Biotechnological Innovations in the Forestry Sector and their Economic Impacts on Other Sectors via Embodied Technology Transfer: An Investigation within Dynamic GTAP Framework[1]

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Abstract

In this paper, we consider technology transfers embodied in trade flows within a seven-region, seven-traded-commodity version of the dynamic GTAP model. 0.63% Hicks-Neutral technical progress in forestry sector (logging) in source regions has differential impacts on productivity of the logging-user sectors. This is ascribed to the differential rates of induced technology transmission via traded intermediates. Destination regions' ability to utilize new technology depends on their *absorptive capacity* (AC) *and structural similarity* (SS). Together with trade flows, these two factors determine the recipient's success in assimilating foreign technology. Sectors intensive in logging like wood products, paper products, publishing register higher productivity growth. Differences in productivity improvements depend on the differentials in the magnitude of technology capture.

1. Introduction

In the recent past, the advent of biotechnological innovations and its potential impact on sustained productivity growth in forestry is well documented. For example, inventions such as herbicide and insect tolerant seedlings, pest and disease resistant seedlings, and improved fiber properties (to name a few) have resulted in significant productivity gains in the logging sector. In this paper, we offer a quantitative assessment of the potential economic benefits of biotechnological research in the logging sector and its transmitted productivity gains in the wood products and pulp and paper sectors. International trade flows are the primary conduits for technology transfer. Also, acquisition and absorption of 'new' forestry technologies and their local usability is crucial for the development of forest product industries. In our model, we attribute absorption capacity to the human capital content of the labour force while structural congruence between the source/s of technological change and the recipient/s are defined in terms of factor proportions. The underlying database is the Version 4 of the GTAP database. For implementation, we aggregate the Version 4 of the GTAP database into 7 traded sectors and 7 regions. In Section 2, we document the prototypical patterns of biotechnological innovations in forestry. Section 3 sets out the conceptual framework for trade-induced technology transmission. Section 4 discusses the database and the sectoral and regional

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aggregation. This aggregation is motivated primarily by computational convenience. Section 5 describes the particular GTAP implementation, the closure and shock for the experiment. Simulation results are reported in Section 6 and concluding remarks are offered in Section 7.

2. Forestry Biotechnology: Technological and Economic Perspectives.

It is well established in the literature that in the face of scarcity of factors of production, technical change favors the activity depending heavily on relatively scarce factors of production. Biological chemical innovations like biotechnology offer potentials for such technological change. Forestry biotechnology is one of the most promising areas of biological invention with potential for productivity enhancement in the forestry sector.

According to Simpson (1999), three mutually reinforcing factors contributing to the technological advancement in the natural resource sectors are: resource-depletion led escalation of cost of extraction, synergies and agglomeration of existing independent (but complementary) technologies and continuing ability to generate new innovations and "*adoption*" of new research outcome. Technological innovation is a way to augment resource extraction capabilities. Forestry sector has undergone rapid depletion of accessible stocks due to harvesting technology and also, environmental other regulation has led to preservation (and hence withdrawal from production) of forestlands. In this sector, depletion of accessible stocks has led to 'innovation'—plantation forestry with embodiment of new management practices and the "*adoption*" of biotechnological innovations for intensive land-use. As trees are growingly treated as 'agricultural crops', for success in achieving the desired tree growth the complementary innovations like irrigation, fertilization and pesticides are important which have reinforcing effects.

On the face of growing demand, therefore, we see consequent transition away from logging in forestlands towards the practice of 'tree farming'. Broadly speaking, two sources have principally been identified for increased forest sector productivity—(i) technical change for logging and resource extraction and (ii) technical and institutional innovations focusing on intensive forest management and plantation forest for commercial wood production via shifting to agricultural crop-type production technique (see Sedjo (1997; p.142, 1999a)), Parry (1997), Simpson (1999)—to name a few). The second source is becoming dominant and not surprisingly, 33% of global industrial wood production is contributed by plantation management (see Sedjo (1999a)). Investments in genetic improvements through biogenetic engineering and microbiology and planting of superior traits are essential for commercial benefits from the forestry sector. Tree plantations along with intensive management through the introduction of fertilization, pest control and thinning allow for achieving higher productivity with same level of inputs. Three broadly overlapping areas of application of biotechnology identified are namely, improvement of trees, biopesticides for forest management and propagation, conservation and restoration see Gaston et al. (1995), Parker et al. (1995)). The relevant desired traits for forestry are tolerance for herbicide, insects, drought, tree growth and wood quality—to name a few. So far as the potential gains in terms of wood production is concerned, these contribute to significant cost-savings (see Sedjo (1999b)).

Also, the acquisition and exploitation of transferred technologies effectively is essential for the development of forest product industries. Being a science-based industry demanding intellectual capital, it needs development of a sound knowledge-base with high-level technical and scientific capabilities. This is related to development of competencies or capabilities to identify, acquire and assimilate the ‘novelty’ associated with the innovation. This aspect of adoption of newer research output is important for ‘effective’ utilization of the latest state-of-the-art. We ascribe this to ‘*Absorptive Capacity* (henceforth, AC)’ of the recipient sectors and regions. The importance of AC in technology acquisition has been discussed at length by Cohen and Levinthal (1989, 1990), Abramovitz (1994), Nelson (1990), Nelson et al. (1999), Lall (1982), World Bank’s (1999) World Development Report —to name a few. This aspect of absorption has been stressed in the literature in the context of biotechnology as well.[2] In particular, Fontes (2001, pp. 59-61) has stressed the role new biotechnology firms as well as the skilled young professionals (*technological intermediary*) who ‘can play a critical role in such a process by acting as disseminators of new technology and translators of competencies to user sectors.’ Thus, Fontes (2001) emphasizes the crucial role of ‘hybrid entrepreneurs’ (i.e., the professionals with technical competence) who facilitate the transfer of technology, its absorption and promoting its further development. Sedjo (1999a) refers to “political, social and cultural prerequisites” for innovation and adoption of the state-of-the-art. According to Straquadine et al. (1995), education and literacy rate play key role for success of extension service related to agroforestry research and techniques. Extension programs facilitating technology flows hinge on the importance of capacity to ‘*adopt*’ new technique. Success in assimilation of transferred productivity benefits depends on the skill content of the labor force.

