Embodied Technology Transfer via International Trade and Disaggregation of Labour Payments by Skill Level: A Quantitative Analysis in GTAP Framework

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Abstract

In this paper, all technology transfers are embodied in trade flows within a three-region, six-traded-commodity version of the GTAP model. 4% Hicks-Neutral technical progress in heavy manufacturing in one region has uneven impacts on productivity elsewhere. Why? Destination regions' ability to harness new technology depends on their *absorptive capacity* and on the *structural congruence* of the source and destination. Together with trade volume, these two factors determine the recipient's success in capturing foreign technology. Sectors intensive in heavy manufacturing register higher productivity growth. Percentage changes in real wages of skilled and unskilled labour do not differ much due to neutrality of the shock.

1. Introduction

This paper offers a disaggregated labour market study of the impact of embodied technology transmission. Technology crosses borders along with traded intermediate inputs in which it is embedded. International trade flows are the primary conduits for technology transfer. The aim here is two-fold: (i) to validate the treatment of substitution between skilled and unskilled labour; and (ii) to assess the income-distributional effects across the two broad skill categories of a total factor productivity [TFP] shock.

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 similarity of factor proportions in the source and destination countries (i.e., on *Structural Similarity*—*SS*). In particular, the effects of *AC* and *SS* (exogenously specified parameters) in harnessing technologies transferred via trade are considered. The

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improved technology transferred via traded inputs into production determines the TFP of the client regions endogenously. These ideas are implemented using the Global Trade Analysis Project's [GTAP] computable general equilibrium model and its database. Section 2 spells out the technology embodiment hypothesis. To implement the technology transmission equations, we made the necessary modifications in the extant GTAP theory as documented in Section 3. In Section 4, based on our econometric estimation of the substitution elasticity between two skill categories, the standard value-added nest of the production function in GTAP is modified by introducing a Constant Elasticity of Substitution [CES] labour nesting.

The underlying database is the Version 3 of the GTAP database with split of labour payments between two skill categories in the same proportions as in the Version 4 database. For implementation, we aggregate the 30 regions $\times$ 37 traded-sectors Version 3 of the GTAP database into 6 traded sectors and 3 regions viz., USA, EU and ROW. Section 5 discusses the sectoral and endowment mapping. This aggregation is motivated primarily by computational tractability. Section 6 documents the GTAP implementation. Section 7 discusses the closure and shock for the experiment. Simulation results are reported in Section 8 and concluding remarks are offered in Section 9.

2. Theoretical Premise: Embodied Spillover Hypothesis[1]

The latest, advanced technologies are researched and 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, or capabilities, for effectively absorbing and adopting 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 newly created 'ideas'. The 'ideas' generated at the sources of inventions, spill over to the destinations through bilateral trade linkages between the nations in an integrated world. Thus, international trade in commodities entails trans-border flows of superior 'technologies' embodied in those traded goods and services [see for example, Coe, et al. (1995, 1997), World Development Report (World Bank 1999) for empirical evidences]. This is the "*embodiment hypothesis*": technical knowledge flows through traded goods. 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 local usability of the diffused technologies depends on the *Absorptive Capacity* [Cohen and Levinthal[2] (1989, 1990)] of the destinations and the *Structural Similarity* [e.g., Hayami and Ruttan (1985)] between the trading nations. The maximum potential for productivity enhancement attainable with a given stock of ideas can be achieved only if both AC and SS are high.[3]

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[1] Our approach is more modest than the approach by Eaton and Kortum (1996a & b) [henceforth, EK], Grossman and Helpman (1991a & b), Connolly (1997). All of these dynamic general equilibrium models have considered the possible interlinkages between invention, technology diffusion and productivity growth. Eaton and Kortum have developed an empirical dynamic general equilibrium model of technology-diffusion based on a "quality-ladder" approach in which, a la Grossman and Helpman (1991a), concerted R&D effort improves the quality of the inputs over a production spectrum in continuum and this quality improvement embodied in the inputs is transmitted via the final products.

[2] The role of such factors in assimilating the foreign technology was first emphasised in the literarure 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] This aspect of "*effective* absorption" has not been studied by the authors cited above in footnote 1.

In a model of relatively recent vintage, van Meijl and van Tongeren (April 1997, 1998) [henceforth, MT] have analysed the issues of technology transfer using the GTAP model. Productivity growth rates of countries are related through international trade linkages and associated "embodied" knowledge-spillovers. However, MT's model incorporates the essential elements of 'AC' and 'SS' factors in determining the domestic usability of foreign technologies. 'AC' is constructed as a binary (source- and destination-specific) index of human-capital-induced absorption capacity of Country A vis-a-vis Country B. Analogously, SS is also a binary index based on the similarity of factor proportions in the two regions (but unlike AC, SS is symmetric). Together with trade volume, these two indexes conjointly determine the 'productive efficiency' parameter.[4] It is argued that domestic usability of the transmitted foreign technology depends mainly on the recipient's capability to utilise the diffused technology. This simplification of MT's treatment of AC is motivated by the desire to keep the model simple by concentrating on first-order effects. It seems likely that if region 'C' is good at absorbing technology from region 'A', it will (to a first approximation) be equally good at absorbing technology from another region 'B' which (from C's point of view) is structurally similar to 'A'. Thus, the AC factor is made destination-specific only. The implementation of our model broadly resembles that of MT so far as the 'framework' is concerned. However, ours differs from theirs in several details. *Firstly*, we modify the technology spillover equations. *Second*, unlike MT where AC is a binary index involving both 'source' and 'destination', we make the 'AC' factor destination-specific only. The 'SS' factor retains its 'binary' affix, though. *Third*, as will become evident from Section 4, we have incorporated a CES nesting of skilled and unskilled labours. The necessary modifications made in the basic spillover equation of MT are rationalised in the next section.

