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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. Inter-regional competition coupled with changes in price relativities loom large in general equilibrium adjustment. Hicks-neutrality of the TFP improvement implies that, at the initial configuration of inputs, the marginal products of land, labour, and capital change by the same proportion in any region. However, for the experiment conducted, productivity changes and the spillover coefficients dominate the variable impact across sectors and regions.

JEL Classifications: D58, F16, O4.

Key Words: Absorptive Capacity, Capture Parameter, Trade, Technology, Armington, TFP.

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1. Introduction

The paper models multi-sectoral issues involved in embodied technology spillover. This entailed necessary modifications in the global trade model to incorporate technology spillover equation. For implementation, we aggregate the 30 regions × 37 traded-sectors Version 3 of the Global Trade Analysis Project's (GTAP) database into six traded sectors and three regions. To understand the channel of spillover, we are motivated primarily by computational tractability and hence, use a lower dimensional database of a large-scale non-linear model. However, we aggregate the database into three regions viz., USA, EU and Rest-of-the-World (ROW). The choice of sectoral aggregation is based on the sectors' technology-intensiveness. Since our purpose is to illustrate the role of the capture parameter in absorbing transmitted technology and ensuing changes in regional trade competition, the low regional dimensionality of the model does not undermine the primary focus of the article. Sections 2 and 3 discuss aggregation of sectors and the aggregation procedure respectively. Section 4 spells out the necessary adjustments made in the theory for implementation of the technology transmission equation and, also describes the simulation design for this implementation. Section 5 reports the results. Section 6 concludes.

2. Aggregation of Sectors

In this implementation, the sectors are defined within broad categories because of shared characteristics. High-technology products such as heavy manufacturing are assumed to be the primary vehicles for embodied technology flows. In Table 1, we map these broad categories with the GTAP Sectoral classification Version 1 (GSC1) industries in Version 3 of the GTAP database.

Table 1 Concordance of GTAP Version 3 Sectors with Current Implementation

GTAP Version 3 Sectors	GSC1 Identifier	Mapped Sectors
paddy rice	pdr	PrimaryInds (Primary Industries)
wheat	wht	
grains	gro	
non grain crops	ngc	
wool	wol	
other livestock	olp	
forestry	for	
fisheries	fsh	
coal	col	
oil	oil	
gas	gas	
other minerals	omn	
processed rice	pcr	FoodProds (Food Products)
meat products	met	
milk products	mil	
other food products	ofp	
beverages and tobacco	b_t	
textiles	tex	Textl_LMfg (Textiles and Light Manufacturing)
wearing apparels	wap	
leather etc	lea	
lumber	lum	
nonmetallic minerals	nmm	
fabricated metal products	fmp	
other manufacturing	omf	
pulp paper etc	ppp	HeavyManuf (Heavy Manufacturing)
petroleum and coal	p_c	
chemicals rubbers and plastics	crp	
primary ferrous metals	i_s	
nonferrous metals	nfm	
transport industries	trn	
machinery and equipment	ome	
electricity water and gas	egw	Services
construction	cns	
trade and transport	t_t	
other services (private)	osp	
other services (govt)	osg	
ownership of dwellings	dwe	Dwellings

3. Aggregated Database: Procedure and Consistency Check

The aggregated database is produced by using GTAP's aggregation programme on the 37×30 trade, production and input-output data in Version 3 of the GTAP database.[2] This involved writing a mapping text file following the concordances presented in Table 1 and

[2] See Robert A. McDougall (Chapter 8), 'Overview of the Data' and 'Guide to the GTAP Database' in McDougall, R.A. (January, 1997), *Global Trade Assistance and Protection: The GTAP 3 Data Base*, Center for Global Trade Analysis, Purdue University. Since our purpose is demonstrating illustrative mechanism of trade-led technology spillover and its impacts across sectors in regions, adoption of Version 3 serves our purpose. Version 6 of database is much disaggregated and the simulation exercise could easily be mounted without loss of generality of results that we discuss here.

running the aggregation programme. This produced the aggregated database comprising the files for base case data, sets and parameters. We refer to this three-region, six-traded-commodity model as GTAP3x6. In order to check for the consistency of the aggregated database, we performed some routine exercises as described below.

It is customary to perform homogeneity tests for checking correct implementation of general equilibrium models. By this we mean conducting two test simulations to verify (i) *real* homogeneity of the model: homogeneity of first degree of the real endogenous variables and homogeneity of degree zero of nominal endogenous variables with respect to real exogenous variables and (ii) *nominal* homogeneity of the model: homogeneity of first-degree of the nominal endogenous variables and homogeneity of degree zero of the real endogenous variables with respect to the numeraire of the model. In both the cases, we adopt the standard short-run closure of the GTAP model as documented in Hertel (1997).

In the first case, we exogenize each region's 'population' and 'endowment factors' and shock them uniformly by 1 percent while holding the numeraire unaltered. This should have reprecussions only on the real endogenous variables to the effect that they are increased by exactly 1 percent. In the second case, the numeraire (i.e., the price of the savings commodity (PSAVE)) is increased by 10 percent.[3] As expected, the prices and dollar values also registered an increment of 10 percent whereas the real variables remained unperturbed by the shock. Thus, the nominal homogeneity test is confirmed as well. In both of these tests, we checked that the endogenous *walraslack* variable was zero to machine accuracy, ensuring market-clearing for the 'saving' commodity *à la* Walràs' Law and also the post-shock equilibrium in the global economy. We also checked for *macro-balance* by ensuring that (i) the zero pure profit condition is satisfied; (ii) GDP from expenditure and income sides match each other for the three regions. The next section documents necessary theoretical adjustments for the basic technology transmission equation.

4. A Mechanism for Trade-mediated Technology Spillover

4.1 Technology Transmission Equations:

Technology embodied in traded and domestic intermediate inputs, in the multi-sectoral analysis, spills over to *all* other recipient sectors and affects their output via induced productivity escalation. These include other sectors in the source region as well as all sectors in the client regions. 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* improvement in total factor productivity (TFP). 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), Nelson, 1990; World

[3] In the standard closure (as documented in GTAP.TAB model), all savers face a common price—PSAVE —for the savings commodity.

Development Report (World Bank 1999), Kosempel, 2007]. The effects of Absorptive Capacity (*AC*) and Structural Similarity (*SS*) in harnessing trade-embodied technologies are considered. We argue that domestic country's ability to use the foreign technology depends on the recipient's capacity to identify, procure and use the diffused state-of-the-art (i.e., on *AC*). *SS* relates to the similarity of factor proportions in the source and destination countries. Recently, Cunha and Heckman (2008) has discussed to role of diverse abilities of people in facilitating productivity of investment in technological knowledge. The degree to which new technology can be absorbed by the destinations depends on the differentials in embodied spillover (depending on AC and SS) which characterizes the extent to which the new foreign improvement in technology is captured locally (Cohen and Levinthal (1989, 1990), Keller, 1997, 2001; Meijl and Tongeren, 1998, Das and Powell, 2001, Das, 2002). For the current implementation, we adopt two different specifications for the technology spillover 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.

In case of multi-sectoral analysis, the amount of trade-induced knowledge spillover from a source sector in the donor region to a particular sector via traded intermediates depends on source and using sector-specific trade-embodiment index.

Let index [E_{ijrs}] be 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 domestically sourced as well as composite imported inputs usage of intermediate input 'i' by sector 'j' in region 's'. Thus,

$$E_{irjs} = F_{irjs}/M_{ijs} \qquad (1)$$

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.

Now, 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 inputs. The GTAP database needed to be adjusted to incorporate this degree of disaggregation: to derive the regional composition of imports for individual using sectors in s, we make a pro-rata *assumption* based on import proportionality--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

$$F_{irjs}/F_{ij\bullet s} = F_{ir\bullet s}/F_{i\bullet\bullet s} \qquad (2)$$

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 (2) 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 (2) 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 source region, the technological change arising exogenously in a particular sector *directly* spills over to the other sectors via the locally produced material inputs embodying advanced technology and *indirectly* via the relative price changes in mported intermediates. The latest state-of-the-art technology embodied in the intermediate inputs experiencing technological progress diffuses to other sectors using that material input/s sourced domestically. Hence, the exogenous TFP improvement in the region of origin endogenises the TFP improvement via a *domestic* spillover effect so that we write the relevant sectoral embodiment index [E_{ijr}] for the sectors in the source region of innovation:

$$E_{ijr} = D_{ijr}/M_{ijr} \qquad (i \neq j) \qquad (3)$$

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'. In GTAP notation, D_{ijr} is VDFA (i, j, r) i.e., the value of purchases of domestically supplied intermediate i by sector j in region r. In fact, the right-hand ratio is the domestic input-output coefficient from the source sector 'i' to the recipient sector 'j' in 'r'. For the source country, the technology capture parameter is defined in terms of the human capital-induced absorption capacity (AC) only. Thus, the higher AC in 'r', presumably, will induce a higher domestic trade-mediated transmission such that the spillover coefficient for source region is written as

$$\gamma_{ijr}(E_{ijr}, \theta_r) = E_{ijr}^{1-\alpha_r} \qquad (4)$$

where $\alpha_r \in [0, 1]$ is the human capital [HK] induced capture-parameter for source 'r'. It is to be noted that the definition for the spillover coefficient for all other regions is:

$$\gamma_{ijrs}\left(E_{ijrs}, \theta_s\right) = E_{ijrs}^{1-\theta_s} \qquad (5)$$

where γ_{ijrs} is the spillover coefficient between 'i' in source 'r' and 'j' in destination 's' and θ_s is the product of human capital [HK] and structural similarity [SS]. $\gamma_{ijr}(\bullet)$ is a convex function of α_r and strictly concave function of E_{ijr}.

