.34)]$. These figures indicate that ROW loses its competitive position in the world market whereas USA strengthens its competitive edge relative to EU as well as ROW. For the two major beneficiaries of the TFP improvements (i.e., USA and EU), we see only rises in these quantity indexes of exports - see columns 1 and 2, Table 7.

Table 7. Simulated Effect on Aggregate Regional and Global Quantity Index for Exports

GTAP Sectors	Regions			
	USA (1)	EU (2)	ROW (3)	WORLD (4)
1. PrimaryInds	4.48	2.18	+0.12	+0.68
2. FoodProds	3.66	1.47	-0.58	+0.68
3. Textl_LMfg	4.94	3.01	+0.23	+1.20
4. HeavyManuf	4.04	2.65	-0.50	+1.11
5. Services	3.10	2.27	+0.02	+1.36

By contrast, for the relatively technologically laggard region ROW, regional exports declines in heavy manufacturing and food products with a very small rise in services. Comparing USA and EU, we see that the much larger fall in regional export prices in USA than in EU (as is evident from Table 6) causes the aggregate volume of exports in all the traded commodities from USA to rise by a higher percentage than those from EU.

Considering USA as the destination of exports from EU and ROW, we observe that the percentage increases in the volume of imports from EU are uniformly greater than those from ROW. Since the market prices of the tradeables imported from ROW to USA registered a positive increment as opposed to falls in the import prices for tradeables from EU, the relative price changes in favour of EU translate into a higher percentage increase in demand for commodities in USA imported from EU as opposed to imports from ROW. Similar consideration explains the much larger percentage increases in bi-lateral imports of the tradeables into EU's market from USA than from ROW.

By contrast, in case of ROW (a composite region) there are substantial intra-regional trade flows so that the changes in price relativities between ROW itself and the other supplying regions determine the percentage changes in bi-lateral import sales in ROW between the base-case scenario and the solution under the TFP shock. In the post-simulation scenario, we see that intra-regional imports in the tradeables in ROW from its constituent regions decline whilst USA and EU gain market share in ROW. Thus, in the rest-of-the world, within region sales in heavy manufacturing sector declined by 1.31 percent whereas from USA and EU, the exports increased by 3.8 and 2.3 percents respectively (see Tables 8 and 9). This decline can be ascribed to the rise in the prices of the intra-regional imports from the constituent regions relative to USA and EU. Thus, for USA and EU, we observe that trade creation occurs whereas ROW experiences trade diversion. These are, as expected, associated with relative price changes and sectoral performances in capturing the spillover of improved technology in the USA. However, Table 9 shows that volume of *global* merchandise exports of heavy manufacturing increases after the TFP improvements. Thus, the productivity shock has been trade creating for the global economy as a whole.

Table 8. Percentage Changes in Bi-lateral Import Volumes in the Tradeables in ROW[1)]

GTAP Sectors	Source of Imports:		
	USA (1)	EU (2)	ROW (3)
1. PrimaryInds	4.18	1.86	-0.73
2. FoodProds	3.53	1.40	-0.81
3. Textl_LMfg	4.62	2.61	-0.83
4. HeavyManuf	3.77	2.28	-1.31
5. Services	3.03	1.89	-0.87

Note: 1) Simulated effects of 4% TFP shock in Heavy manufacturing in USA.

Table 9. Simulated Effect on Regional and Global Exports in Heavy Manufacturing Sector

GTAP Sector	Regions			
	USA (1)	EU (2)	ROW (3)	WORLD (4)
HeavyManuf	4.04	2.65	-0.50	+1.11

C. Differential Sectoral Effects

There has been uneven distribution of productivity enhancements across sectors. This can be ascribed to the differentials in base-period values of the bi-lateral sectoral embodiment indexes $[E_{irjs}]$ for the three regions. Considering the case of the two client regions of embodied technological spillover (namely, EU and ROW), it is evident that these indexes depend on the source and user sector-specific trade-embodiment index via the Equations (1) and (2).

From the database, the embodiment indexes for textiles and light manufacturing, heavy manufacturing and services in EU are higher than those in ROW for these industries. Although the indexes do not vary greatly between EU and ROW, the magnitude of the sectoral spillover coefficients for all the sectors in EU are of a higher order of magnitude than those in ROW. Since the magnitude of the economy-wide capture parameter is much higher in EU (0.85) than that in ROW (0.03), this magnifies the values of the sectoral spillover coefficients in EU as compared to ROW. This accounts for the more or less neutral sectoral effects in USA and ROW as reflected in Table 6. As opposed to this, in EU, the range of variation is larger. Since primary industries and food products reap lesser potential benefits from the endogenous technology spillover (via Equations (1) and (2)) than the other three sectors, the percentage declines in the relative prices of these two sectors are not so pronounced like the three remaining traded sectors - see column 2 of Table 6. Note that in USA, the origin of the technological improvement, the values of both of the indexes for embodiment and spillovers are of greater magnitude than the corresponding indexes in EU and ROW. The largest accrual of productivity gains in USA is due to its sourcing of a relatively high proportion of heavy manufacturing from its own market. Given our assumptions about relatively lower endowments of capture-parameters in both EU (0.85) and ROW (0.03) as compared to USA (0.96), it accords well with our *a priori* expectations. So far as the *endogenous* TFP improvements in the three regions are concerned, there is not much variation across sectors within a region (especially in USA and ROW). As conjectured, the TFP improvements across sectors are more or less in conformity with the magnitude of the spillover coefficients. This is reflected in sectoral output growth in three regions (see Table 10).