3. Spillover Equations: Modifications to Theory

Technology embodied in traded and domestic intermediate inputs spills over to *all* other sectors and affects their total factor productivities. 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* total factor productivity improvement. For the current implementation, we adopt two different specifications for the technology transmission equation: the first one applies for the *trade-induced spillover* between client regions and the source of innovation, while in the second one, we consider endogenous *domestic spillover* to the sectors in the source itself from the sector experiencing exogenous technological change there. Moreover, we define the embodiment index in terms of input-specific trade intensity. We discuss these modifications in turn.

3.1 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

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4 It is worthwhile to mention here that AC depends not only on Human Capital alone, but also on constellation of factors such as Infrastructural Facilities, Learning Effects, and Own R&D in the recipients. However, we have not considered these factors while defining AC in our model.

$$E_{irjs} = F_{irjs}/M_{ijs} \quad (3.1)$$

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

$$\gamma_{ijrs}\left(E_{ijrs}, \theta_s\right) = E_{ijrs}^{1-\theta_s} \quad (3.2)$$

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

$$\theta_s = AC_s.SS_{rs} \quad (3.2a)$$

The realised productivity level from the potential streams of 'latest technology' is dependent on $\theta_s \in [0,1]$ with $\theta_s = 1$ implying full realisation of the foreign technology-induced productivity improvement. θ_s and E_{ijrs} jointly determine the value of the '*Spillover Coefficient*' γ_{ijrs} (E_{ijrs}, θ_s) for the destination 's'. $\gamma_{ijrs}(.)$ is a strictly concave function of E_{ijrs} with the properties that

$$\gamma_{ijrs}(0) = 0,\ \gamma_{ijrs}(1) = 1,\ \gamma'_{ijrs} = (1-\theta_s)E_{ijrs}^{-\theta_s} > 0,\ \gamma''_{ijrs} = -\theta_s(1-\theta_s)/E_{ijrs}^{1+\theta s} < 0.$$

where primes indicate the first (′) and the second (″) derivatives with respect to E_{ijrs}.

To avoid notational clutters, we suppress 'i' and 'j' indexes for E_{ijrs} and 'i', 'j' and 'r' indexes for γ_{ijrs} so that

$$\gamma_s\left(E_{rs}, \theta_s\right) = E_{rs}^{1-\theta_s}\ ,\ 0 \leq \theta_s \leq 1 \quad (3.2b)$$

Given the functional form, $\gamma_s\left(E_{rs}, \theta_s\right) \leq E_{rs} \leq 1$ for $0 < \theta_s < 1$, $0 \leq E_{rs} \leq 1$ and $\frac{d\gamma'_s}{d\theta_s} = -E_{rs}^{-\theta_s}[1 + \ln\gamma_s] < 0$. $\frac{d\gamma'_s}{d\theta_s} < 0$ implies that marginal returns of γ_s to E_{rs} are a decreasing function of θ_s. It can also be shown that $\frac{\partial\gamma_s}{\partial\theta_s} = [-\gamma_s(E_{rs}).\ln E_{rs}] > 0$ and $\frac{\partial^2\gamma_s}{\partial\theta_s^2} = [\ (\ln E_{rs})^2 .E_{rs}^{1-\theta_s}\ ] > 0$ i.e., γ_s is a convex function of θ_s. Thus, the γ_s function shows increasing marginal returns to θ_s.

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 GTAP 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.[5] 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

[5] 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.

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

$$F_{irjs}/F_{ij\bullet s} = F_{ir\bullet s}/F_{i\bullet\bullet s} \qquad (3.3)$$

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 (3.3) 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 (3.3) is the market share of source ‘r’ in the aggregate imports of tradeable ‘i’ in region ‘s’ evaluated at market prices. In GTAP notation for the coefficients, $F_{ij\bullet s}$ is VIFA (i,j,s)—the value of purchases of imported intermediates i by sector j in any region s evaluated at agents’ prices, $F_{ir\bullet s}$ is VIMS (i,r,s)—the value of imports of tradeable good i from r to client s, $F_{i\bullet\bullet s}$ is VIM (i,s) —the value of aggregate imports of tradeable commodity i in region r evaluated at importer’s market prices and the right-hand ratio is the coefficient MSHRS (i,r,s). MSHRS (i,r,s) is *assumed* to hold for all industries ‘j’ in ‘s’ using imported ‘i’ from origin of innovation ‘r’. In the GEMPACK implementation, we define a new coefficient VIFA_RS (i, j, r, s) to match F_{irjs}.