Having chosen a particular source sector of technical change in a particular region r, and following our discussion above, the productivity transmission equation for the client regions can be written as

$$\text{ava(j, s)} = E_{ijrs}^{1-\theta_s}.\text{ava (i, r)} \qquad (6)$$

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, the transmission equation is given by

$$\text{ava(j, r)} = E_{ijr}^{1-\alpha_r}.\text{ava (i, r)} \qquad (7)$$

where i and j (i≠j) are the innovating sector and the receiving sectors in the source region 'r'. 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.

4.2 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.

The economic model includes additional equations appended to the standard GTAP model [Hertel (1997)], some additional coefficients and one additional parameter for AC of region 'r'. We assume that USA is the source of technological invention, although other countries do perform, but not so rapidly as North America. For the absorption capacity parameter for USA [AC_{USA}], a high value for α_r proxying AC_{USA} is assigned in keeping with our presumption. The rationale being: USA and EU are more similar in terms of their human capital endowment than Rest-of-the-world (ROW) such that $AC_{USA} > AC_{EU} > AC_{ROW}$. 'ROW' consists of typically the less developed or dynamic developing economies—laggard compared to the US and EU. In the next section, we choose from history a plausible value for the magnitude of the exogenous shock.

4.3 Total Factor Productivity Shock: Background Quantitative Evidence

We consider total factor productivity growth as the indicator of technological progress. We need to identify the source sectors of acquired technology for the GTAP sectors classified into 6 broad categories. There are several empirical studies estimating TFP indexes across regions. Very few provide industry specific TFP indexes. To the best of our knowledge, amongst the recent studies only Keller (1997, 1999) calculated a TFP index by industry for 8 OECD countries. We reproduce the figures below in Table 2 and match with the GSC1 sectors in our current implementation. From the figures, it is evident that the industries included in the heavy manufacturing and textiles and light manufacturing clusters experienced higher average annual TFP growth.

Table 2: Total factor productivity index [Average Annual Growth 1970-91 (%)] by industry for 8 OECD countries

ISIC Code (Rev. 2)	Name	GSC1 mapping (Rev. 3)	Mapped Sectors of GTAP Version 3	Average growth rate	Arithmetic average
31	Food, Beverages, and Tobacco	OFD, B_T	Food Products	1	1.65
32	Textiles, Apparel and Leather	TEX, WAP, LEA	Textiles and light manufacturing	2.3	
33	Wood Products and Furniture	LUM/OMF	Textiles and light manufacturing	2	2.83
34	Paper, Paper products and printing	PPP/OMF	Heavy Manufacturing	1.7	
351/2	Chemicals and Drugs	CRP	Heavy Manufacturing	3.8	
353/4	Petroleum refineries and products	P_C	Heavy Manufacturing	4.3	
355/6	Rubber and plastic products	CRP	Heavy Manufacturing	2.5	
36	Non-metallic mineral products	NMM	Textiles and light manufacturing	2.5	
37	Basic metal industries	NFM	Heavy Manufacturing	3	
381	Metal products	FMP	Textiles and light manufacturing	1.9	1.9
382/5	Non-electric machinery, OCA, professional goods	OME	Heavy Manufacturing	4.3	4.45
383	Electrical machines and communication equipment	OME	Heavy Manufacturing	4.6	
384	Transportation equipment	TRN	Heavy Manufacturing	3.2	3.2

Source: Table A.1, Keller (February 1997), NBER WP # 6113 and Keller (March 1999), NBER WP # 6990

Since the heavy manufacturing sector includes the goods with the relatively most rapid rates of technological improvement, we consider heavy manufacturing as the source of innovation. Having selected heavy manufacturing in USA as the source sector for technological progress, we shock the Hicks-neutral technological coefficient there by 4 percent so that ava (i,r) = 4. Here 'i' is 'Heavy Manufacturing' and 'r' is USA. The 4% TFP change in the USA is approximately the annual rate of technical change recorded for this industry over 1970-91. In the real world, there exist particular patterns of technology diffusion between the source and the recipient sectors. In the model we attribute these patterns (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.

5 Analysis of Simulation Results

5.1 Differential Macroeconomic Effects across Regions

We inject a 4 percent exogenous TFP shock into heavy manufacturing in USA. Table 3 summarizes the differential regional impacts of such a shock. After the TFP improvement in heavy manufacturing in the USA and the associated endogenous TFP both domestically and abroad, the regional economy-wide index of TFP register an improvement with marked differences across the regions.

Note that the aggregative TFP index in any region is a weighted sum of each sector's TFP improvements—the weights being the shares of each sector's value-added in the economy-wide value-added.[4] The endogenous technical change in a sector, in turn, depends crucially on the input-specific trade intensity of a sector; thus, analysis of the effects of such endogenous technical change at the micro (sectoral) level via the composition of intermediate inputs is essential for understanding inter-sectoral competition. However, the extent and magnitude of inter-sectoral technology diffusion and the concomitant rise in the sectoral TFP index depends also on the magnitude of the *region-wide* capture-parameter.

USA, being the source of innovation, experiences the highest overall technological progress. More importantly, amongst the two recipients, EU receives higher doses of technology transmission than ROW. This depends on the magnitudes of the embodiment index and the spillover coefficient at the sectoral level, and of the capture-parameter, which is available only at the region-wide level.

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[4] Share of value-added of sector j in region r is defined as VA_Share(j,r)= $\sum_i$ EVFA(i,j,r)/$\sum_i$ EVOA (i,r) where i∈ENDW_COMM, j∈PROD_COMM and r∈REG. Here EVFA(i,j,r) is the coefficient for firm j's purchase of primary factor input 'i' in region 'r' and EVOA (i,r) is the value of primary factor endowment 'i' in region 'r'. Thus, the aggregate TFP index for region 'r' (Tec_Chg (r)) is given by Tec_Chg (r) = $\sum_j$ VA_Share(j,r) × ava (j,r).

Table 3 Simulated macroeconomic effects of technological change across regions[#]

Percentage change in:	USA	EU	ROW
1. Region-wide index of TFPgrowth [Tec_Chg (r)]	3.98	2.30	0.05
2. Nominal GDP at Factor Cost [NA_gdpfc]	3.24	1.92	0.44
3.Real GDP from Income side [NA_realgdpinc] (market prices)	3.97	2.28	0.07
4.Real GDP from Expenditure side [qgdp] (at market prices)	3.97	2.28	0.07
5.Price index of GDP from Expenditure side [pgdp] (market prices)	-0.70	-0.36	+0.37
6. Change in Trade Balance [DTBAL][Ψ]	+7301.1	+7176.2	-14477.3
7. McDougal Terms-of-trade [tot]	-0.76	-0.44	+0.39
8. Price index for GNE [NA_prigne]	-0.62	-0.31	+0.29
9. Real Gross National Expenditure [NA_realgne]	3.75	2.12	0.29
10. Region-wide index of Real Value-added [qva_agg] (in conventional units)[b]	0.00	0.00	0.00
11. Region-wide Price index of Value-added [pva_agg] (in conventional units)[c]	3.24	1.92	0.44
12. Region-wide index of Real Value-added (in constant efficiency units)[b]	3.98	2.30	0.05
13. Real value of exports [qxwreg]	3.84	2.50	-0.18

[#] These values are for percentage changes of level variables from their control values (post-shock). The shock is a 4% increase in TFP in heavy manufacturing.

Economy-wide indexes of spillover coefficients are constructed [see Table 4 below] to simplify discussion of the role of the region-wide capture parameter in harnessing the benefits of technical change.[5] This aggregate spillover index gives us an average *overall* magnitude of assimilated technology by all user sectors as well as client regions from the heavy manufacturing sector in the USA via intermediates.

[5] 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) $\times E_{ijrs}$. Note that source region 'r' being unique, we need not aggregate over 'r'. Additional coefficients in GTAP notation added in the TABLO file are presented in the Appendix to this Chapter below.

Table 4: Values of economy-wide spillover coefficients and capture-parameters

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

From Table 4, it is evident that the aggregate embodiment index in USA [E_{ir}] is higher than those in the destinations [E_{irs} ($s \neq r$)] and since the capture-parameter (θ_r) in USA is higher than θ_s in both EU and ROW, it is clear that USA harnesses the maximum spillover (γ_{ir}). In the case of EU and ROW, there has not been full diffusion of technical change from USA due to lower values of θ_s in the destinations. The aggregate spillover coefficient (γ_{irs}) is, however, of much higher magnitude in EU than in ROW. This is attributed to the higher value of the capture parameter [θ_r] enabling EU to record a much higher rate of TFP improvement than in ROW.