As biotechnology research opens up many new opportunities for sustainable forestry, its proper management and technology transfer of such research output are avenues to satisfy the need of biogenetic diversity. In an integrated world issue of cross-border technology flows between geographical regions is of crucial importance. The intersectoral spillover of technology is one such channel for transfer of biotechnology research and delivering potential benefits. This calls for an analysis of biotechnological invention and its associated repercussion in a multi-sectoral, multi-regional framework.

3. A Conceptual Framework for Trade-induced Technology Transmission: Theoretical Premise.

Advanced technologies are primarily researched and developed in the developed countries (DCs). The relatively laggard countries (LDCs) have depended for their growth and development on foreign technologies originating in the source of technology creation. Their growth and development depend not only on the extent and nature of the transmitted technology, but also on their competence for effectively assimilating and adopting the diffused technology. The technology generated at the sources of inventions spill over to the destinations through bilateral trade linkages. Thus, international trade in commodities facilitates propagation of superior ‘technologies’ embodied in those traded goods and services [see for example, Coe, et al. (1995, 1997), Dietzenbacher (2000), Eaton and Kortum (1996), Connolly (1997), Keller (1999, 2001), World Development Report (World Bank 1999) for empirical evidences]. This is the “*embodiment hypothesis*”: advanced technical knowledge flows through traded goods. In a multisectoral, multi-regional framework such spillovers are more obvious to be traced. In such pursuit, van Meijl and van Tongeren (April 1997, 1998) [henceforth, MT], Dietzenbacher (2000), Keller (2001), Connolly (1997)—to name a few, have modeled the issues of technology transfer.

[2] Fontes, Margarida (2001), “Biotechnology Entrepreneurs and Technology Transfer in an Intermediate Economy”, Technological Forecasting and Social Change, 66, pp. 59-74.

Productivity growth rates of countries are related through international trade linkages and associated "trade-embodied" technology spillovers. However, MT's model incorporates the essential elements of 'AC' and 'SS' factors in determining the domestic usability of foreign technologies. 'AC' is constructed as a binary (source- and destination-specific) index of human-capital-induced absorption capacity of the participating trade partners. Analogously, SS is also a binary index based on such features as similarity of factor proportions in the two regions. Together with trade volume, these two indexes jointly determine the 'productive efficiency' parameter.[3] It is argued that domestic usability of the transmitted technology depends mainly on the *recipient's* capability to utilize the diffused technology. This simplification of MT's treatment of AC is motivated by the desire to keep the model simple by concentrating on first-order effects. It seems likely that if region 'C' is good at absorbing technology from region 'A', it will (to a first approximation) be equally good at absorbing technology from another region 'B' which (from C's point of view) is structurally similar to 'A'. Thus, the AC factor is made destination-specific only. Ours differs from MT's in several other details. *Firstly*, we modify the technology spillover equations. *Second*, unlike MT, we make the 'AC' factor destination-specific only. The 'SS' factor retains its 'binary' affix, though. The trade-induced technology transmission mechanism implemented here is based on Das (2000a&b)—the model developed and implemented within the Static GTAP framework. *Third*, as will become evident from Section 4, the framework, unlike MT (1997, 1998) and Das (2000a&b), is dynamic GTAP with a CES-nesting of skilled labor (human capital) and physical capital producing composite capital. The basic spillover equations and necessary modifications made are described in the next section.

3.1 Spillover Equations: Modifications to Theory

Technology embodied in foreign and domestic intermediate inputs spills over to *all* other sectors and affects their total factor productivities. That is, following an exogenous technological improvement in one sector of one region, all other sectors in the source region, and all sectors in other regions experience trade-induced *endogenous* Hicks-Neutral total factor productivity [henceforth, TFP] improvement. The embodiment index is defined in terms of input-specific trade intensity. For the current implementation, following Das (2000a&b) we adopt two different specifications for the technology transmission equation: the first one applies for the *trade-induced spillover* between destination regions and the source of technological change, while the second one captures endogenous *domestic spillover* to the sectors in the source itself from the source sector of *exogenous* technological change. Below, we discuss these modifications in turn.

3.2 Definition of Embodiment Index

The amount of trade-induced knowledge spillover from a source sector in the region of origin to a particular sector in the destinations via traded intermediates depends on the input-specific trade intensity of production of that sector. Hence the embodiment index is defined in terms of trade intensities for different specific material inputs; i.e., source and using sector-specific trade-embodiment index. We define this index [E_{ijrs}] as the flow of imported intermediate produced in sector 'i' in source region 'r' that is exported to firms in

[3] Although AC depends not only on Human Capital alone, but also on constellation of factors such as learning effects and own R&D in the recipients; however, while defining AC in our model we have not considered these factors. In the model, technology creation is not considered and hence, is treated as exogenous perturbation in the system.

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 the total (i.e., domestic as well as composite imported inputs) usage of intermediate input ‘i’ by sector ‘j’ in region ‘s’. Thus, it is expressed as

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

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 s. It is to be noted that the definition for the spillover coefficient bears an additional subscript for source sector 'i' so that we write it as

$$\gamma_{ijrs}\left(E_{ijrs},\theta_s\right) = E_{ijrs}^{1-\theta_s} \qquad (2)$$

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

$$\theta_s = AC_s . SS_{rs} \qquad (2a)$$

The realized productivity level from the potential flows of ‘current technology’ depends on $\theta_s \in [0,1]$ with $\theta_s = 1$ implying full exploitation of the foreign technology-induced productivity improvement. For the destination region ‘s’, θ_s and E_{rs} jointly determine the value of the ‘*Spillover Coefficient’* $\gamma_s(E_{rs}, \theta_s)$.