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 price relativities of imported intermediates. The basic premise here is: the latest technology embodied in the intermediate inputs experiencing technological progress diffuses to other sectors using that material input/s sourced in its own market (i.e., domestically). 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

$$E_{ijr} = D_{ijr}/M_{ijr} \qquad (i \neq j) \qquad (3.4)$$

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

$$\gamma_{ijr}(E_{ijr}, \theta_r) = E_{ijr}^{1-\alpha_r} \qquad (3.5)$$

where $\alpha_r \in [0, 1]$ is the human capital [HK] induced capture-parameter for source ‘r’. In conformity with our notation for the capture-parameter, θ_r maps one-to-one with α_r (where r is the source region). As before, $\gamma_{ijr}(\bullet)$ is a convex function of α_r and strictly concave function of E_{ijr}.

3.2 Spillover Equation and Productivity Shock

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

$$\text{ava}(j, s) = E_{ijrs}^{1-\theta_s} .\text{ava } (i, r) \qquad (3.6)$$

where ava (i,r) and ava(j,s) are respectively the percentage changes in TFP levels (HNTP parameters, AVA) in source and destinations [i≠j, r≠s]. For the source region ‘r’, the transmission equation [where i and j (i≠j) are the innovating sector and the receiving sectors respectively] is given by

$$\text{ava}(j, r) = E_{ijr}^{1-\alpha_r} .\text{ava } (i, r) \qquad (3.7)$$

However, since in our experiment the source of TFP improvement is *uniquely* in sector 'i' in the single donor region 'r', the equations involving i- and r-subscripted variables on the right do not necessarily carry these indexes on their left hand sides.

4. Labour-labour Substitution: Modified Value-added Nest in GTAP

We propose a Constant Elasticity of Substitution (CES) nesting of the two types of labour. Specifically, we assume that skilled and unskilled labours are combined in a CES-nest to form an effective labour composite.[6] We do not provide the algebraic derivations of the percentage change forms for the CES-demand functions for labour types. These are analogous to the derivations for the demands for labour by industry and skill groups in the ORANI model [see e.g., Equation (12.56) in Table 23.1, p-130 in DPSV (1982)]. However, we present the equations (in the GTAP notation) added for the labour nesting—see Table 1.[7]

Table 1: Additional equations for the composite labour nesting in the TABLO Source file

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EQUATION E_qfeO
! Demands for Occupational Types by Industry and skill groups!
(All,o,OCC)(ALL,j,PROD_COMM)(All,r,REG)
qfe(o,j,r) + afe(o,j,r) = qfe_o(j,r) - ESUBUS(j) * [pfe(o,j,r) - pfe_o(j,r)];
EQUATION E_pfe_O
!Price to Each Sector of Labour Composite, Divisia Index of pfe(o,j,r)!
(ALL,j,PROD_COMM)(All,r,REG)
(EVFA_o(j,r)) * pfe_o(j,r) = Sum [o, OCC, EVFA(o,j,r) * pfe(o,j,r)];
EQUATION E_qfe_O
!Each Industry's Demand for Effective Labour Composite!
(ALL,j,PROD_COMM)(All,r,REG)
qfe_o(j,r) = qva(j,r) - afe_o(j,r) - ESUBVA(j) * [pfe_o(j,r) - afe_o(j,r) - pva(j,r)];
EQUATION E_pmO
! This equation assures market clearing in the Composite Labour Markets !
(All,o,OCC)(All,r,REG)
VOM(o,r) * qo(o,r) = sum(j,PROD_COMM, VFM(o,j,r) * qfe(o,j,r))
           + VOM(o,r) * endwslack(o,r) ;
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5. Methodology and Database: Aggregation of Sectors and Endowments

Version 4 of the GTAP database (i.e., GTAP Sectoral Classification, revision 1 (GSC1)) distinguishes 45 regions and 50 sectors and provides us with the splits of labour payments between the two above-mentioned categories. Version 3 of the GTAP database, however, lacks the split between skilled and unskilled labour. So we take the proportions of skilled and unskilled labour from the Version 4 database and use them to derive the skilled and unskilled labour proportions for the GTAP Version 3 sectors. We proceed in several stages: (i) matching the 50 sectors in the Version 4 of the GTAP database with our mapped sectors in the Version 3 of the database (ii) aggregation of the 5 primary factors of production in Version 4 of the GTAP database into 4 primary factors viz., skilled and unskilled labor, land and capital; (iii) derivation of the ratios of skilled and unskilled labour in total sectoral labour force for the aggregated GTAP database (Version 4); and (iv) applying these proportions to derive the labour splits for Version 3 of the database.

Table 2 presents the sectoral mapping.

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[6] 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. This has been spelt out in more detail in the subsequent chapter.