Table 3 shows that, region by region, the overall technical change translates into an equivalent percentage increment of real value-added (see row 12). For all the regions, we computed the change in region-wide real value-added and the change in the aggregate price index of value-added —both measured *in conventional units*.[6] For USA, following the shock, one-hundred input hours of composite real value-added are equivalent to almost one-hundred and four quantity units of composite value-added measured in *constant efficiency units* applicable in the base-period. Consequently, there have been no changes in [measured in conventional units] the solution period whereas the index of aggregate real value-added measured in constant efficiency units exhibits an increment equal in magnitude to region-wide improvement in TFP growth. Similar considerations explain the changes in those variables for EU and ROW.

As regards the changes in the GDP deflator, it preserves the same rank and order of magnitude as the ensuing changes (*ex post*) in competitiveness of the regions. Following the HNTP shock in heavy manufacturing in USA, as has been argued elsewhere, USA reaps the maximum potential benefits vis-à-vis its trade partners viz., EU and ROW, by dint of relatively higher capture of technical change. This implies that USA has the highest spillover coefficient followed by EU and ROW in the second and third rank respectively. Needless to

[6] 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. Table 4 is also detailed in my other paper, but with different focus.

say, average improvement in economy-wide TFP follows the same ranking and ordering as well. All these factors contribute to the marked increase in competitiveness of USA vis-à-vis EU and ROW. Therefore, USA becomes the most efficient player in the world market and EU, having experienced medium-sized technical change, becomes relatively less competitive vis-à-vis the USA, but more competitive vis-à-vis ROW.

From rows 5 and 8 in Table 3, it is clear that for each region the shock has differential impacts on the *absorption deflator* [*NA_prigne (r)*] and the *GDP deflator* [*pgdp(r)*]. The changes in *real* GDP and *real* GNE can be accounted for by the changes in these deflators. It is to be noted that USA and EU, despite becoming more competitive as compared to relatively laggard ROW, experience deterioration in their terms-of-trade [TOT] whereas ROW registers an improvement in it—see row 7, Table 3. The ordering of these changes in TOT matches the changes in export volumes (see row 13 in Table 3), suggesting that the effects of movements along export demand curves may be an important component of the TOT changes. These movements in TOT and the associated changes are dependent on *inter-regional competition and compositional changes* in each economy following the perturbations. These are now discussed below. In particular, we consider the movements in *pgdp (r)*, *NA_prigne (r)* and their components, starting with the impact on regional income and the three categories of income-use, as specified in the model structure.

5.2 Effects on Regional Income and Components of GDP and GNE

From the above discussion, it is evident that following the shock the aggregate price index of value-added measured in conventional units [*pva_agg (r)*] increases in each region (row 11, Table 3). This is equivalent to the market price index of primary factors in a region. Since economy-wide endowments of primary factors are exogenous and do not change, the increase in endowment income is the dominant source of the increase in *nominal* income in all three regions—compare row 1 with row 18, Table 5. 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. If all factors of production were mobile between sectors, then with economy-wide endowments fixed, an increase in *pva_agg (r)* would translate into an equal percentage increase in the rental price of capital, in the nominal wage and also in the rental price of land. The increase in nominal wage is the same as the increase in regional labour income—see row 23, Table 5. By subtracting the consumer price index (CPI) from the nominal wage, we get the real wage that rises most in the USA followed by EU and ROW in the second and third rank respectively. With fixed supplies of factors of production and the rise in the economy-wide factor incomes, the percentage increase in wage and rental is almost equal to the percentage change in the nominal factor income.

Table 5: Simulated regional effects on regional income, categories of final demand and selected macrovariables$^{\Theta}$

Percentage change in:	USA	EU	ROW
1. Regional household income [y (r)] (Nominal)	3.71	2.22	0.47
2. Regional income deflator [incdeflator (r)]	-0.60	-0.28	+0.25
3. Regional household income [u (r)] (Real)	4.32	2.50	0.22
4. Regional demand for net savings [qsave] (Real and nominal)	3.71	2.22	0.47
5. (Real) Public consumption [ug (r)]	4.37	2.61	0.16
6. Nominal Public consumption [yg(r)]	3.71	2.22	0.47
7. Nominal Private household expenditure [yp]	3.71	2.22	0.47
8. (Real) Private household consumption [up]	4.35	2.50	0.17
9. Consumer price index [ppriv]	-0.62	-0.28	+0.29
10. GDP price deflator [pgdp]	-0.70	-0.36	+0.37
11. McDougal Terms-of-trade (tot)	-0.76	-0.44	+0.39
12. Aggregate export price index [pxwreg]	-0.63	-0.34	+0.30
13. Aggregate import price index [piwreg]	+0.13	+0.09	-0.09
14. Real value of exports [qxwreg]	3.84	2.50	-0.18
15. Real value of imports [qiwreg]	1.78	1.12	0.90
16. *Real* GDP from Expenditure and income side [qgdp] (at market prices)	3.97	2.28	0.07
17. Government purchase price index [pgov]	-0.64	-0.38	+0.31
18. Contribution of Endowment income [CON_pfacy (r)]	3.35	2.08	0.45
19. Price of Investment goods [pcgds (r)]	-0.55	-0.34	+0.26
20. *Real* Gross regional investment [qcgds (r)]	0.39	0.53	0.66
21. Price index for GNE [NA_prigne]	-0.62	-0.31	+0.29
22. *Real* Gross National Expenditure [NA_realgne]	3.75	2.12	0.29
23. Regional Labour Income [Nominal]	3.24	1.90	0.45

Θ Figures in this table are rounded to 2 or, 3 decimal places. Author's simulation results.

Under the behavioural assumptions in GTAP[7] for the allocation of regional household income among three income-uses viz., private household expenditure [PRIVEXP (r)], public consumption [GOVEXP (r)] and saving [SAVE (r)], each category enjoys a fixed budget share in total regional income. Following the increase registered in nominal income, the fixed budget share of each of these categories translates into equal percentage increases in nominal demand for private and public consumption as well as for saving—see rows 4, 6 and 7 in Table 5. For the corresponding real variables, we see that in each region they also move together in the same direction—see rows 3, 5 and 8 in Table 5. However, they do not move strictly in proportion to each other. The changes in real consumption expenditures are attributed to the differential impacts of movements in public and private consumption deflators viz., *pgov* and *ppriv* (i.e., the *CPI*) respectively.

[7] In the standard GTAP framework, at the top level of aggregation, the representative regional household maximises per capita Cobb-Douglas utility function subject to exogenous regional income.

The regional income deflator [*incdeflator (r)*] has the same sign and ranking as the *CPI* and *pgov*—compare row 2 with rows 9 and 17 in Table 5.

Now for public and private household consumption, domestically produced traded commodities as a whole dominate the consumption baskets as compared to total imported commodities.[8] As USA and EU become more competitive after the TFP improvement, the fall in the prices of all the traded goods in USA and EU causes the *CPI* to decline there. On the other hand, for ROW, the increase in supply prices of all the commodities translates into a rise in the consumption deflators there—see row 9, Table 5.[9] However, much larger changes in *pgov (r)* than the *CPI* are attributed to the relatively higher share of domestically sourced products in the government consumption basket (vis-à-vis private consumption) and the relative price changes of imported versus domestic goods.[10]

Turning to the case of *pgdp*, we see that it is weighted sum of percentage changes in the absorption deflator [*NA_prigne*], in the regional export price index [*pxwreg*], in the regional import price index [*piwreg*], and in the price index for exports to the global transportation sector (same as *pxwreg*)—the weights being the shares in GDP of GNE, of exports [VXWD], of imports [VIWS], and of sales to global transport services [VST]. Tables 6 and 7 respectively list the base and post-simulation figures for the weights of components of *pgdp* as stated above. From Table 6, we observe that the difference between *pgdp* and *NA_prigne* reflects the percentage deviation of the TOT from the control scenario.

[8] As per the calculations from the base-case data, the share of domestically sourced products in the private household consumption (for 6 traded goods as a whole) is 94% for the USA, 96% for EU and 92% for ROW. This is lower than that in public consumption—i.e., 97% for USA, 99% for EU and 96% for ROW. Moreover, for private household the share of composite imports in total consumption is higher than that for public consumption.

[9] The fall in the supply prices of each of the 6 traded commodities in both USA and EU is governed by the endogenous productivity enhancement and resultant changes in composition of material inputs. The opposite is the case with ROW.

[10] It is pertinent to note that the changes in price relativities between domestically sourced goods and foreign goods affect the composition of demand for each traded commodity for each category of consumption. We do not discuss it in detail.