Table 10. Simulated Effects on Sectoral Output across Regions[1)]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	3.78	2.18	-0.06
2. FoodProds	2.25	1.29	-0.05
3. Textl_LMfg	4.27	2.39	-0.001
4. HeavyManuf	4.11	2.28	-0.23
5. Services	3.98	2.33	+0.15

Note: 1) Simulation results of 4% TFP shock.

In Section 6.B, we have noted that with fixity of supplies of the primary factors of production, the TFP improvements in all the three regions cause nominal and real wages to increase and that with the sluggish factor land having only a negligible share in the region-wide value-added, the percentage increases in the wage and rental to capital - both real and nominal - are almost identical to the percentage rise in the economy-wide factor incomes. However, with the aggregate labour force split into skilled and unskilled categories, we observe differential impacts on the wage rates of these classes of labour in each of the three regions - compare row 1 with row 2 in Tables 11.

Table 11. Simulated Effect on Nominal Returns to Factors of Production across Regions[1)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. Nominal Wage of Skilled Labour	3.25	1.89	0.48
2. Nominal Wage of Unskilled Labour	3.22	1.88	0.44
3. Return (nominal) to Land	2.97	2.04	0.30
4. Return (nominal) to Capital	3.26	1.96	0.44

Note: 1) Simulation results of 4% TFP shock.

As is clear from these Tables, the percentage increases in the skilled and unskilled wage rates differ although by small magnitude. For EU, the percentage changes in the skill-specific wage rates do not differ to four significant digits. Given that the changes in wage relativities are small, with a substitution elasticity of 0.83 applying in every sector, the reallocations between skilled and unskilled labour are small. With region-wide labour mobility, common wage relativities apply across all sectors, so that the percentage changes in the skill-mix ratios are the same in all sectors within a given region. But these changes are small.

Consider the following equations relating to labour demand and supply in any given region:

$$l_{Aj} = l_j - s\,[p_A - p_L]\,, \tag{8}$$

$$l_{Bj} = l_j - s\,[p_B - p_L], \tag{9}$$

$$\sum_j S_j^A l_{Aj} = 0\,, \tag{10}$$

and $$\sum_j S_j^B l_{Bj} = 0\,, \tag{11}$$

in which l_{Aj}, l_{Bj} and l_j respectively are the percentage changes in sector *j*’ s demands for skilled, unskilled, and composite labour; p_A, p_B and p_L respectively are the economy-wide wage rates for skilled, unskilled and composite labour; s is the skilled/unskilled substitution elasticity; and S_j^A and S_j^B respectively are the shares (value basis) of sector *j* in the economy-wide wage bills for skilled and unskilled labour.

Equations (10) and (11) severely constrain the movements that are possible in labour usage. If wage relativities change (and they do), the only channel possible is via changes in the sectoral values of l_j. To see this, subtract (9) from (8), obtaining:

$$l_{Aj} - l_{Bj} = -s\,[p_A - p_B], \tag{12}$$

so that the skilled/unskilled labour ratios must change by the same percentage in every sector (as asserted above). Since there is an increase in the relative wage of skilled labour, $p_A > p_B$ in (12), and we therefore conclude

$$l_{Bj} - l_{Aj} > 0 \quad \text{(for all } j\text{)}. \tag{13}$$

Multiplying (13) by S_j^A and summing over sectors, we obtain

$$\sum_j S_j^A l_{Bj} - \sum_j S_j^A l_{Aj} > 0\,. \tag{14}$$

Using the fixity of the endowment of skilled labour (i.e., Equation (10)), we see that since the second term in (14) vanishes, it follows that:

$$\sum_j S_j^A l_{Aj} = 0 \quad \text{and} \quad \sum_j S_j^A l_{Bj} > 0 . \tag{15}$$

Adding to and subtracting $\sum_j S_j^B l_{Bj}$ simultaneously from (15), we find:

$$\sum_j S_j^A l_{Bj} = \sum_j (S_j^A - S_j^B) l_{Bj} + \sum_j S_j^B l_{Bj} > 0 . \tag{16}$$

But the fixed endowment of unskilled labour (11) implies that the third term in (16) is zero. Hence, from (16) we write

$$\sum_j (S_j^A - S_j^B) l_{Bj} > 0 . \tag{17}$$

Using a similar construction we can also establish that

$$\sum_j (S_j^A - S_j^B) l_{Aj} > 0 . \tag{18}$$

Thus we have found two necessary conditions which make it possible for the sectoral skill intensities to decline in the face of the higher relative wage for skilled labour; namely (17) and (18). In words these say that the proportional changes in both skilled and unskilled labour must be positively correlated across sectors with the difference between each sector's share of the economy-wide skilled wage bill and its share of the corresponding unskilled wage bill. Applying this to all three regions, we find that for the terms in inequalities (17) and (18) that both necessary conditions are satisfied.