[7] All the Coefficients and Variables declared in the TABLO source file for this particular simulation are not reported here.

Table 2: Concordance of sectors in GTAP Version 4 with GTAP Version3 mapped sectors

GTAP Version 3 Sectors	GTAP Version 4 Sectors	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

We lump natural resources together with land as both of them are sluggish by nature. The estimated elasticity of substitution between skilled and unskilled labour in a sector 'j' [ESUBUS (j)] is added in the existing parameter file. The value is taken from our econometric estimation.[8] Notice that the substitution elasticities [ESUBUS (j)] do not vary across sectors i.e., they are the same across all the firms in all sectors in all three regions. The aggregated database, comprising the files for base period data, sets and parameters, is produced by Mark Horridge's programme "*GTAPAGG*" on the 50×45 trade, production and input-output data in Version 4 of the GTAP database.[9]

6. GTAP Implementation

In our current experiment, we consider one unique source sector of innovation 'i' identified by the set named 'SRCSEC'. SRCSEC is a single-element subset of the set of traded commodities i.e., TRAD_COMM. We define a complementary subset named NSRCSEC comprising the traded sectors other than the sector in 'SRCSEC'. The source region 'r' is also unique. Following our notations and specification of sets, i∈SRCSEC, j∈NSRCSEC, r∈SRC and s∈REG_NOT_SRC, with SRCSEC and SRC singletons. USA is assumed as the source of technology creation. As regards the absorption capacity parameter for USA [AC_{USA}], we assign an arbitrary, high value for α_r proxying AC_{USA}. The rationale behind choosing such a high value is governed by the assumption that USA and EU are more similar in terms of their human capital endowment than ROW. We assign AC_{USA}= 0.96, AC_{EU} = 0.95 such that $AC_{USA} > AC_{EU} > AC_{ROW}$. The economic model includes two additional equations viz., (3.6) and (3.7) appended to the standard GTAP model [Hertel (1997)], some additional coefficients and one additional parameter for AC of region 'r'.[10]

7. Total Factor Productivity Shock and Closure

Empirical studies confirm that heavy manufacturing (including transport equipment), and textiles and light manufacturing are the two industries experiencing relatively rapid rates of technological change [see Keller (1997, 1999)]. We consider heavy manufacturing as the source of innovation in USA and shock the Hicks-neutral technological coefficient there by 4 percent (approximately the annual rate of technical change over 1970-91) so that ava (i,r) = 4. The complete list for the exogenous-endogenous split is given in Table 3.

Table 3: Closure of the current GTAP model *

Exogenous	Endogenous
pop psave profitslack incomeslack saveslack endwslack cgdslack govslack tradslack ao af atr afe *afe_o* ava(SRCSEC, SRC) ava("CGDS", REG) to txs tms tx tm qo(ENDW_COMM,REG);	Rest;

*The contents of the table is an excerpt from the edited GEMPACK command file used in the simulation.

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). We intend to contrast the differences between impacts on the user sectors. In what follows, we report the simulation results with particular attention to the implications of the disaggregation of the labour market.

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[8] See Das (October 1999), "What is assumed in the GTAP database's disaggregation of labour payments by skill level?", CoPS/IMPACT Project's Preliminary Working Paper No. IP-75.

[9] See Robert A. McDougall (Chapter 8), 'Guide to the GTAP database' in McDougall, R.A., A. Elbehri, and T.P. Truong (1998), *Global Trade Assistance and Protection: The GTAP 4 Data Base*, Center for Global Trade Analysis, Purdue University.

[10] Structural equations of the model encoded in TABLO language are not reported for space limitations.

8. Analysis of Simulation Results

8.1 Regional Macroeconomic Repercussions

Table 4 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 4). 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 5 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. 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.[11]

Table 4: Simulated regional effects of technological change in the USA on selected macroeconomic variables[#]

Percentage change in:	USA	EU	ROW
1. Region-wide index of TFP [(a)] growth [Tec_Chg (r)]	3.98	2.30	0.05
2. Real GDP at Factor Cost [NA_realgdpfc]	3.98	2.30	0.05
3. Price Index of GDP at Factor Cost [NA_prigdpfc]	-0.71	-0.37	+0.39
4. Nominal GDP at Factor Cost [NA_gdpfc]	3.24	1.92	0.44
5. Real Gross National Expenditure [NA_realgne]	3.75	2.12	0.29
6. Region-wide index of Real Value-added [qva_agg] (in conventional units)	0.00	0.00	0.00
7. Region-wide Price index of Value-added [pva_agg] (in conventional units)	3.24	1.92	0.44
8. Region-wide index of Real Value-added (in constant efficiency units)	3.98	2.30	0.05
9. Region-wide Price index of Value-added [pva_agg] (in constant efficiency units)	-0.72	-0.36	+0.37
10. Nominal Wage	3.24	1.90	0.45
11. Real Wage [Nominal wage–CPI (ppriv)]	3.86	2.18	0.16
12. Rental price of Capital	3.26	1.96	0.44

[#] These values are for percentage changes of level variables from their control values (after the shock). Figures are rounded to 2 or 3 decimal places. The shock is a 4% increase in TFP in heavy manufacturing.
(a) Figures for row 1 are obtained by incorporating the '*Tec_Chg*' variable.