$\gamma_s(.)$ has the properties that

$$\gamma_s(0) = 0, \gamma_s(1) = 1, \ \gamma_s' = (1-\theta_s)\, E_{rs}^{-\theta_s} > 0, \ \gamma_s'' = -\theta_s(1-\theta_s)/E_{rs}^{1+\theta s} < 0.$$

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

More specifically,

$$\gamma_s\left(E_{rs},\theta_s\right) = E_{rs}^{1-\theta_s} \ , \ 0 \le \theta_s \le 1 \qquad (2b)$$

It is to be noted that trade intensity is treated as a *binary* variable indexed both for the recipient sector ‘j’ in a given region ‘s’ and for the source sector ‘i’ and region ‘r’ of the intermediate products that it uses as inputs. In the GTAP database, however, while we know by source region the aggregate imports of the composite intermediate good used by any given sector in any given region (i.e. $F_{ij\bullet s}$), the regional composition of imports for individual using sectors in s is not known. Therefore, we make a pro-rata *assumption*—i.e., it is assumed that an imported input is proportionally distributed across all user sectors.[4] Thus, if F_{irjs} indicates usage in region ‘s’ by industry ‘j’ of imported intermediate ‘i’ from source ‘r’, we assume that the share of imported input ‘i’ from source ‘r’ in receiving region ‘s’ holds for all industries ‘j’ in ‘s’ using imported input ‘i’

$$F_{irjs}/F_{ij\bullet s} = F_{ir\bullet s}/F_{i\bullet\bullet s} \qquad (3)$$

where $F_{i\bullet\bullet s}$ is the aggregate imports of tradeable commodity ‘i’ in region ‘s’ from all source regions. In equation (3), the left-hand ratio is the quantity share of source r in the imports

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

of i by sector j in its total imports of ‘i’ whereas the right-hand ratio is the market share of source ‘r’ in the aggregate imports of tradeable ‘i’ in region ‘s’ evaluated at market prices. Following GTAP notation, the coefficients $F_{ij\bullet s}$ is VIFM (i, j, s)—the value of purchases of imported intermediates i by sector j in any region s evaluated at market 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 SM_IRS (i, r, s). As said before, SM_IRS (i, r, s) is *assumed* to hold for all industries ‘j’ in ‘s’ using imported ‘i’ from origin of innovation ‘r’. In the GEMPACK implementation, we define a new coefficient VIFM_RS (i, j, r, s) to match F_{irjs} for the definition of the embodiment index.

In the source region, the benefits of a technological change (exogenous) in a particular sector is reaped *directly* by the other sectors via the usage of locally produced intermediate inputs embodying advanced technology and *indirectly* via the *relative price changes* of foreign intermediates. Thus, the latest technology embodied in the intermediate inputs diffuses to other sectors using that material input/s sourced *domestically*. Hence, the exogenous TFP improvement in the source sector in the region of origin endogenises the TFP improvement in the receiving sectors via a *domestic* spillover effect. Hence, the relevant sectoral embodiment index [E_{ijr}] for the sectors in the source region is given by

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

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

$$\gamma_{ijr}(E_{ijr}, \theta_r) = E_{ijr}^{1-\alpha_r} \qquad (5)$$

where $\alpha_r \in [0, 1]$ is the human capital [HK] induced capture-parameter for source ‘r’.

3.3 Spillover Equation and Productivity Shock

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

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

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 ‘r’, the transmission equation [where i and j (i≠j) are the innovating sector and the receiving sectors respectively] is given by