Table 6: Base-case values of GDP, GNE and some shares[(d)]

Base-case values of:	USA	EU	ROW
1. GNE	5970780	7041530	10288300
2. GDP	5943700	7034240	10322700
3. GNE/GDP	1.004556	1.001036	0.996668
4. Exports [VXWD]/GDP	0.096535	0.104355	0.196077
5. Imports [VIWS]/GDP	0.1078	0.1121	0.2029
6. Trade balance (in million U.S. $) [= (VXWD + VST -VIWS]	-27084.2	-7290.16	+34374.46
7. Sales to Global transport sector [VST](at market prices)/GDP	0.007	0.007	0.010

(d) Calculated from base-period data

Table 7: Post-shock values of GNE, GDP and some related shares[(e)]

Post-shock values of:	USA	EU	ROW
1. GNE	6156260	7168620	10348600
2. GDP	6136480	7168510	10368500
3. GNE/GDP	1.0033	1.0001	0.9981
4. Imports [VIWS]/GDP	0.1064	0.1114	0.2036
5. Exports [VXWD]/GDP	0.0966	0.1046	0.1954
6. Trade balance (in million U.S. $)	-19783.1	-113.84	+19896.96

(e) All the figures are calculated from post-shock, updated data base.

Now, *pgdp* includes the price of exports [*pxwreg*] with a positive weight as well as the price of domestic consumption. Moreover, *pgdp* includes the price of imports [*piwreg*] with a negative weight. On the other hand, the absorption deflator [*NA_prigne*] includes imports with a positive weight. Therefore, the positive values of *piwreg* and the negative values of *pxwreg* in USA and EU lead to a more negative change in *pgdp* than in *NA_prigne*. The opposite is the case with ROW.

Table 8: Component-wise effects on pgdp [(f)]

Share weighted values of:	USA	EU	ROW
1. GNE deflator [= NA_prigne × GNE/GDP]	-0.618	-0.313	+0.289
2. Price of exports [= pxwreg × Exports/GDP]	-0.061	-0.036	+ 0.059
3. Price of imports [= piwreg × Imports/GDP]	+0.014	+ 0.011	- 0.017
4. Price of exports for international transportation sector [= ps × VST/GDP]	-0.004	- 0.002	+ 0.003
5. Percentage changes in GDP price deflator [pgdp = (1)+ (2)+ (4)- (3)]	-0.697	-0.362	+0.368

(f) Calculated from base-period data and the figures.

Turning to the case of GNE and its components, we observe in Table 7 that in the base-case scenario, *nominal* GNE exceeds GDP for USA and EU whereas *nominal* GDP is bigger in magnitude than *nominal* GNE in the case of ROW. The same is the case in the solution period—compare rows 1 and 2 in Table 6 and the same rows in Table 7. This shows that in both the scenarios, USA and EU has trade deficits whilst ROW enjoys a surplus in trade—see row 6 in Tables 6 and 7. Although real GNE [*NA_realgne (r)*] and real GDP [*qgdp (r)*] register unidirectional movements in each region, they diverge from each other—compare rows 16 and 22 in Table 5. Since GNE includes (apart from private and public household expenditures) regional demand for gross investment expenditure [REGINV (r)], we consider the impact of the perturbation on the value of output of capital goods sector in each region. In the current closure, price of the savings commodity (PSAVE) is the *numeraire*. As explained before, the increases in *y(r)* lead to equal percentage increases in the regional demands for nett savings, *qsave* (*nominal and real*) which are aggregated into a global nett savings pool. Thus, the global supply of saving—used to finance global expenditure on nett investment—increases by 1.29 percent following the shock. This figure for the global supply of capital goods composite [*globalcgds*] is a weighted average of *qsave* (Table 5)[11].

Now the sum of regional nett saving commodities provides a composite investible fund. Due to the allocation of the world pool of the *real* CGDS composite across regions in the same fixed proportion of NETINV(r) to GLOBINV as in the base-case and given its higher base-period proportion, ROW gets a larger allocation (61 percent) from the global nett saving pool than USA (13 percent), while EU receives the remainder (26 percent). Given the fixity of the regional composition of global nett investment in this closure, after the simulation the region-specific ratios of NETINV(r) to the GLOBINV pool remain unperturbed from the base case, so the percentage changes in regional *real* nett investment demand [*qnetinv (r)*] share a common value—'*globalcgds*'. Regional demand for *real gross* domestic capital formation [*qcgds(r)*] is determined by multiplying a region-specific ratio of conversion from *nett* to *gross* investment[12]. Hence, the allocation mechanism leads to a higher percentage increase in *real* gross investment demand in ROW than those in USA and EU, leading to a surge in real GNE relative to real GDP in ROW—compare rows 16 and 22 in Table 5.

In the control scenario, USA and EU had trade account deficits and ROW enjoys a trade surplus. The favourable TFP shock enables USA and EU to *reduce* their trade and saving deficits, whereas ROW sees a *decline* in its surpluses. Whilst ROW receives a higher

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[11] The formula used for this calculation is**:** $globalcgds = \sum_r$ [SAVE(r)/GLOBINV] $*$ qsave (r). The values for these shares in the base case are 0.11, 0.26 and 0.63 for USA, EU and ROW respectively.

[12] The base-case values for the 'proportion' of NETINV(r) to REGINV(r) calculated from the database are respectively 0.30, 0.41 and 0.51 for USA, EU and ROW. The increase *qcgds(r)* is this ratio times the percentage deviation (1.29) of regional *nett* investment demand from the control scenario.

allocation of '*globalcgds*' than USA and EU, the percentage increase in saving in ROW, (*qsave*) is less than that in USA and EU (see row 4, Table 5).[13] However, a larger rise in gross saving coupled with relatively modest rise in gross investment has managed to reduce the '*saving gap'* in USA and EU. The opposite is the case with ROW. As there has been a higher percentage increase in the *value* of exports than in the *value* of imports in both USA and EU, the trade deficits in these two regions are reduced. These improvements in trade balances are equal to the differences between row 6 of Table 6 and the same row in Table 7. The declines in the trade deficits almost exactly match the reductions in the saving gaps. With inadequate domestic saving for meeting its relatively large gross investment demand, ROW finances the gap by capital inflow, which shows up here as a fall in its trade surplus. This is matched by the sum of the improvements in the trade balances of USA and EU (the sources of the capital inflows). We see that ROW's surplus has declined by US $ 14477.3 million. However, the TFP shock causes the aggregate *volume* of imports in ROW to *rise* by 0.90% whereas its exports registered a *decline* by 0.18%. As regards the value of aggregate imports, for ROW it increases by a larger proportion (0.81%) than the value of aggregate exports (0.12%).

In this closure, regional capital stocks in use are kept at their control equilibrium values. With full capacity utilization, the percentage changes in the *flow* of capital services, *ksvces(r)*, from these stocks are zero. As the percentage change in the end-of-solution period capital stock KE(r)[14] depends on the change in *real* gross investment flows in a region and on the base-period value of the ratio of gross regional investment [REGINV(r)] to [KE(r)] namely, INVKERATIO(r), higher values of INVKERATIO(r) and *qcgds(r)* in ROW are reflected in relatively larger percentage changes in its end-of-period capital stock as compared to those in EU and USA (row 7, Table 9).

[13] This follows from the fixed budget-share of regional saving in regional income under the Cobb-Douglas specification.

[14] In levels form, the *stock-flow* relation for KE(r) and beginning-of-perid capital stock [KB(r)] is: KE(r)= KB(r)*[1-DEP(r)] + REGINV(r). Corresponding percentage change form is given by: ke(r)= INVKERATIO(r)* qcgds (r) + kb(r) * [1- INVKERATIO (r)].

Table 9: Simulated effects on rate of returns and base-period values of some capital-related coefficients[(a)]

Values of:	USA	EU	ROW
1. GRNETRATIO [r]	1.49	1.43	1.45
2. INVKERATIO [r]	0.056	0.066	0.079
3.Percent changes in Rental price of capital [ps(Capital,r)]	3.26	1.96	0.44
4.Percent changes in Price of Capital Goods [ps(CGDS,r) = pcgds (r)]	-0.55	-0.34	+0.26
5.Percent changes in Current net rate of return [rorc(r)]	5.72	3.29	0.26
6.Percent changes in Expected net rate of return [rore(r)]	5.49	2.94	-0.27
7.Percent changes in End of period capital stock [ke(r)]	0.022	0.034	0.052
8. Value of beginning of period capital stock [VKB (r)] (in million US $)	16107373	21142688	31888734

(a) The figures in this Table are rounded to 2 or, 3 decimal places. Values for the coefficients are reported from base period data.

As we assume that the sensitivity of the prospective rate of return (for the period following the solution period) to the prospective proportional expansion in the regional capital stock are the same across all regions, we see that a relatively larger percentage increase in KE(r) and a smaller value of current rates of return *rorc(r)*[15] in ROW cause *rore(r)* to fall there. On the other hand, a relatively larger *rorc(r)* and very small percentage increases in KE (r) in USA and EU causes *rore(r)* to increase in the period following the solution period in these two regions (rows 5 and 6, Table 9).

As has been mentioned elsewhere, the movements in TOT have been associated with changes in trade balance [DTBAL (r)] to the effect that the USA and EU record an improved balance whilst in ROW, the balance deteriorates—see row 6, Table 3. 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. In the case of multi-sectoral analysis, differential impacts on sectoral performance give rise to inter-generic commodity competition. By this we mean that since there are intersectoral differences in embodiment indexes [Eijr and Eijrs] and in spillover coefficients [γijr and γijrs], the trade-induced endogenous TFP improvements also vary across sectors—both at the inter- and intra- regional level. This, in turn, affects the competitiveness of the industries. In the next section, we document the component-wise effects on regional TOT and on sectoral performance and competition between each generic commodity.