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[11] The aggregate 'Embodiment Index' for source r [E_{ir}] is defined as the share-weighted average of sectoral embodiment index (E_{ijr})—the weights being the share of output of each sector j in aggregate output of all sectors in a region r [SH_SECOUTAGG (j, r)]. Thus, SH_SECOUTAGG (j,r) = $Y_{jr} / \sum_j Y_{jr}$ where Y_{jr} is gross output of sector j in region r, $\forall$r. Therefore, $E_{ir} = \sum_j$ SH_SECOUTAGG (j, r) $\times E_{ijr}$. Note that since there is only one *unique* source sector 'i' creating the latest technology, we need not have to aggregate over 'i'. Analogously, for the recipient regions we use the same weights and consequently, the aggregate index [E_{irs}, $r \neq s$] is written as: $E_{irs} = \sum_j$ SH_SECOUTAGG (j, s) $\times E_{ijrs}$. Additional coefficients in GTAP notation added in the TABLO file are not presented here owing to want of space.

Table 5: Values of economy-wide embodiment-indexes, spillover coefficients and capture-parameters [(a)]

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

(a) Values shown relate to the pre-shock situation. For EU and ROW, this is product of HK and SS; whilst, for USA this is only the magnitude of HK.

From Table 5, 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 (θ_r) in USA is higher than θ_s in both EU and ROW (see column 4, Table 5), from equations (3.6) and (3.7) it is clear that USA reaps the maximum spillover (γ_{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 (γ_{irs}) is of much higher magnitude in EU than in ROW. This is because the higher value of the capture parameter [θ_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 5 matches the ordering of the real GDP results in row 2 of Table 4.

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 being "inward-looking"—that is, 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 4 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 4). There have been no changes in *qva_agg(r)* [measured in conventional units][12] in the solution period whereas the index of aggregate real value-added measured in constant efficiency units exhibits an increment equal in magnitude to TFP growth—compare figures in column 1, row 6 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

[12] The equations for these two variables as appended in the model are given as:
qva_agg (r) = $\sum_j$ VA_Share (j,r)×qva (j,r) and pva_agg (r) = $\sum_j$ VA_Share (j,r)×pva (j,r) where pva (j, r) and qva (j,r) are respectively the percentage changes in price and quantity indices of value-added of sector j in region r following the shock. VA_Share (j,r) is share of sector j's value-added in total region-wide value-added in region r.

fact, the share of land in the economy-wide value-added is negligible;[13] but varies between the land-using sector and the other sectors (where land's share is zero). Therefore, while the economy-wide rental price 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 (composite) and rental to capital in all sectors—see rows 10 and 12, Table 4. The increase in nominal wage is the same as the increase in regional labour income—see row 10, Table 4. By subtracting the consumer price index (CPI) from the nominal wage, we get the real wage which rises most in the USA followed by EU and ROW in the second and third rank respectively—see row 11, Table 4. With fixed supplies of factors of production and the rise in the economy-wide factor incomes, the percentage increase in composite wage and rental is almost equal to the percentage change in the nominal factor income. All told, we observe that the TFP improvement inflates the returns (nominal and real) to the factors of production so that it has important *factor market* implications to be discussed in detail in section 8.4. Because the changes in price relativities across regions (after the TFP shock) induce changes in regional TOT, we discuss the post-shock changes in the pattern of inter-regional competition in brief.

8.2 Inter-regional Competition

The changes in price relativities coupled with the Armington (1969) specification of commodity substitution open up the scope for inter-regional competition via international trade. Following the shock, the *aggregate* volume of exports [*qxwreg (r)*] increases in the principal beneficiaries of TFP changes namely, USA and EU whilst for ROW, it declines. By contrast, the *aggregate* volume of imports [*qiwreg (r)*] increases in *all* three regions, although not so strongly as the rises in *qxwreg (r)* in USA and EU—see Table 6. 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 [*pxw (i, r)*] 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 [*pxwreg (r)*] in the USA than in EU—see row 2 in Table 6. On the other hand, the rise in *pxw (i, r)* 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. Note that subtracting the figures in row 3 in Table 6 from those in row 2 of the same Table, we reproduce almost exactly the percentage deviation in regional terms-of-trade from the control scenario à la McDougall (1993).[14]

In an altered trading environment, the changes in commodity-specific world export price indexes [*px_i (i)*] manifest themselves as inter-generic commodity competition. However, we do not discuss it here. After the shock, world export price indexes [*px_i*] for all the traded commodities, except those for heavy manufacturing and services, increase—see column 4, Table 7.

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[13] 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.

[14] We do not consider the GTAP definition of Terms-of-Trade as it includes changes in the prices of CGDS which is entirely non-traded. The percentage changes in regional TOT can be decomposed into three components. See McDougall (1993) for the detailed derivations. However, we do not discuss it here due to limitations of space. Interested readers are requested to contact the author.