In our experiment, the share of skilled labour in the value-added by sector '*j*' in region '*r*' does not differ to four decimal places between the base-case and the shocked solution after the TFP shock. Thus for this particular shock, the labour disaggregation works effectively on a '*tops-down*' basis, the feedbacks from the composition of labour demand being of lower order. The Hicks-neutrality of the TFP improvement implies that, at the initial configuration of inputs, the marginal products of all four primary inputs (land, unskilled labour, skilled labour, capital) change by the same proportion in any region. Both types of labour and capital are free to move between sectors in any given region when relative prices move because of the shock. These reallocations are, for the most part, modest in the sense that the changes in sectoral output are dominated, at least in the case of USA and EU, by the productivity changes (rather than by the reallocation of resources). Given the fact that the base-period shares of skilled and unskilled labour, capital and land (the latter having negligible share in the economy-wide value-added) in each sector's value-added in a region do not change after the impingement of the shock, most of the changes in sectoral output must be attributed to the more pronounced sectoral TFP growth - at least in the cases of USA and EU.

The comparison among the columns in Table 10 implies that the USA and EU performed better in every sector than ROW. The explanation lies in the extent of embodied technology transmission in the three regions. In ROW where the productivity gains are very much smaller, the reallocation of factors between sectors becomes an important explanator of the sectoral output results. The TFP shock, despite being neutral in nature, had differential impacts on the demand for composite labour and that for capital across sectors in any region. This depends, *inter alia*, on the base-period shares of composite labour and capital in the sectoral value-added in any region. Very small percentage changes in the labour-capital ratios across sectors in a region were unable to cause the wage of composite labour to vary much across sectors. This is reflected in more or less the same percentage increases in wages across sectors. Since factors are paid according to their marginal products, following the TFP improvements in each sector the increase in the productive efficiency of labour in each region leads to an increase in the real wages of composite labour in all three regions. However, with perfect labour mobility across sectors in a region, percentage changes in average sectoral wages (both nominal and real) are the same as the percentage rises in the economy-wide wages of labour. Similar consideration applies for the movements of wages for each category of labour. Among the three regions distinguished in these simulations there is a positive relationship between the percentage increase in the wage rate and the region-wide spillover coefficient. So for the experiment conducted here, the technology spillover coefficients dominate the changes in wages.

7. CONCLUDING OBSERVATIONS

Embodied technology diffusion through multi-sectoral, multi-regional interlinkages and the role of absorptive capacity and structural congruence for the capture of potential trade-induced technology flows is analysed in this paper. This analysis has shown that in the context of a transmitted Hicks-neutral technological change, the disaggregation of labour works on a tops-down basis. The simulation results show that the technical change in USA have differential productivity improvements in its trading partners EU and ROW depending on constellation of AC and SS of these regions. The TFP improvement in the USA in heavy manufacturing sector and its spillover to other regions and sectors results in a significant productivity growth in this sector and other sectors using it intensively. The higher magnitude of capture parameters in USA and EU enable them to register higher TFP growth. On the contrary, ROW, with lower productive efficiency parameter, experiences relatively less pronounced TFP growth. As higher skill intensity facilitates adoption of transmitted productivity gains for the regions structurally congruent to each other (i.e., USA and EU), we found higher percentage increases in the wages of skilled labor in the major beneficiaries, USA and EU, than in ROW. Given the higher TFP growth and output in USA and EU vis-à-vis ROW, relative prices move favourably in the USA and EU. These economy-wide changes in price relativities for the tradeables show that ROW loses its competitive position in the world market whereas USA strengthens its competitive edge relative to EU as well as ROW due to favourable movement in regional relative prices there.

The research could be further extended to incorporate the simulation design in which the relative endowments of skilled and unskilled labour changed in the regions. Such a scenario might be explored to work out the effects of a long-term investment in education in less developed countries (see for example, Mayer and Wood (1999) for a most recent discussion on this issue). Another possible area would be to consider the case where factor augmenting technical change occurs at very different rates for the skilled and unskilled groups. Also, our adoption of an economy-wide capture parameter ruled out the possibility of spillovers having much of a variable impact across sectors. In the presence of sector-specific capture parameters which vary with skill intensity, trade intensity and structural congruence between source and destination sectors, we expect a richer mechanics for explaining embodied technological spillover. It is quite likely to consider multiplicity of sources of technology creation. In this context, modelling skill formation, appropriateness of technology and indigenous R&D capabilities will impart valuable insights for enunciating policy insights so as to foster absorptive capacity. All these will help in formulating more refined specification of technology capture and adoption. However, given the limited scope of the paper, we do not explore these issues in the current analysis.

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