[15] In level form, rorc (r) is expressed as: RORC(r)= [RENTAL(r)/PCGDS(r)]-VDEP(r). The corresponding percentage change form is: rorc(r)= GRNETRATIO (r) * [rental (r)-pcgds(r)] where GRNETRATIO (r) is the ratio of the gross to the net rate of return in region r.

5.3 Inter-regional Competition via Terms-of-Trade Effects

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. 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.

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). As has been mentioned before, 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.

According to base-period data, ROW has a higher share (61 percent) in total world exports in all traded commodities than USA (17 percent) and EU (22 percent). 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. Now the changes *qxwreg (r)* are obtained as the sum total of the products of the percentage changes in the volume of aggregate merchandise exports of the traded commodities from each region [*qxw (i, r)*] and the shares of the value [VXW (i, r)] of exports of each commodity from the exporting region 'r' in the value of world exports (*fob* prices) [VXWREGION (r)]. In fact, the changes in the aggregate real exports of a commodity from any region [*qxw (i, r)*] and its regional distribution via trade can be ascribed to the altered productive efficiencies and the resultant price movements.

Turning to the case of the aggregate price index of world trade [*pxwwld*], we observe that it falls by 0.01 percent. Following the same vein of arguments, we see that such change has been generated by the percentage changes in the *world* export price index for each traded good [*px_i (i) = pxwcom (i)*]. The latter is a weighted average of the percentage changes in the *regional* aggregate export price indexes of the traded goods [*pxw (i, r)*]—the weights being the share of VXW (i, r) in value of world exports of commodity 'i' evaluated at *fob* prices. In effect, following the HNTP shock the supply prices for all the produced commodities fall in USA and EU whereas for ROW they increase. A relatively much larger fall in *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. 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.

As has been discussed in McDougall (1993), the percentage changes of regional TOT can be decomposed into three components viz., '*W*orld *p*rice *e*ffect' (*Wpe (r)*), 'Export *p*rice *e*ffect' (*Xpe (r)*) and 'Import *p*rice *e*ffect' (*Mpe (r)*). Without reproducing the detailed derivations, we rewrite the expressions for the decomposition as below:

$$\text{tot (r)} = \sum_i (\text{EXP\_SHR(i, r)} - \text{IMP\_SHR(i, r)}) (\text{px\_i(i)} - \text{pxwwld})$$

$$+ \sum_i \text{EXP\_SHR(i, r)} (\text{pxw(i, r)} - \text{px\_i(i)})$$

$$- \sum_i \text{IMP\_SHR(i, r)} (\text{piw(i, r)} - \text{px\_i(i)}) \qquad (8)$$

where the first two terms entering with positive signs are *Wpe* and *Xpe* respectively whilst the last term with the opposite sign represents *Mpe*. In the above expression, *EXP_SHR (i, r)* and *IMP_SHR (i, r)* are the shares of good i in the total exports from region r and in the total imports into region r respectively; *px_i (i)* is the world export price index for commodity i; *pxw (i, r)* and *piw (i, r)* are respectively the export and import price indexes for good i in region r. Table 10 shows the decomposition of regional TOT into three components of which '*Xpe*' dominates the observed changes in *tot*.

Table 10: Decomposition of percentage changes in regional TOT

GTAP Region	World price 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

In an altered trading environment following the technological improvements in all the regions, we need to consider the changes in commodity-specific world export price indexes [*px_i (i)*]. These export price indexes for the commodities are share-weighted averages across regions of the aggregate exports price index of commodity 'i' from exporting region 'r' [*pxw (i, r)*]—the weights being the shares of region r's exports in global exports for i [SW_IR (i, r)]. In a multi-sectoral model, the changes in these price indexes manifest themselves as *inter-generic commodity competition*.[16] From equation (8), it is evident that, from region r's point of view, the world price effect *Wpe (r)* is an inner product across the commodities 'i' it produces of its net exports of 'i', and of the percentage change in the deviation of the world price index of 'i'

[16] Note that in a one-traded-sector framework with no other generic commodities, this effect is not operative (i.e., *Wpe* is identically zero). See Das and Powell (2001).

from the global average price index of all commodities. This component of *tot (r)* will be large and positive if there is a strong positive correlation between the generic commodities that 'r' specializes in exporting and the commodities whose relative prices rise most in the world market. Thus, if the overall world export price index inflates by more than the average world export price of a commodity 'i' of which region 'r' is a *nett* exporter, this affects r's terms-of-trade unfavorably. In Table 10, we observe that *Wpe (r)* in USA and EU are of opposite signs from those in ROW.

So far as the base-period shares of exports of each commodity in aggregate *world* exports of all the commodities from all the regions are concerned, heavy manufacturing has the highest share (47 percent) followed by services (24 percent), textiles and light manufacturing (14 percent) and primary industries (12 percent) with food products having negligible share (0.04 percent). As is suggested by Table 11, EU is a *net exporter*[17] in heavy manufacturing, food products and services whereas USA is a *net* exporter of food products and services (see the numbers with positive signs in columns 1 and 2). Despite having larger shares in *total* world exports of all commodities than USA and EU, ROW is a *net importer* in heavy manufacturing and food products (see numbers with negative signs in column 3).

Table 11: Base-period values of regional nett exports of commodity[(a)]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	-32802.95	-104356.23	+95077.3
2. FoodProds	+5659.86	+7762.96	-24900.9
3. Textl_LMfg	-73690.23	-29529.23	+56075.22
4. HeavyManuf	-23183.69	+40137.31	-107725.1
5. Services	+96932.8	+78695.1	+15847.84

(a) Calculated from the base-period data. Negative sign indicates imports in that commodity into a region.

Tables 12 and 13 present the *sector-wise* regional export and import shares in total regional exports and imports respectively. These are used to calculate the *Wpe* in equation (8).

[17] Net exports of a commodity 'i' in a region 'r' is defined as the difference between the '*value of exports of 'i' from 'r' evaluated at world (fob) prices [VXW (i,r)]*' minus the '*value of imports of 'i' into 'r' evaluated at world (cif) prices [VIW (i,r)]*'.

Table 12: Base-period shares of sectoral exports in total regional exports[a]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	0.07	0.04	0.17
2. FoodProds	0.04	0.05	0.04
3. Textl_LMfg	0.07	0.12	0.16
4. HeavyManuf	0.53	0.48	0.45
5. Services	0.29	0.32	0.19
Total	1.00	1.00	1.00

(a) Calculated from the base-period data

Table 13 Base-period shares of sectoral imports in total regional imports[a]

GTAP Sectors	Regions		
	USA	EU	ROW
1. PrimaryInds	0.11	0.15	0.11
2. FoodProds	0.03	0.03	0.05
3. Textl_LMfg	0.17	0.14	0.12
4. HeavyManuf	0.51	0.40	0.48
5. Services	0.19	0.27	0.24
Total	1.00	1.00	1.00

(a) Calculated from the base-period data

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 14. 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 [*psw (r)*]—compare row 6 with other rows for individual columns for the regions in Table 14. 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 *nett exporter* of the commodities whose world price indexes rise most (i.e., primary industries and textiles, light manufacturing) and is a *nett 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 10.

Table 14 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.

The sectors in which EU is a *nett* 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 *nett* importer (viz., primary industries and textiles, light manufacturing) inflate. In columns (1) - (3) of Table 15, we rank the commodities in each of the three regions in terms of the post-simulation values of *net trade shares* (i.e., commodity-wise regional export shares in total regional exports *net* of each commodity's regional import shares in total imports). In column (4) the world export price indexes of the commodities are ranked. The numbers in the cells indicate the ranking in the interval [1, 5] for the two above-mentioned categories for a particular sector in descending order of performance in that specific category. For example, rank 1 corresponding to the cell in row 1 and column 4 implies that primary industries register the highest increase in the world export price index among all the traded goods. Similarly, the number 5 corresponding to the cell in row 5 and column 3 implies that in ROW services rank last so far as the *net export share* is concerned.

Table 15: Ranking of the world price index and the regional nett exports' share of commodities[(l)]

GTAP Sectors	Rank of:			
	USA's Nett Exports (1)	EU's Nett Exports (2)	ROW's Nett Exports (3)	World Export Price Index (4)
a. PrimaryInds	4	5	1	1
b. FoodProds	3	3	3	3
c. Textl_LMfg	5	4	2	2
d. HeavyManuf	2	1	4	4
e. Services	1	2	5	5

(l) Ranks range from 5 to 1 in ascending order with 1=top rank and 5=bottommost rank.

From the Table 15, it is clear that for ROW there is a strong positive rank correlation between px_i (i) and the difference of shares coefficient in the first right-hand term of (8). 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 10.