Table 6: Simulated regional effects on aggregate trade performance of the regions

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

For USA and EU, regional aggregate export price indexes i.e., *pxw (i, r)* fall in *all* industries whereas it increases in *all* the industries in ROW—see Table 7. In case of USA, the fall in these prices in all the traded goods is almost double the rise *pxw (i, r)* in ROW; in EU, *except* for heavy manufacturing and services, the falls in these price indexes are relatively smaller in magnitude than the increase *pxw (i, r)* in ROW. From the last row of Table 7 (which shows changes in average export prices received by each region), we observe that compared to the USA, the relative price changes in ROW are more pronounced than in EU. Thus, 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 [*psw (EU)*] relative to that in USA is 0.27 [= -(-0.61+0.34)]—see Table 8. 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.

Table 7: Simulated effect on export price indexes (regional and global) of commodities[(a)]

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. psw (r)[(b)]	-0.61	-0.34	+0.29	—
7. Simple Average of pxw (i, r)	-0.65	-0.38	+0.32	—

(a) Simulation results of 4% TFP shock.

Table 8 Region-wide relative price changes

Relative to average commodity price of tradeables produced in:	Percentage change in average commodity price of tradeables produced in:	
	USA	EU
EU	-0.27	
ROW	-0.90	-0.63

For the two major beneficiaries of the TFP improvements (i.e., USA and EU), we see only rises in these quantity indexes of exports. Since the market prices of the tradeables imported from ROW to USA [*pms (i, ROW, USA)*] registered a positive increment as opposed to falls in the import prices for tradeables from EU [*pms (i, EU, USA)*][15], 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, for the relatively technologically laggard region ROW, *qxw (i, r)* 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 *pxw (i, r)* in USA than in EU (as is evident from Table 7) causes the aggregate volume of exports in all the traded commodities [*qxw (i, r)*] from USA to rise by a higher percentage than those from EU. 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 [*qxs (i, r, ROW)*] between the base-case solution and the solution. In the post-simulation scenario, we see that intra-regional imports in all the tradeables in ROW from its constituent regions decline (consider column 3, Table 9) whilst USA and EU gain market share in ROW. Thus, for USA and EU, we observe that trade creation occurs whereas ROW loses share in its own market and hence experiences trade diversion there.

Table 9: Percentage changes in bi-lateral import volumes in the tradeables in ROW[(a)]

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

(a) Simulated effects of 4% TFP shock in Heavy manufacturing in USA.

8.3 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}] and spillover coefficients [γ_{irjs}] for the three regions—see Columns 1, 2 and 3 of Tables 10 and 11 below. A glance at these tables reveals that 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 E_{irjs} indexes do not vary greatly between EU and ROW, the magnitude of the sectoral spillover coefficients γ_{irjs} for all the sectors in EU are of a higher order of magnitude than those in ROW—compare all the rows in columns 2 and 3, Table 11.

[15] See Table 7 for the percentage changes in sectoral price indexes in three regions.

Table 10: Base-period values of sectoral embodiment indexes[(a)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. PrimaryInds	0.858	0.012	0.006
2. FoodProds	0.946	0.009	0.006
3. Textl_LMfg	0.887	0.019	0.009
4. HeavyManuf	0.832	0.029	0.018
5. Services	0.872	0.027	0.012

(a) Calculated from the base-period data

Table 11: Base-period values of sectoral spillover coefficients[(a)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. PrimaryInds	0.994	0.526	0.007
2. FoodProds	0.998	0.505	0.007
3. Textl_LMfg	0.995	0.563	0.011
4. HeavyManuf	0.993	0.597	0.020
5. Services	0.995	0.592	0.014
6. Simple Mean	0.995	0.557	0.012
7. Ranges	[0.993, 0.998]= 0.005	[0.505, 0.597]= 0.092	[0.007, 0.020]= 0.013

(a) Calculated from the base-period data

Relatively much higher magnitude of the economy-wide capture parameter in EU (0.85) than that in ROW (0.03) magnifies the values of the sectoral spillover coefficients in EU as compared to ROW. Comparison across sectors within USA and ROW indicates that there is less variation in spillover coefficients in each of these two regions than in EU—the ranges in columns 1, 2 and 3 are 0.005, 0.092 and 0.013 respectively. This accounts for the more or less neutral sectoral effects in USA and ROW. As opposed to this, in EU, the range of variation at 0.092 is larger—see the last entry in column 2 of Table 11. Moreover, the values of spillover coefficients for primary industries and food products are lower than the values for the coefficients in heavy manufacturing, services and textiles, light manufacturing—compare figures in rows 1 and 2, column 2 in Table 11 with those in rows 3, 4 and 5 in column 2 of the same Table. Since primary industries and food products reap lesser potential benefits from the endogenous technology spillover [via equations (3.1) and (3.2)] 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 7.