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

However, in our experiment the source of TFP improvement is *uniquely* in sector ‘i’ in the single donor region ‘r’. In dynamic GTAP, for enforcing economy wide TFP shock the variable ‘ava (j, r)’ has been made normally endogenous with “avadiff [j]” and “avarega[r]” being exogenous. But, for shocking individual “ava [j,r]” pairs (i.e., for sector and region specific average rate of value added augmenting tech change), an additional Variable *avaall (j, r)* has been appended in the dynamic Tab file and the relevant Equation has been changed as below. Hence, by shocking *exogenously* specific pairs of avaall[j, r] by a given magnitude whilst keeping both avadiff [j] and avareg [r] *unshocked*, one can make ava [j,r] to move together with avaall [j, r] (*exogenous*).

```
Variable (all,j,PROD_COMM) (all,r,REG)
avaall(j,r) # value added augmenting technical change in sector j of r #
EQUATION TFP! enforces economywide TFP shocks !
(all,j,PROD_COMM)(all,r,REG)
ava(j,r) = avareg(r) + avadiff(j)+ avaall(j,r);
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4. Methodology and Database: Sectoral and Regional Aggregation

A reduced dimension 7×7 aggregation of the Version 4 of the GTAP database is used to calibrate the model. Table 1 below presents the regional and sectoral aggregations used in this implementation. The base period is 1995.

Table 1: Sectoral and Regional Aggregations used for the implementation

Version 4 Sectors with Identifier	Version 4 Regions with Identifier
1. AGR [agriculture]	1.USA [United States]
2.FOR [forestry]	2. CAN [Canada]
3. NRE [natural resources]	3. SAM [South America]
4. OMF [other manufacturing products]	4. WEU [Western European Union]
5.LUM [wood products]	5. SEA [South East Asia]
6. PPP [pulp, paper and publishing]	6. JPN [Japan]
7. SVC [services]	7. ROW [Rest of the World]

Source: This is based on the Aggmap.Txt file used for getting the 7×7 aggregation.

Version 4 of the GTAP database (i.e., GTAP Sectoral Classification, revision 1 (GSC1)) distinguishes 45 regions and 50 sectors and provides us with the splits of labor payments between the skill and unskilled categories [see McDougall et al. (1998)]. Thus, the starting period of our simulation is 1995 and the base case scenario comprises macro projections of the database over seven periods (of varying length) in future with shocks to macro variables like population, factor endowments, gross domestic investment, real GDP over the years and also the policy forecasts for combined tax in a region on tradable bound for a region (i.e., export subsidies) and import tax in a region on imported goods from other region/s (import tariffs). These are mentioned very briefly in the following section.

5.GTAP Implementation:

A modified dynamic GTAP model [GTAP-Dyn] is used to achieve this task. GTAP–Dyn is a multi-regional, multi-sectoral *dynamic* computable general equilibrium global trade model [see Ianchovichina and McDougall (December 2000), Ianchovichina, McDougall and Hertel (1999)] based on the standard, *static* GTAP model as documented in Hertel ed. (1997). In our model, technological change in the logging sector at the source USA is treated exogenously. Thus, technological change in the origin of development is *exogenous* and intermediate input is the primary vehicle for technology transfer from source to destinations. Such a technological innovation entails induced productivity enhancements when the output of the logging sector is used as an intermediate in other sectors especially wood products and pulp, paper and publishing. In other words, we specify a total factor productivity improvement in the logging sector in USA and trace the ensuing changes in the recipients via trade and sectoral feedback. In the current experiment, we assume one unique source sector of innovation 'i' (i.e., forestry/logging sector) identified by the set named 'SRCSEC'. SRCSEC is a subset of the set of traded commodities i.e., TRAD_COMM. A complementary subset—NSRCSEC—comprises the traded sectors other than the sector in 'SRCSEC'. The source region 'r' (i.e., USA) is also unique. Following our notations and specification of sets, $i \in$SRCSEC, $j \in$NSRCSEC, $r \in$SRC and $s \in$REG_NOT_SRC, with SRCSEC and SRC being single-element sets.

As regards the destination-specific absorption capacity parameter, we calculate the skill-unskilled labor payment shares for all the regions as of 1995 and use those skill-intensity ratios as proxying AC. As per our calculation, α_r proxying AC_{USA} is highest of all the regions. Calculated AC-values are such that $AC_{USA} > AC_{WEU} > AC_{JPN} > AC_{SAM} > AC_{ROW} > AC_{CAN} > AC_{SEA}$. For SS, we proceed in two steps: (i) calculating the land/labor ratios from the GTAP database. (ii) on the basis of these observations, we assume that USA, WEU, CAN and JPN are more similar structurally as opposed to SEA, SAM and ROW. Hence, this leads us to assign higher values for the former group of four regions whereas for the rest three we choose lower magnitude. Accordingly, the default parameter file in GTAP-Dyn [GDPARC.Dat] has been modified by including specific values for these parameters. The economic model includes additional equations viz., (6) and (7) and the modified equation for TFP appended to the standard dynamic GTAP model, some additional coefficients and additional parameters for AC and SS.[5] The model is solved recursively using customized windows program RunGDYN.[6] The policy experiment is conducted in the first period i.e., 1996.

5.a) Base line Projections: Assumptions and Scenarios