Considering *Xpe (r)* and *Mpe (r)*, the second and third right-hand terms in equation (8), we can infer that their contributions to '*tot*' depend in each case on a trade share and on a relative price movement. The respective price terms are the changes in relativities between *pxw (i, r)* and *piw (i, r)* vis-à-vis *px_i (i)*. However, the extent of such relative price divergences depends, *à la* Armington specification (1969) of *inter-generic commodity substitution*, on the degree of product differentiation by location of production. According to the Armington assumption, in any given region domestic output and imports of the same generic commodity are imperfect substitutes so that the domestic price vector and the import price vector both appear in the demand functions for domestic outputs and imports. Thus, the changes in price relativities between region-specific varieties of the same commodity class have effects on changes in *tot* through *pxw (i, r)* and/or, *piw (i, r)*. If the price of the varieties exported by any region r inflates relative to that of the varieties exported by regions other than r, then this will be good for region r's *tot*—this is the export price effect, *Xpe (r)*. The divergences between *pxw (i, r)* received by exporting region r and the *world price index of good 'i'* [*px_i (i)*] depend, apart from the magnitude of the shock, on the values of the Armington elasticities, so that for low elasticities of substitution these divergences will be larger.

On the other hand, if region 'r' imports a large share of its imports of commodity i from source regions in which the export prices of this generic commodity have risen by more than the world average export price of this commodity—that is, if *piw (i, r)* rises by more than *px_i (i)*—then region r's TOT suffers. The *net* effect on *tot (r)*, however, will depend on the magnitude of overall changes in *Wpe* and *Xpe* minus the changes in *Mpe*.

The magnitude and directions of the changes in *px_i(i)* are driven by the changes in regional aggregate export price indexes i.e., *pxw (i, r)*. For USA and EU, *pxw (i, r)* falls in *all* industries whereas it increases in *all* the industries in ROW—see Table 14. However, in the 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 14 (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. 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 produced in the 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)]. These economy-wide changes in price relativities for the tradeables can be arranged as in Table14a.

Table 14a 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

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. Although the changes in competitiveness between region- and sector-specific commodities are dominated by the changes in sector-wide relative supply prices shown in Table 14a, a glance at Table 14 reveals that the impact of the technological improvement is not so uniform across sectors in EU as it is in the other regions. Therefore, 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. In what follows, we will see that this has been governed by the magnitude of the sectoral embodiment indexes and spillover coefficients.

Comparison of column 2, Table 10 with row 6 of Table 14 reveals that the average regional price indexes for the tradeables [*psw (i, r)*] match almost exactly the regon-wise *Xpe*. Divergences between the export price for the exportables produced by any region and the average world price dominate the changes in *tot*. Whilst there is some inter-commodity variation within columns of Table 14, it is small *relative* to the variation of shares within columns of Table 12. Therefore, to a first approximation, we expect that the *Xpe* for the three regions can be calculated as the simple mean over commodities of the region's commodity price deviations from commodity-specific global export prices.[18] That is, our first

[18] The rationale underlying this is based on the following: for a fixed region 'r', let S_i be the relevant share values for each commodity 'i' and D_i be the respective price deviations of *pxw (i, r)* from *px_i (i)* for that region. Since we postulate on the basis of the observed share values that *Variance [S_i]* is much larger than *Variance [D_i]*, ignoring variation in D_i across i leads us to write $D_i \cong E(D)$, $\forall$ $i \in$ TRAD_COMM. Thus, while $\sum_i S_i D_i \cong \sum_i S_i \times E(D)$, it boils down to writing: $\sum_i S_i D_i \cong E(D) \times \sum_i (S_i)$. As $\sum_i (S_i)=1$, $\sum_i S_i D_i \cong E(D)$. Note that E(D) stands for the mean of D.

approximation to column (2) in Table 10 is row (7) of Table 14. If instead of a simple average we use the weighted averages *psw (i, r)*—see row (6) of Table 14—then we obtain a good approximation to *Xpe* as shown in column (2) of Table 10.

Considering the case of *Mpe*, from equation (8) we see that it depends on the values of IMP_SHR (i, r) (which are necessarily positive) and the price deviations [*piw (i, r)*–*px_i(i)*]. Moreover, at the sectoral level, except for primary industries, all the regional aggregate import price indexes for composite imports of commodities [*piw (i, r)*] fall in ROW so that the *nett* changes in *piw (i,r)* vis-à-vis *px_i (i)* is negative for all 'i' in ROW—see Table 14b. For USA and EU, however, these deviations are largely positive excepting in the case of services sector.

Table 14b Simulated effect on regional import price indexes and global export price indexes of commodities[(a)]

GTAP Sectors	Regions			
	Import Price Indexes			Export Price Index
	USA (1)	EU (2)	ROW (3)	WORLD (4)
1. PrimaryInds	0.29	0.25	0.13	+0.22
2. FoodProds	0.15	0.13	-0.04	+0.02
3. Textl_LMfg	0.19	0.20	-0.01	+0.10
4. HeavyManuf	0.13	0.04	-0.14	-0.05
5. Services	-0.11	-0.002	-0.17	-0.10
6. pdw (r)[(b)]	+0.09	+0.06	-0.05	—
7. Simple Average of piw (i, r)	+0.13	+0.12	-0.05	—
8. Mpe[(c)]	+0.13	+0.09	-0.08	—

(a) Simulation results of 4% TFP shock.

The methodology used above to explain the outcome for the export price effect can be applied also to the import price effect. Because there is more variation across commodities of price changes within columns than previously, the method does not work as well as it did with exports. Nevertheless, the covariation within regions of shares with price movements seems to be second-order. This can be verified by comparing row 8 of Table 14b with the preceding two rows: in both cases the signs, and ranking across regions, are preserved.

Having identified the principal force contributing to the observed changes in the regional terms-of-trade, we need to investigate the impact that the altered conditions of inter-regional competition have on the volumes of foreign trade. The analysis above has demonstrated that the biggest component of changes in relative prices is regional (rather than associated with particular commodities). In examining what happens to the market shares of the three supplying regions in each of the regional markets, we start with the hypothesis that the differing *general cost advantages* flowing to the three regions from the HNTP shock is a major explanator. So in the quantitative exercises reported below, we abstract from sectoral details.

5.4 Stylized Numerical Assessment

We adopt a stylized model based on the constant elasticity of substitution [CES] production function—the underlying rationale being that at the bottom level, the firm combines the material inputs sourced from overseas and domestically using CES technology. However, we apply the CES production function and the relevant shares at the 'macro' or regional level where each region is assumed to be the supplier of generic "commodities". This is based on the assumption that if the inter-regional price competition explains most of the changes in the pattern of trade, then the changes in the quantity indexes and the relevant market shares would predominantly be accounted for by the accompanying changes in the region-wide prices.

In order to approach the problem, we consider the shares of the value of imports (at importers' market prices) of all the traded commodities from foreign sources [VIM_i (r, s)] (and also of the region's own supply) in the domestic absorption of the traded goods in each region. Now, GNE (r) of a region 'r' shows the domestic absorption of commodities by private households, public consumption and gross regional demand for capital formation. In each of the three regions, market demand is satisfied by two competing foreign regions and the domestic region itself. To isolate the contribution of solely imported stuffs in the domestic absorption, we need to exclude from GNE (r) the item which does not use the foreign-sourced intermediates. This entails some adjustments in the calculation of an *adjusted* region-wide GNE. As the 'dwellings sector' is non-traded (with some negligible trade flows from the services sector), we exclude the value of output of the dwelling services in each region [VOM (dwellings, r)]. The *adjusted* GNE of region 'r' [GNE_ADJ (r)] is obtained as *nett* of dwelling sector's output [VOM (dwellings, r)].[19] The share of the bilateral imports [VIM_i (r, s)] in GNE_ADJ (r)—SH_MGNEADJ (r, s)—measures the extent of import penetration by region r in the gross domestic absorption of traded commodities in recipient 's'.[20] The *changes* in such shares between the base-case and shocked solution show the changes in the domestic demand for source-specific "stuff". In the present case, as there are three such sources of supply of tradeables in each trading region, we get nine such shares.

On the basis of our simplifying assumption, we use the following mathematical expressions derived from the CES production function at the regional level:

[19] The coefficient defined is: GNE_ADJ (r) = GNE (r) – VOM ("Dwellings", r).