Note that in USA, the values of both of the indexes for embodiment and spillovers are of greater magnitude than the corresponding indexes in EU and ROW—compare column 1 with columns 2 and 3 in Tables 10 and the same columns in Table 11. The largest accrual of productivity gains in USA is due to its sourcing of a relatively high proportion of the technologically advanced input (i.e., 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. As conjectured, the *endogenous* TFP improvements (see Table 12) across sectors are more or less in conformity with the magnitude of the reported spillover coefficients in Table 11.

Table 12: Simulated effects on sectoral TFP growth in each region[(a)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. PrimaryInds	3.98	2.09	0.03
2. FoodProds	3.99	2.00	0.03
3. Textl_LMfg	3.98	2.24	0.04
4. HeavyManuf	**4.00**	2.38	0.08
5. Services	3.98	2.36	0.06

(a) Simulation results of 4% TFP shock in Heavy Manufacturing in the USA

8.4 Impact on Disaggregated Labour Market

In Section 8.2, 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 (both real and nominal) of these classes of labour in each of the three regions—compare row 1 with row 2 in Tables 13 and 14.

Table 13: Simulated effect on nominal returns to factors of production across regions[(a)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. Nominal Wage of Skilled Labour[(b)]	3.251	1.8882	0.478
2. Nominal Wage of Unskilled Labour	3.229	1.8880	0.436
3. Return (nominal) to Land	2.971	2.041	0.298
4. Return (nominal) to Capital	3.256	1.960	0.439

(a) Simulation results of 4% TFP shock.

(b) Region-wide prices of skilled and unskilled labour is the same as those price changes at the sectoral level.

Table 14: Simulated effect on real[(*)] returns to factors of production across regions[(a)]

GTAP Sectors	Regions		
	USA (1)	EU (2)	ROW (3)
1. Real Wage of Skilled Labour	3.874	2.176	0.188
2. Real Wage of Unskilled Labour	3.852	2.175	0.146
3. Real return to Land	3.594	2.323	0.008
4. Real return to Capital	3.879	2.242	0.149

(a) Simulation results of 4% TFP shock. (*) These are obtained by subtracting regional CPI's from the nominal figures.

As is clear from these Tables, the percentage increases in the skilled and unskilled wage rates do not differ much. 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. To understand these results, it is helpful to consider the following equations relating to labour demand and supply in any given region:

$$l_{Aj} = l_j - \sigma\,[p_A - p_L] \qquad (8.4.1)$$

$$l_{Bj} = l_j - \sigma\,[p_B - p_L] \qquad (8.4.2)$$

$$\sum_j S_j^A\, l_{Aj} = 0 \qquad (8.4.3)$$

and

$$\sum_j S_j^B\, l_{Bj} = 0 \qquad (8.4.4)$$

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; σ 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 (8.4.3) and (8.4.4) 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 (8.4.2) from (8.4.1), obtaining:

$$l_{Aj} - l_{Bj} = -\sigma\,[p_A - p_B], \qquad (8.4.5)$$

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 (8.4.5), and we therefore conclude

$$l_{Bj} - l_{Aj} > 0 \qquad \text{(for all j).} \qquad (8.4.6)$$

Multiplying (8.4.6) by S_j^A and summing over sectors, we obtain

$$\sum_j S_j^A\, l_{Bj} - \sum_j S_j^A\, l_{Aj} > 0 \qquad (8.4.7)$$

Using the fixity of the endowment of skilled labour [i.e., equation (8.4.3)], we see that since the second term in (8.4.7) vanishes, it follows that:

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

and

$$\sum_j S_j^A\, l_{Bj} > 0 \qquad (8.4.8)$$

Adding to and subtracting $\sum_j S_j^B\, l_{Bj}$ simultaneously from (8.4.8), we find:

$$\sum_j S_j^A \, l_{Bj} = \sum_j (S_j^A - S_j^B) \, l_{Bj} + \sum_j S_j^B \, l_{Bj} > 0 \qquad (8.4.9)$$

But the fixed endowment of unskilled labour (8.4.4) implies that the third term in (8.4.9) is zero. Hence, from (8.4.9) we write

$$\sum_j (S_j^A - S_j^B) \, l_{Bj} > 0 \qquad (8.4.10)$$

Using a similar construction we can also establish that

$$\sum_j (S_j^A - S_j^B) \, l_{Aj} > 0 \qquad (8.4.11)$$

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 (8.4.10) and (8.4.11). 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 USA, we find the following values (see Table 15) for the terms in inequalities (8.4.10) and (8.4.11) (where evaluation has taken place at base-case shares). From the final entries in this Table it can be seen that both necessary conditions are satisfied. In our experiment, the share of skilled labour in the value-added by sector 'j' in region 'r' [SVA (i, j, r)] does not differ to four decimal places between the base-case and the shocked solution after the TFP shock (we report the values of such shares in Table 16).