The base case scenario corresponding to this particular aggregation is constructed on the basis of macro and policy forecasts based on Walmsley et al. (2000). It comprises forecasts for the year 1996 to 2017 for gross domestic product (GDP), gross domestic investment (GDI), population growth, endowments of skilled and unskilled labors and capital. Real GDP and GDI are exogenously set equal to the forecasted value in the base case so that in the base case simulations we achieve the forecasted rate of growth in GDP and GDI. The base case scenario represents a plausible state of development of the world economy over 1996-2017. Different period lengths for the periods have been chosen to isolate the effect of Asian Crisis.[7] There are 7 periods of varying lengths—last 5 periods being of 4 years' length each while the first 2 periods are each of one-year length. Regarding policy projections in the base case, implementation of the Uruguay Round, elimination of quota rents (by reducing export taxes) under the Agreement on Textiles and Clothing (ATC) and China's pre-WTO and WTO-accession led tariff removals (over 1995-1999 and 2000-2004) was made. Amongst all, the base line projections give also an annual

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

[6] This is developed by Ken R. Pearson and colleagues at the Centre of Policy Studies/IMPACT, Monash University, Australia based on GEMPACK software suite. See Harrison and Pearson (1996) for GEMPACK simulation software.

[7] It has been found that small length over 1995-2000 period often leads the model to crash as results drive to negative numbers due to the Asian Crisis (correspondence with Dr. Walmsley is gratefully appreciated).

average percentage increase in *global* production (supply), exports, imports and demand for all commodities (see Table 2 below for the base case projections).

Table 2: Base line projections for global supply and trade by commodity, 1996-2017

			Supply				
	dv1r1996	dv1r1997	dv1r2001	dv1r2005	dv1r2009	dv1r2013	dv1r2017
agr	2.83	3.03	7.5	12.84	17.58	19.18	20.33
for	3.75	3.97	9.89	15.43	22.06	23.74	25.55
nre	3.37	3.49	9.97	14.37	19.45	21.36	22.4
omf	2.96	3.25	9.36	13.08	17.75	18.9	19.7
lum	2.67	3.07	9.37	12.5	16.27	18.52	18.92
ppp	2.67	3.02	8.95	12.62	17.49	18.39	18.85
svc	2.66	2.95	9.51	12.48	17.08	17.96	18.11
			Import				
	dv1r1996	dv1r1997	dv1r2001	dv1r2005	dv1r2009	dv1r2013	dv1r2017
agr	2.6	3.1	11.58	11.79	43.19	18.04	17.01
for	5.09	4.81	4.91	10.43	27.44	23.02	22.75
nre	3.37	3.64	10.31	15.35	21.52	20.72	20.93
omf	3.37	3.36	13.98	15.72	31.33	20.52	21.43
lum	3.22	3.73	12.53	14.68	24.18	21.58	20.83
ppp	2.94	3.04	10.5	14.71	25.3	19.69	20.16
svc	3.26	3.38	11.21	16.04	19.62	20.88	20.55
			Export				
	dv1r1996	dv1r1997	dv1r2001	dv1r2005	dv1r2009	dv1r2013	dv1r2017
agr	2.61	3.11	11.67	11.79	42.98	18.05	16.97
for	5.02	4.74	5.08	10.41	27.71	22.98	22.67
nre	3.38	3.64	10.27	15.37	21.51	20.69	20.91
omf	3.36	3.35	14	15.7	31.3	20.46	21.39
lum	3.22	3.74	12.52	14.69	24.25	21.6	20.84
ppp	2.94	3.04	10.5	14.71	25.3	19.68	20.15
svc	3.29	3.4	11.52	15.96	21.82	20.99	20.83

*Figures are in percentage changes of the respective variables following base case shocks.

However, in our analysis we focus on forest products (FOR), wood products (LUM) and paper products and publishing (PPP) and hence report the results for *regional* supply, demand and trade in such products (see Table 3 below). Given the base case scenario and policy projections (towards a more liberalized trade with gradual reduction of tariffs to zero levels in the Post-Uruguay round), overall for the global economy as a whole there has been an increase in global trade in almost all the products. Production (supply) of goods has also increased during the period being simulated. Also, domestic demand has registered growth during 1996-2017. Global as well as regional supply has shown the same upward trend with USA continuing to be the net exporters of forest products (for, lum and ppp) whereas for SEA there is a large cumulative increase in imports in ‘for’ and ‘lum’. WEU and Japan emerge as importers of ‘lum’ and ‘ppp’ with cumulative percentage increase in imports being more than the exports. For SAM, the cumulative percentage increase in imports is higher than that in exports. Figure 1 shows the movements of world supply of FOR, LUM and PPP during 1996-2017.

Table 3: Base line Projections for regional supply, trade, and domestic demand by selected commodities, 1996-2017*

Regions	Sectors	Production (Supply) 1996	Production (Supply) 1996-2017 (Cumulative)	Total Exports 1996	Total Exports 1996-2017 (Cumulative)	Total Imports 1996	Total Imports 1996-2017 (Cumulative)	Demand 1996	Demand 1996-2017 (Cumulative)
USA	for	2.37	98.93	1.25	148.44	2.77	107.67	2.45	95.15
	lum	2.66	94.23	0.68	158.85	3.65	92.73	2.79	90.21
	ppp	2.34	101.2	2.34	167.26	2.76	89.6	2.34	96.51
CAN	for	2.08	87.81	1.41	347.34	2.31	62.8	2.09	83.73
	lum	1.97	73.86	1.84	59.58	2.39	127.49	2.12	89.25
	ppp	2.72	96.19	2.99	100.27	2.27	117.34	2.52	93.21
SAM	for	0.96	142.55	-2.91	67.12	3.5	370.11	1.16	146.37
	lum	1.78	175.59	3.78	249.71	0.94	185.12	1.53	166.04
	ppp	1.79	179.6	3.77	275.76	1.22	155.08	1.56	168.49
WEU	for	1.9	107.66	0.21	250.61	3.34	50.65	2.01	98.05
	lum	1.89	93.89	-0.14	102.18	3.67	106.53	2.43	91.67
	ppp	2.05	89.67	1.43	95.17	2.55	97.05	2.23	88.08
SEA	for	8.6	314.67	3.19	176.75	11.3	443.96	8.8	319.72
	lum	7.86	315.31	5.45	310.42	8.92	427.56	9.26	319.39
	ppp	8.68	385.89	7.11	532.87	8.64	361.06	8.86	369.31
JPN	for	0.33	50.87	-3.08	539.38	4.04	29.59	0.33	50.62
	lum	1.23	45.25	0.77	57.02	3.59	139.59	1.24	45.19
	ppp	1.32	51.95	3.12	84.83	2.71	116.38	1.3	51.53

* Figures are in percentage changes of the respective variables following base case shocks to 1995 database.

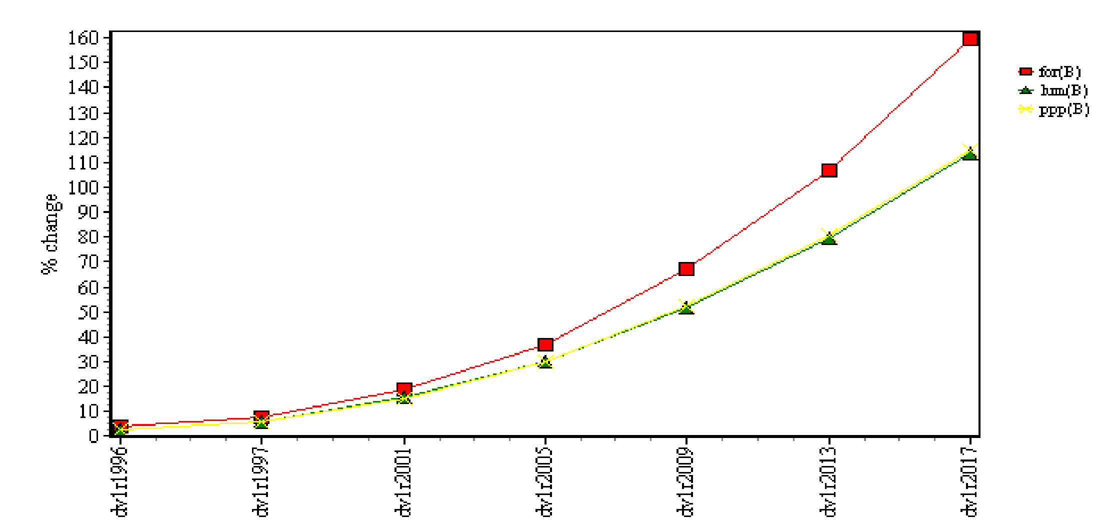

Figure 1: Baseline projections of global supply of logging, wood products and paper and publishing.

Following section describes the particular policy experiment and the results.

5.b) Policy Experiment: Policy Shock and Policy Closure