[20] The relevant share is: SH_MGNEADJ (r, s) = VIM_i (r, s)/ GNE_ADJ (r). These are not reported for parsimony. The detailed code of equations in the TABLO file is too elaborate to be reported.

$$S_{rs} = \frac{\delta_s^{\sigma} P_s^{\rho\sigma}}{\sum_{k \in R_s} \delta_k^{\sigma} P_k^{\rho\sigma}} \qquad (9)$$

where S_{rs} is the relevant share of supplier 'r' in market 's' [SH_MGNEADJ (r, s)] and P_s is the average region-wide price index for the tradeables in region 's'. In (9), 'R_s' stands for the two foreign sources of imports as well as the recipient's own supply. σ [= $1/(1+\rho)$] is the global Armington substitution elasticity.[21] Also, the distribution parameter for each source's supply in the adjusted GNE of region 's' is computed as:

$$\delta_s = \frac{P_s X_s^{1/\sigma}}{\sum_{k \in R_s} P_k X_k^{1/\sigma}} \qquad (10)$$

where the δ_k are the three CES distribution parameters related to the sourcing of stuffs in 's'.[22] Log-linear transformation of (9), after algebraic manipulation, yields:

$$d \ln S_{rs} = \rho\sigma \, d \ln P_s - \frac{\sum_k \delta_k^{\sigma} \rho\sigma P_k^{\rho\sigma} (d \ln P_k)}{\sum_{k \in R_s} \delta_k^{\sigma} P_k^{\rho\sigma}} \qquad (11)$$

where $d \ln S_{rs}$ is the logarithmic change in the share of supplying source r in the adjusted GNE of region 's' between base- and snapshot solutions whereas $d \ln P_s$ is the change in the average region-wide price index. The P_k in the above equations refer to the updated price in the solution period and are used for calculations of the relevant distribution parameters (via equation (10)) and for evaluating the right-hand side of equation (11).[23] Our numerical calculation involves computation of the right-hand side of equation (11) and its comparison with the change in the log of the relevant share between the levels databases before and after the HNTP shock.

If inter-regional competition at the macro level were to dominate the change in the calculated shares [S_{rs}], then the right-hand side and the left-hand side of equation (11) would match almost exactly. However, our calculation using the simulated values of the relevant variables reveal that given the high degree of non-linearity in the postulated relationship via

[21] This is calculated as the simple average of the commodity-wise default parameter settings (as given in the GTAP database) of such elasticities.

[22] Note that in strict notation the δ_k needs two subscripts: one for the market being analysed (here, s) and one for the supplying region (here $k \in R_s$).

[23] The formulae were evaluated using both base-case and final solution shares.

the equations, these two do not match; all signs but one, though, do match.[24] This signifies that we cannot discern definitely that inter-regional competition *per se* explains the change in regional demand for tradeables. Thus, there is room for *inter-generic commodity competition* to be discussed below. As will become evident, these are *reflected in disparate regional export performances* in the traded commodities.

In effect, following the shock, the regional aggregate export sales of commodity 'i' [*qxw (i, r)*] increase—see Tables 16 and 17. For the two major beneficiaries of the TFP improvements (i.e., USA and EU), we see only rises in these quantity indexes of exports. 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. Table 16 shows that ROW experiences a larger percentage decline in aggregate exports in heavy manufacturing and food products with much smaller (as compared to the USA and EU) increases in other sectors. 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 14) 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.

However, the changes in the volume of regional aggregate merchandise exports [*qxw (i, r)*] entails changes in the composition of bi-lateral imports in commodity 'i' from source 'r' to destination 's' [*qxs (i, r, s)*]. Taking any region 's' as the destination of exports of 'i' from sources 'r', *qxs (i, r, s)* gives percentage changes in imports of 'i' from source 'r' to recipient 's'. Now, *qxs (i, r, s)* depends on the Armington elasticity, on the size of the expansion in regional aggregate import demand for 'i', on the import share of the other source region 'k' (k≠r≠s) in total imports into 's' and the divergence between the price of imported 'i' from source 'r' to 's' [*pms (i, r, s)*] vis-à-vis that from source 'k' to 's' [*pms (i, k, s)*].

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—compare columns 1 and 2, Table 16. 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)*], 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. In EU, imported commodities are sourced from USA and ROW. Similar consideration explains the much

[24] The computed values for the left-hand side of equation (11) give change in the log of the relevant market shares in each region between base-case solution and the shocked solution. The percentage changes in such values are: for USA as the destination, 0.16 (USA as the supplier), 0.87 (EU as the source) and -1.74 (ROW as the source); for EU as the recipient, 0.08 (from EU itself), -1.28 (from ROW), 2.32 (from USA); whilst for ROW, -0.71 (from ROW itself), 2.49 (from USA) and 1.23 (from EU). The sign does not match for the changes in the values of log of market shares from EU to USA.

larger percentage increases in bi-lateral imports of the tradeables into EU's market from USA than from ROW—compare figures in columns 1 and 2, Table 17.

Table 16: Percentage changes in bi-lateral import volumes in the tradeables in USA[(a)]

GTAP Sectors	Sources of Imports:	
	EU (1)	ROW (2)
1. PrimaryInds	4.23	1.57
2. FoodProds	1.90	-0.34
3. Textl_LMfg	5.03	1.50
4. HeavyManuf	4.39	0.71
5. Services	4.26	1.43

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

Table 17: Percentage changes in bi-lateral import volumes in the tradeables in EU[(a)]

GTAP Sectors	Sources of Imports:	
	USA (1)	ROW (2)
1. PrimaryInds	5.66	0.67
2. FoodProds	4.18	-0.23
3. Textl_LMfg	6.17	0.61
4. HeavyManuf	4.87	-0.28
5. Services	4.26	0.31

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

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 [*qxs (i, r, ROW)*] between the base-case solution and the solution under the TFP shock.[25] In ROW's market, USA faces competition from ROW itself (supplying 50% of total imports) and EU

[25] The percentage change in demand for exports of 'i' from 's' to 'r' can be expressed as: qxs(i, s, r)=qim(i, r)– ESUBM∗MSHRS (i, k, r)∗[pms (i, s, r)–pms(i, k, r)] , where k ≠ s, where MSHRS (i, k, r) is the share of imports from 'k' to 'r' in aggregate imports from both 'k' and 's' to 'r' and ESUBM is the Armington elasticity for imports from sources 'k' and 's'. Thus, we can write MSHRS (i, k, r)+ MSHRS (i, s, r) =1. For ROW as composite region supplying in its own market, the equation is written as:

qxs (i, s, r)= qim (i, r)–ESUBM∗MSHRS (i, k, r)∗[pms (i, s, r) – pms (i, k, r)]

– ESUBM∗MSHRS (i, t, r)∗[pms (i, s, r) – pms (i, t, r)] where s ≠t ≠ k are different *sources* of exports to *destination* 'r'. For *intra-regional exports*, source 'r' is the same as recipient 's' so that the above equation can be expressed as:

qxs (i, r, r)= qim (i, r)–ESUBM∗MSHRS (i, k, r) ∗ [pms (i, r, r) – pms (i, k, r)] – ESUBM∗MSHRS (i, t, r) ∗ [pms (i, r, r) – pms (i, t, r)] where r ≠t ≠ k.

(supplying 29% of ROW's imports). USA and EU export respectively 73% and 81% of their export sales (excluding sales to global transport sector) to ROW. The share of intra-regional exports in total exports in ROW is 48%. The decline in intra-regional imports in all the traded goods in ROW 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 loses share in its own market and hence experiences *trade diversion* there.

As individual regions experience TFP growth, it is worthwhile to consider whether the pattern of comparative advantage (*ex post*) alters between industries and across regions. Of course, the differences in regional performances in merchandise exports from each sector depends on improvements in productive efficiency at the sectoral level in the sense that after the total factor productivity improvements, some sectors perform better than some other sectors. In a multi-sectoral general equilibrium framework, this passes through the *differential industry effects* and the relative price divergences. As a preliminary step, we construct indexes of *revealed comparative advantage* by sector by region [*RCA (i, r)*]. These indices measure the extent of export specialisation in sectors; thus, they indicate the extent to which a region's exports are specialised in a particular sector relative to the world average. Following Balassa (1965, 1979), *RCA (i, r)* for sector 'i' in 'r' is defined as the share of exports of sector 'i' [*VXW (i, r)*] in the region's total exports [*VXWREGION (r)*] deflated by the share of aggregate global exports of 'i' [*VXWCOMMOD (i)*] in overall world exports [*VXWLD*]. The change in the values of these indices between the base-case and the shocked solution would help to account for the change in export patterns of sectors after the perturbations. *Commodity-specific ranking* for the three regions based on the calculated indexes (using base-period data) show that USA has its highest RCA index values (i.e., greater than unity) in heavy manufacturing and services whereas EU has its highest values for the RCA indexes in food products and services. By contrast, ROW is revealed to have highest comparative advantages in primary industries and in textiles, light manufacturing. However, a *country-specific ranking* of these indexes reveals an altogether mixed picture. For example, in USA and EU the regions' exports are relatively more specialised in services than heavy manufactures whereas in EU, food products have a higher RCA index than heavy manufactures. The reverse is the case with ROW where primary industries and textiles, light manufacturing have relatively strong trading positions.

These indices for the base- and the shocked solutions are reported in Tables 18a and 18b respectively. Comparison of the tables reveals that only very small changes in comparative advantage result from the technology shock.

Table 18a Revealed Comparative Advantage in base-period by type of sectors in the regions[(a)]

GTAP Sectors	Regions[(b)]			
	USA (1)	EU (2)	ROW (3)	REMARKS[(c)] (4)
1. PrimaryInds	0.558	0.306	1.382	ROW:Rank 1
2. FoodProds	0.993	1.174	0.938	EU: Rank 1
3. Textl_LMfg	0.534	0.867	1.183	ROW:Rank 1
4. HeavyManuf	1.126	1.028	0.954	USA: Rank 1
5. Services	1.248	1.349	0.801	EU: Rank 1
REMARKS[(d)]	Services: Rank 1	Food Products: Rank 1	Textl_LMfg: Rank 1	—

(a) Computed from the GTAP's *base-period* database.
(b) These values can also be expressed as percent form by multiplying them with 100.
(c) *Rank* in this column refers to commodity-specific ranking across regions.
(d) *Rank* in this row refers to ranking across sectors in a region.