Table 15: Values for the terms involved in the calculations for equations (8.4.10) and (8.4.11) for USA[(a)]

Sectoral share in economy-wide wage of skilled labour (1)	Sectoral share in economy-wide wage of unskilled labour (2)	(1)- (2) = (3)	Percentage changes in sectoral demand for skilled labor (4)	Percentage changes in sectoral demand for unskilled labor (5)	Column (3) × Column (4) = (6)	Column (3) × Column (5) = (7)
S_j^A	S_j^B	$S_j^A - S_j^B$	L_{Aj}	l_{Bj}	$(S_j^A - S_j^B) \, l_{Aj}$	$(S_j^A - S_j^B) \, l_{Bj}$
0.007	0.025	-0.018	-0.210	-0.190	0.004	0.003
0.010	0.023	-0.013	-1.680	-1.660	0.022	0.021
0.028	0.060	-0.031	0.280	0.290	-0.009	-0.009
0.150	0.141	0.009	0.100	0.120	0.001	0.001
0.804	0.751	0.053	-0.010	0.010	-0.001	0.001
					Sum =0.017	Sum = 0.017

(a) Figures for columns (1) and (2) are calculated from base-period data. Columns (4) and (5) are simulation results.

Table 16: Shares of skilled labour in value-added in each sector

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	0.0618	0.0545	0.0177
2. FoodProds	0.1004	0.1157	0.0722
3. Textl_LMfg	0.1600	0.1707	0.1294
4. HeavyManuf	0.2597	0.2527	0.1650
5. Services	0.2995	0.2771	0.2261

Thus for this particular shock, the labour disaggregation works effectively on a '*tops-down*' basis, the feedbacks from the composition of labour demand being negligible. 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). The percentage deviations from base-case of output in sector 'j', region 'r', may be decomposed as

$$y_{jr} = S_k\,(j, r)\times k\,(j, r) + S_{ul}\,(j, r)\times ul\,(j, r) + S_{sl}\,(j, r)\times sl\,(j, r) + S_t\,(j, r)\times t\,(j, r) + ava\,(j, r) \quad (8.4.12)$$

where Sk (j, r), Sul (j, r), Ssl (j, r), St (j, r) are respectively the shares of capital, unskilled labour, skilled labour and land in sector j in region r; k (j, r), ul (j, r), sl (j, r) and t (j, r) are respectively the percentage deviations in the demands for capital, unskilled labour, skilled labour and land following the shock; and *ava (j,r)* is the percentage deviation in the productivity level in sector 'j' in region r'. In this particular experiment, the sectoral total factor productivity growth '*ava (j,r)*' dominates the change y_{jr}.[16] 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 [SVA (i, j, r)] 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.

Table 17: Simulated effects on sectoral output across regions[(a)]

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

(a) Simulation results of 4% TFP shock.

The comparison among the columns in Table 17 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 reallocations of factors between sectors becomes an important explanator of the sectoral output results. A glance at the Tables 18 and 19 reveals that 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 'r'. Very small percentage changes in the labour-capital ratios across sectors in a region were unable to cause the real wage of composite labour to vary much across sectors. This is reflected in more or less the same percentage increases in real wages (as a cost) across sectors—see Table 20.

[16] The magnitude of sectoral TFP improvements across sectors in regions are reported in Table 12.

Table 18: Simulated effects on sectoral demand for composite labour across regions[(a)]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	-0.20	+0.12	-0.11
2. FoodProds	-1.66	-0.66	-0.08
3. Textl_LMfg	+0.29	+0.18	-0.05
4. HeavyManuf	+0.11	-0.07	-0.31
5. Services	+0.01	+0.01	+0.09

(a) Simulation results of 4% TFP shock.

Table 19: Simulated effects on sectoral demand for capital across regions[(a)]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	-0.21	+0.06	-0.11
2. FoodProds	-1.69	-0.74	-0.08
3. Textl_LMfg	+0.26	+0.09	-0.04
4. HeavyManuf	+0.09	-0.16	-0.30
5. Services	-0.02	-0.09	+0.11

(a) Simulation results of 4% TFP shock.

Table 20:Simulated effects on sectoral real wages(as a cost) for composite labour across regions[(a)]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	3.90	2.08	0.09
2. FoodProds	3.88	2.07	0.12
3. Textl_LMfg	3.86	2.18	0.15
4. HeavyManuf	3.85	2.24	0.18
5. Services	3.91	2.27	0.11

(a) Simulation results of 4% TFP shock

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.[17] 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 spillover coefficients dominate the changes in real wages.

9. Concluding Observations

The analysis of embodied technology diffusion by incorporating disaggregation of labour payments by skill levels has shown that in the context of a transmitted Hicks-neutral technological change, the disaggregation of labour does not lead to any significant changes in the sectoral and regional results. But such a conclusion would be unlikely to hold in simulations in which the relative endowments of skilled and unskilled labour changed. Such

[17] The real wages for the effective labour in each sector (from the cost side) is defined as: wage of effective labour in that sector deflated by the sectoral product prices.

a scenario might be explored to work out the effects of a long-term investment in education in less developed countries. Another example would be a scenario in which factor augmenting technical change occurred at very different rates for the skilled and unskilled groups. However, we do not explore these issues further in this thesis. Our adoption of an economy-wide capture parameter ruled out the possibility of spillovers having 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 progress.

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