The particular policy experiment is a Total Factor Productivity improvement in logging sector in USA. According to Sedjo (p.21, 1999b), aggregate productivity in the U.S. registered annual average growth rate of 0.5 to 1 percent over 1935-80. According to Parry (1997, 1999), the average annual growth in multifactor productivity in the logging sector was 0.3% between 1980-1992. Since we do not have data for the periods being simulated in our experiment, linear extrapolation method is used to extrapolate growth rates over 25 years encompassing the entire simulated period i.e., 1996-2017. Thus, the extrapolated growth rate of 0.63% is used as the TFP shock in the experiment. In particular, assuming USA as the origin of technology creation we shock the Hicks-Neutral technological coefficient in USA in forestry (logging) sector by 0.63% in 1996 and simulate the technology Spillovers from USA to other sectors and regions. Like the base-case closure, the policy closure is the standard GTAP Dynamic closure [GTAP-Dyn closure] with added exogenous variable '*avaall*' added in both the cases to suit our purpose—the components *avaall (SRCSEC, SRC)*, *avaall ("CGDS", REG)* are treated as exogenous in the closure file. Since the policy experiment of our interest is conducted in the first period, we consider the policy impact in 1996 working in unison with the base period shocks (expected to occur in the world economy over the simulated period) so as to trace the effects of the base and policy scenarios.

6.Analysis of Selective Simulation Results: Macroeconomic and Sectoral Impacts.

6.1) Impact of Policy Shock: Macro Aspects

We confine our discussion mainly for three sectors viz., FOR, LUM and PPP and the regions USA, CAN, WEU and JPN.[8] The reason being USA, CAN and WEU are the major players in the international market for forest products. Figure 2 shows that following the TFP shock in the USA and its transmission via traded intermediates to the other regions there has been increase in real GDP at factor cost in all the regions with USA, Canada, and Japan showing higher percentage increases. For WEU and SAM, it does not show much change, rather remains the same. Also, following the TFP improvement in the forestry sector the region-wide index of TFP registers improvement in most of the regions with Canada, USA and JPN as the leading regions. The magnitude of the shock being very small, the impact has been much lower.

Being neutral in nature, the TFP change translates into an equivalent increase in real GDP at factor cost in the regions. As all primary factors become equally productive following the Hicks-neutral shock and its transmission, regional index of real value-added (in effective units) register an equivalent TFP improvement; however, the differences in the performances being driven by the differentials in technology transfer and its capture.

[8] All the results are not reported due to limitations of space.

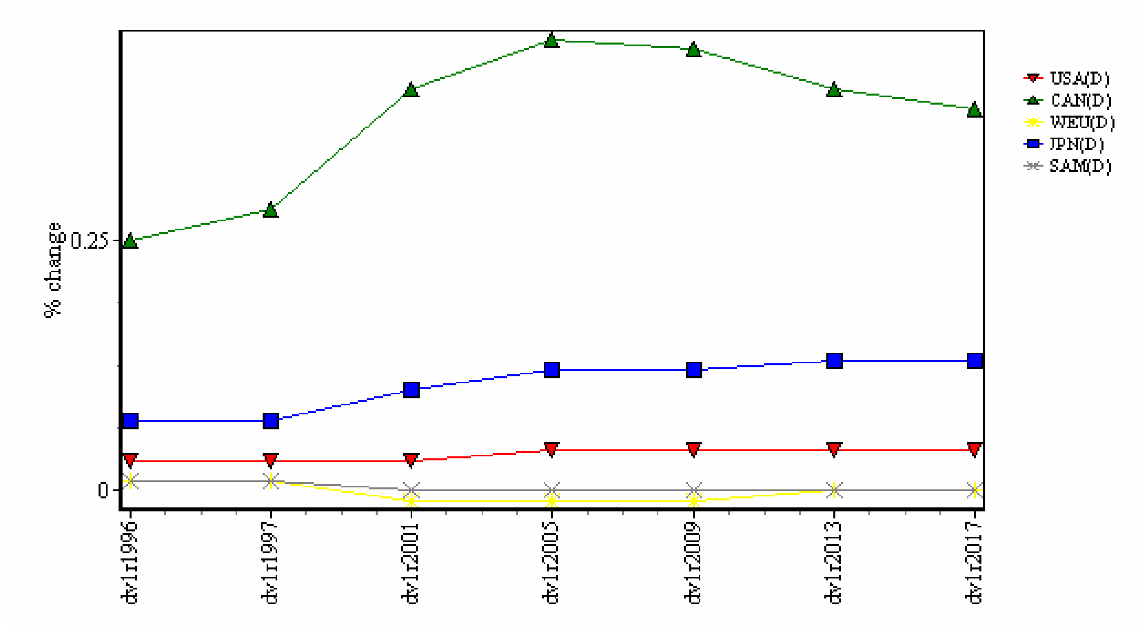

Figure 2: Simulated impact of a TFP shock in forestry sector in USA on real GDP at factor cost.

As will be evident from Table 4 below, the capture of transmitted technology depends on the magnitudes of the sectoral embodiment indexes and spillover coefficients vis-à-vis source and the destinations. Since the policy shock is injected in the first period (i.e., 1996 following the base period 1995) we quote the base-period values of such indexes.

Table 4: Values of economy-wide embodiment-indexes, spillover coefficients and capture-parameters [(a)]

GTAP Regions (1)	Embodiment Index (E_{irs}/E_{ir}) (2)	Spillover Coefficient (γ_{irs}/γ_{ir}) (3)	Capture-Parameter (θ_r) (4)
USA	0.42	0.76	0.68
CAN	0.73	0.52	0.40
SAM	0.01	0.012	0.25
WEU	0.0001	0.014	0.60
SEA	0.0001	0.001	0.17
JPN	0.04	0.13	0.54

(a) Values shown relate to the base period.

From Table 4, it is evident that the aggregate embodiment index in Canada is highest among the client regions due to higher volume of trade flows from USA and also we see higher magnitude of spillover coefficients as compared to other destinations (see columns 2 and 3). Having the highest magnitude of capture-parameter and largest domestic spillover and having supplied mostly the locally produced intermediate inputs of logging in its own market, USA is able to capture most of the productivity gains from the domestic technology transmission. Canada, although having lower θ_r as compared to WEU and Japan, registers higher technology spillover due to higher values of trade-embodiment index (see Column 2, Table 4). Similar considerations explain the cases for other destination regions. We observe that TFP shock makes all the factors more productive so that the marginal productivity of the primary factors improves by equal percentage changes and hence, the returns to factors (being paid according to their marginal products) also increased during the simulation period. However, following the TFP shock all the *sectors* experience differential TFP growth depending on the values of *sectoral* embodiment indexes and spillovers as discussed below.

6.2) Impact of Policy Shock: Sectoral Aspects

The values of *sectoral* embodiment indexes and spillovers reported in Table 5.

Table 5: Simulated impact on sectoral TFP, output (1996) and spillover coefficient by sectors (base period)*

Regions (1)	**Sectors** (2)	**Spillover Coefficients (Base period)** (3)	**Sectoral TFP Growth** (4)	**Percentage changes in Sectoral Output** (5)
USA	for	0.69	0.63	2.73
	lum	0.47	0.30	2.88
	ppp	0.26	0.17	2.50
CAN	for	0.15	0.10	1.57
	lum	0.03	0.02	1.27
	ppp	0.03	0.02	2.37
SAM	for	1.4	1.03	1.39
	lum	0.02	0.01	1.86
	ppp	0.02	0.01	1.83
WEU	for	0.12	0.08	1.90
	lum	0.02	0.01	1.88
	ppp	0.01	0.01	2.08
JPN	for	0.09	0.06	0.24
	lum	0.03	0.02	1.30
	ppp	0.08	0.05	1.39

*Figures are in percentage changes of the respective variables following TFP shock.

From Table 5, it is clear that USA, having reaped most of the benefits from domestic spillover via the logging sector (source of TFP improvement), the sectoral TFP growth is highest in all three sectors as compared to other regions (column 4, Table 5). The highest value of capture parameter magnifies the values of spillovers there and hence resulted in higher TFP growth. Similar considerations apply for Canada and WEU with the magnitudes differing—depending on the differentials in the values of embodiment indexes and spillover coefficients across sectors. However, for the relatively laggard regions with lower magnitude of θ_r viz., SEA and ROW, the resultant sectoral TFP growth is much lower compared to the regions performing better. The sectoral TFP improvement resulted in higher percentage increases in output 1996 in all the regions (see column 5, Table 5).