Table 18b Post-shock values of revealed comparative advantage by type of sectors in the regions[(a)]

GTAP Sectors	Regions[(b)]			
	USA (1)	EU (2)	ROW (3)	REMARKS[(c)] (4)
1. PrimaryInds	0.562	0.306	1.390	ROW:Rank 1
2. FoodProds	0.995	1.169	0.938	EU: Rank 1
3. Textl_LMfg	0.539	0.870	1.186	ROW:Rank 1
4. HeavyManuf	1.129	1.030	0.951	USA: Rank 1
5. Services	1.236	1.343	0.801	EU: Rank 1
REMARKS[(d)]	Services: Rank 1	Food Products: Rank 1	Textl_LMfg: Rank 1	—

(a) Computed from the GTAP's *post-simulation* database.

Despite the fact that inter-regional competition is the dominant force underlying the movements in terms-of-trade, the above analysis suggests that there is scope for inter-generic commodity competition in the explanation of changes in suppliers' shares of other different regional markets. In the next section, we spell out the differential sectoral technology capture and the differences in trade-induced endogenous productivity enhancement responsible for differential industry effects.

5.5 Inter-generic Commodity Competition and Multi-Sectoral Effects:

As noted above, there has been uneven distribution of productivity enhancements across sectors, especially in EU. Specifically, in EU primary industries and food products are the sectors which experience relatively lesser percentage decreases in their export price indexes as compared to the other three sectors (compare the figures in rows 1 and 2, Table 14 with those in rows 3, 4 and 5 in column 2 of the same Table). As expected, this can be ascribed to the differentials in the embodiment indexes and sectoral spillover coefficients across sectors.

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:

$$E_{irjs} = F_{irjs}/M_{ijs} \qquad (1)$$

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. The equation for the spillover coefficient γ_{irjs} is written as:

$$\gamma_{irjs}\,(E_{irjs}, \theta_s) = E_{irjs}^{1-\theta_s} \qquad (5)$$

where θ_s is the destination-specific capture parameter as elaborated before. Columns 2 and 3 of Tables 19 and 20 below report the base-period values of the bi-lateral sectoral embodiment indexes [E_{irjs}] and spillover coefficients [γ_{irjs}] for the three regions respectively.

Table 19 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 20 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

A glance at these tables reveals that the embodiment indexes for some of the sectors in EU (namely textiles and light manufacturing, heavy manufacturing and services) 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 20. 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.

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. As opposed to this, in EU, the range of variation at 0.092 is larger—see the last entry in column 2 of Table 20. 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 20 with those in rows 3, 4 and 5 in column 2 of the same Table. That is, the wider variation in column 2 is largely due to the difference between the spillover coefficients in the first two sectors relative to the rest. Since primary industries and food products reap lesser potential benefits from the endogenous technology spillover [via equations (1) and (5)] 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.

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—compare column 1 with columns 2 and 3 in Tables 19 and the same columns in Table 20. Recall that the specification used for the sectoral embodiment index [E_{ijrr}] for the sectors in the source region of innovation is based on the domestic input-output coefficient as given below:

$$E_{ijrr} = D_{ijr}/M_{ijr} \qquad (i \neq j) \qquad (3)$$

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' used by sector ‘j’ in ‘r’. Correspondingly, the magnitude of domestic spillover is computed by using:

$$\gamma_{ijrr}(E_{ijrr}, \theta_r) = E_{ijrr}^{1-\alpha_r} \qquad (4)$$

The values of the indexes based on equations (3) and (4) are reported in column 1 of Tables 19 and 20 respectively. Closer inspection of the figures in column 1 in both the tables suggests the fact that 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. This implies that by using the more productive domestically-sourced heavy manufacturing, it captures the highest embodied domestic technology spillover in every sector. 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). Table 21 reports these values. Considering the technology transmission Equations (6) and (7), we see that the magnitudes for the endogenous HNTP changes between the base-case and shocked solution are contingent on the base-case values of the spillover coefficients as well as on the magnitude of the exogenous TFP shock in heavy manufacturing (i.e., source sector) in USA. As conjectured, the TFP improvements across sectors are more or less in conformity with the magnitude of the reported spillover coefficients in Table 21.

Table 21 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) Author's simulation results of 4% TFP shock in Heavy Manufacturing in the USA

6. Sensitivity analysis and Concluding remarks

In this article, embodied technology transmission through bi-lateral trade linkages has been analysed in a multi-sectoral, multi-regional framework. The analysis suggests that regional differences in transmitted productivity changes dominate the results above. However, the analysis of changes in market shares of each of the trading regions in their partners' markets indicates that the effect of the TFP improvement in heavy manufacturing in the USA has been more or less uniform across sectors within regions. This can be partially explained by relative uniformity of embodiment indexes and spillover coefficients within regions. The values of such indexes are based on regional trade patterns in the base-period. Given the exogenous TFP shock in heavy manufacturing in USA, the magnitudes of embodied spillover coefficients in the sectors depend on sector-specific trade intensities in EU and ROW and on domestic input-output coefficient in USA.

We have seen that inter-regional competition, *inter alia*, depends on the TFP shock-induced relative price effects. The Armington (1969) assumption of product differentiation by origin keeps open the scope for inter-generic commodity competition. This competition, however, depends on the values of Armington parameters. As the products are differentiated by sources, divergences between the export supply price of tradeables in any region and their average world price have led to changes in regional terms-of-trade and also in inter-commodity substitution. The relative decline in the price of Armington substitutable imports in the principal beneficiaries of technical change (i.e., both USA and EU) have caused substitution in favour of traded commodities imported from USA and EU in ROW (which experiences a relative rise in the supply prices of all domestically produced tradeables).

We have observed that in GTAP Armington elasticities of substitution between imports from different sources are assumed to be identical across regions. That is, the substitution elasticities vary only by commodity.[26] Notice that the relative strength of substitution between imported commodities depends on the values of Armington elasticities of substitution [σ_M (i)]. We conjecture that allowing for more variations in the substitution elasticities across sectors as well as regions could change the flavour of the results. Because standard GTAP does not allow regional variation in substitution elasticities, we can only test our conjecture with respect to their variations across commodities. To do this, we run a simulation with modifications in the default parameter settings of the Armington elasticities. Since in standard GTAP's treatment, such elasticities of substitution are hard-wired to commodities and are invariant across the three regions, we assign a new set of values for the commodity-specific Armington parameters. We choose a very low value for the elasticity of substitution in heavy manufacturing sector [i.e., σ_M (i) = 0.1) whereas for rest of the traded sectors, we assign a common higher value [i.e., σ_M (i) = 6]. The simulation results for percentage changes in bi-lateral trade flows in heavy manufacturing are reported in Table 22.

Table 22: Simulated effects on percentage changes in bi-lateral trade flows in heavy manufacturing sector with alternative Armington Elasticities[(a)]

Sources of Imports:	Destination Regions: USA (1)	EU (2)	ROW (3)
USA	0.00	0.70	1.41
EU	0.77	0.00	1.38
ROW	0.70	0.59	1.30

(a) Simulation results of 4% TFP shock

[26] See Chapters 2 and 4, Hertel (ed.), 1997, Global Trade Analysis: Modeling and Applications.

Table 23: Simulated effects on regional export price index of heavy manufactures with alternative Armington elasticities[(a)]

Export price index for heavy manufactures	USA	EU	ROW
pxw (i, r) [New]	-0.83	-0.46	+0.36
pxw (i, r) [Old]	-0.61	-0.35	+0.27

(a) Simulation results of 4% TFP shock

The results accord well with our expectation. Taking ROW as the destination, it is evident that the percentage increases in bi-lateral exports of heavy manufacturing to ROW from USA and EU are lower than the corresponding numbers obtained in our previous simulation—compare numbers in column 3, Table 22 with those in Tables 16 and 17. More importantly, unlike the earlier experiment, in the new experiment ROW registers an *increase* in intra-regional imports in heavy manufactures.[27] Although there has been a decline in the price of heavy manufactures in both USA and EU, with a very low Armington elasticity in this sector, the scope for substitution of heavy manufactures imported from overseas with ROW's own supply is limited. Although there a price incentive for ROW to substitute heavy manufactures from abroad—see Table 23—there is limited technical scope to do so, so it relies on its own supply of heavy manufactures, resulting in a 1.3 percent increase in its intra-regional imports.

Further work on sensitivity to Armington elasticities is called for. In particular, differences in substitutability by source region (as well as by commodity) may well change the main feature of the results presented in this chapter; namely, that the benefits of trade embodied technological change seem to be fairly uniform in their distribution across commodities within any given region.

[27] Compare last entry in Table 22 with entry in row 4, column 3 of Table 16 and 17. For the other traded sectors, although the magnitude of changes differ from the results obtained in the simulations reported in the earlier sections, the sign remains the same as before.

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