Following the shock, the differential sectoral performances are reflected in the inter-regional competition in an altered trading environment. The differential transmitted productivity gains are reflected in the relative price changes and changes in the terms-of-trade open up the scope for competition across sectors and regions. Table 6 summarizes the regional aggregate trade performance in the policy period.

Table 6: Simulated regional effects on aggregate trade performance of the regions in 1996

Percentage change in:	USA	CAN	SAM	WEU	JPN
1. McDougall Terms-of-trade (tot)	0.01	0.01	-0.002	-0.01	0.01
2. Aggregate export price index [pxwreg]	-0.01	0.001	-0.021	-0.04	0.013
3. Aggregate import price index [piwreg]	-0.02	-0.02	-0.019	-0.03	-0.010
4. Real value of exports [qxwreg]	0.03	0.16	0.05	0.05	-0.18
5. Real value of imports [qiwreg]	0.07	0.50	-0.02	-0.02	0.20
6. Change in trade balance [DTBAL]	-284.492	-561.08	+181.81	+1259.15	-1696.46

(a) Simulation results of 0.63% TFP shock.

It is clear that overall TFP enhancement acts as an export supply shifter in all the regions with variations in regional performances being driven by differences in technology capture and productivity improvements. This is reflected in percentage increases in regional aggregate exports [*qxwreg (r)*]—more pronounced in USA, WEU and Canada followed by Japan and WEU (i.e., the major beneficiaries of such TFP improvement). There has been increase in aggregate imports [*qiwreg (r)*]. Thus, overall global trade in these three sectors increased. As is evident from Table 8 (column 5), also world export price indexes [px_i (i)] for FOR, LUM and PPP fall between base case and policy—resulting in higher global exports in these commodities. From row 1, Table 6 we see that Terms-of-trade improves for the major beneficiaries of TFP improvement.

Considering the region-wide index of prices [psw (r)] received for *all* the tradable produced in each region, the region-wide relative price changes (as reported in Table 7) show that compared to other regions USA experiences decline in relative price, except in the case of WEU. However, these region-wide indexes include relative price changes in agriculture, natural resources, manufactures and service sectors as well. For WEU, the region-wide relative price movements have been dominated by the changes in the relative prices in those sectors. We do not discuss about those sectors here. In the policy experiment, the magnitude of the TFP shock and its resultant transmitted productivity gains is of small magnitude. Following TFP shock, productive efficiency of 'raw' value-added composite increases and marginal productivity of primary factors improve. As factors are paid according to their marginal products, there has been increase in price of value added in efficiency units in almost all the regions [pva (j, r)]. However, for USA (the major beneficiary of TFP improvement), as compared to Canada and Japan, following the shock the percentage increase in supply price is much less. Opposite is the case with WEU with much lesser productivity gains but sourcing mostly in its own market (compare the columns in Table 8).

Table 7: 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	CAN
CAN	-0.13	—
SAM	-0.14	-0.01
JPN	-0.45	-0.32
WEU	+0.19	+0.32

From Table 7a below, we infer that as changes in relative price in all three sectors in both Canada and Japan vis-à-vis USA is much higher, the regional aggregate exports [qxw (i,r)] in all three sectors from USA to all the destination regions increase following the shock. For the major beneficiaries of TFP improvements and its tranmitted gains, viz., USA, Canada, WEU and Japan, the percentage increase in the quantity index of exports [qxw (i,r)] is governed by the relative changes in the market prices of the tradeables imported from one source to another [i.e., pms (i,r,s)-pms (i, t, s) where r≠t]. In the simulation, as expected we find that for USA the percentage increases [qxw (i, r)] for FOR, LUM and PPP are respectively 1.63, 0.84 and 0.35 whereas for Canada these figures (declining) are respectively: -1.1, -1.2, -0.9; for Japan, the figures are: -0.66, -0.52, -0.30 respectively (see Table 7a below).

Table 7a: Simulated effect on aggregate regional exports of commodities[(a)]

GTAP Sectors	Regions				
	USA (1)	WEU (2)	CAN (3)	JPN (4)	ROW (5)
1. FOR	1.63	-0.11	-1.10	-0.66	-0.31
2. LUM	0.84	0.01	-1.20	-0.52	-0.01
3. PPP	0.35	0.07	-0.87	-0.26	-0.01

(a) Simulation results of 0.63% TFP shock.

Table 8: Simulated effect on export price indexes (regional and global) of commodities (near term)[(a)]

GTAP Sectors	Regions				
	USA (1)	WEU (2)	CAN (3)	JPN (4)	WORLD [px_i(i)] (5)
1. FOR	-0.50	-0.12	-0.01	-0.01	-0.23
2. LUM	-0.18	-0.05	+0.22	+0.06	-0.22
3. PPP	-0.08	-0.04	+0.30	+0.08	-0.07

(a) Simulation results of 0.63% TFP shock.

All said, we observe that given the very small magnitude of TFP shock, differentials in capture of potential benefits from trade-induced technology transmission (owing to differences in the values of region-wide technology capture parameters) altered the trading environment between the base period and policy scenario and impacted on the patterns of regional and sectoral competition. In the base line projections, for the policy period (i.e., 1996) annual average percentage growth rates of endowments of skilled and unskilled labor, real GDP are of much higher magnitude in USA as compared to Canada and WEU and other regions excepting SEA. Regarding policy forecasts, in forest products there is free trade in FOR, LUM and PPP between USA and Canada. For the forestry sector, zero tariff rates prevail in all the regions whereas for some regions like SAM, ROW and SEA the tariffs are very low with varying (but very small) magnitudes in LUM and PPP sectors. Since between base case and policy period, there is no further trade liberalization in forest products, the trade-embodiment is low, spillover coefficient is low and hence the scope of induced TFP improvement via trade flows in forest products is low.

From the foregoing discussion of policy effects, we have seen that regional differences in transmitted TFP improvements have resulted in differences in performances across regions as well as sectors in near-term (i.e., policy period 1996). Similar explanation applies in case of isolating the policy effects per se in longer term. As before, we consider the three sectors and regions of our interest. Tables 9 and 10 below give the percentage changes in supply prices [ps (i, r)] and outputs [qo (i, r)] of the sectors respectively.

Table 9: Simulated effect on regional price indexes of commodities (policy effect *per se* in longer term)[(a)]

GTAP Sectors	Regions				
	USA (1)	WEU (2)	CAN (3)	JPN (4)	SAM (5)
1. FOR	-0.72	-0.12	-0.20	-0.09	-2.01
2. LUM	-0.24	-0.02	-0.02	-0.03	-0.22
3. PPP	-0.12	-0.01	0.04	-0.01	-0.06

(a) Simulation results of 0.63% TFP shock.

Table 10: Simulated effect on regional output of commodities (policy effect *per se* in longer term)[(a)]

GTAP Sectors	Regions				
	USA (1)	WEU (2)	CAN (3)	JPN (4)	SAM (5)
1. FOR	0.45	0.08	+0.10	-0.12	0.67
2. LUM	0.22	-0.03	-0.17	+0.09	0.18
3. PPP	0.11	-0.01	+0.05	+0.12	0.03

(a) Simulation results of 0.63% TFP shock.

From Table 10, it is evident that outputs of FOR, LUM and PPP in USA register higher percentage increase as compared to all other regions excepting SAM. This is due to the fact that USA being the source of TFP improvement captures most of the potential productivity benefits as compared to other regions. However, the results are mixed across sectors —primarily driven by the differences in sectoral TFP growth following the shock. For Canada, in LUM sector output shrinks after the policy experiment in the longer term. From Table 5, we observe that percentage increase in sectoral TFP growth [ava (j, r)] is of very low magnitude in Canada (as compared to the USA). Although the capture parameter and spillover coefficients are higher, it was able to appropriate the productivity benefits in the policy period, but not as much as in the case of USA or SAM so as to register much percentage increase in output. Thus, ava [j, r], being low, does not dominate the percentage changes in sectoral output in this region. Hence, the effect of endogenous TFP improvement has been modest with reallocation of factors across sectors, to some extent, influencing the changes in output in Canada and other regions (as opposed to USA where more pronounced sectoral TFP growth inflates the sectoral output supply). Regarding supply price changes, from Table 9 it is evident that USA reaps the maximum potential TFP improvements and the cost-savings is reflected in lower prices [ps (i, r)] in all three sectors. For SAM and WEU, having supplied almost 97 percent of FOR domestically the price also falls—depending on the extent of transmitted productivity gains. The falling cost is largely attributed to a decline in price of composite value-added and its constituents in a sector 'j' in region 'r' [pva (j, r)] (in conventional units).

In case of Canada, the relative prices in all three sectors increase as compared to its biggest competitor USA. That is, it increases by 0.52 (FOR), 0.22 (LUM) and 0.16 (PPP). As relative prices increase, the demand falls. Due to the contractionary effect of a decline in demand, given the attendant general equilibrium effects, output has to fall in these sectors. With fixity of land and natural resources, the TFP shock and its repercussions have different impacts on the demands for categories of labor and capital across sectors. Labor and capital are perfectly mobile across sectors as relative prices move across the commodities after the shock (see Table 9). However, following the neutrality of the shock the shares of value-added and its components in any sector j in the regions 'r' [SVA (j,r)] do not change between the base period and policy period. With almost no change in factor proportions [Capital/Labor ratios], there has been negligible impact on the relative factor prices of mobile factors across sectors in a particular region. With intersectoral and region-wide mobility of capital and skilled and unskilled labor, this resulted in uniform percentage increases in returns to respective factors across sectors in a region. Due to shifts of resources to other sectors (especially manufactures, services) following lesser magnitude of transmitted productivity gains, the cost reduction is not fully reflected in higher yields in these sectors. Thus, the demands for skilled and unskilled labor and capital change across sectors [qfe (i, j, r)] whereas neutrality of the shock translates into the same percentage increase in demands for factors in a sector for a region.

So far as the index of prices received for tradeables produced in a region [psw (r)] is concerned, we see that it declines in USA, SAM and WEU by 0.01, 0.02 and 0.04 percentage points respectively whereas for Canada, it increases by 0.05 percent. Accordingly, we see that aggregate exports of the three commodities from USA, WEU and SAM register an increase whilst from Canada it shrinks. Overall, volumes of *global* merchandise exports in FOR, LUM and PPP increase over the entire period (see figure 3 below). Thus, the TFP improvement and its transmission have been trade creating for the world economy as a whole. The effect has been welfare-augmenting—mainly due to allocative efficiency effect, value-added augmenting technical change and partly due to terms-of-trade effect (see figure 4 below). WEU and SAM, by experiencing minor benefits from trade-induced spillovers, has relative lesser welfare enhancement as compared to USA, Canada and Japan.

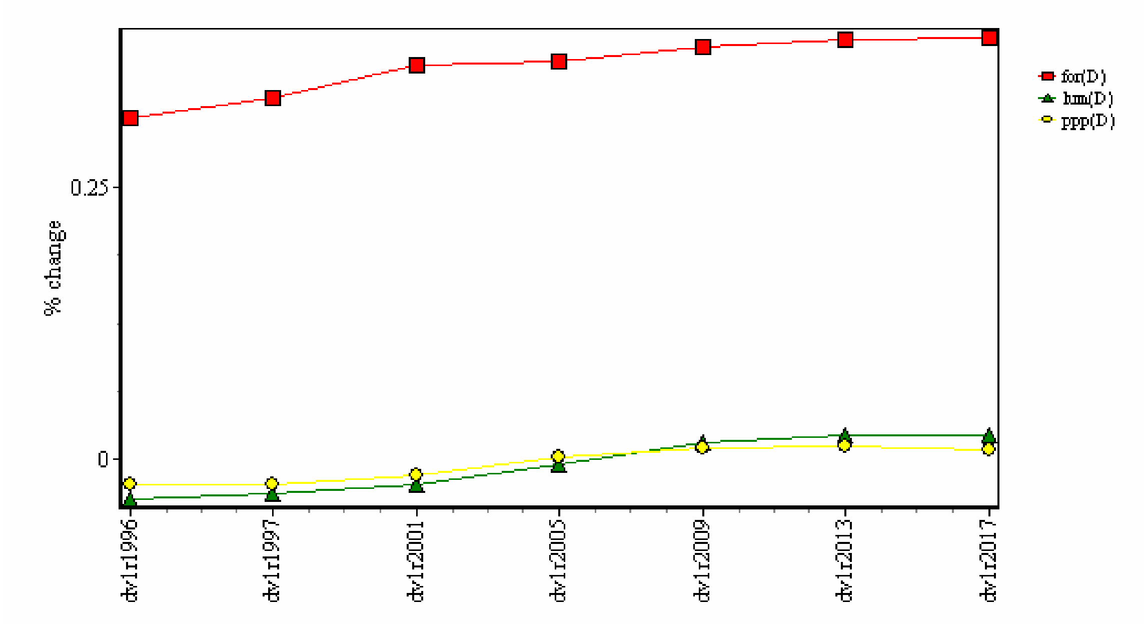

Figure 3: Simulated impact of a TFP shock in forestry sector in USA on global merchandise exports in FOR, LUM and PPP, 1996-2017.

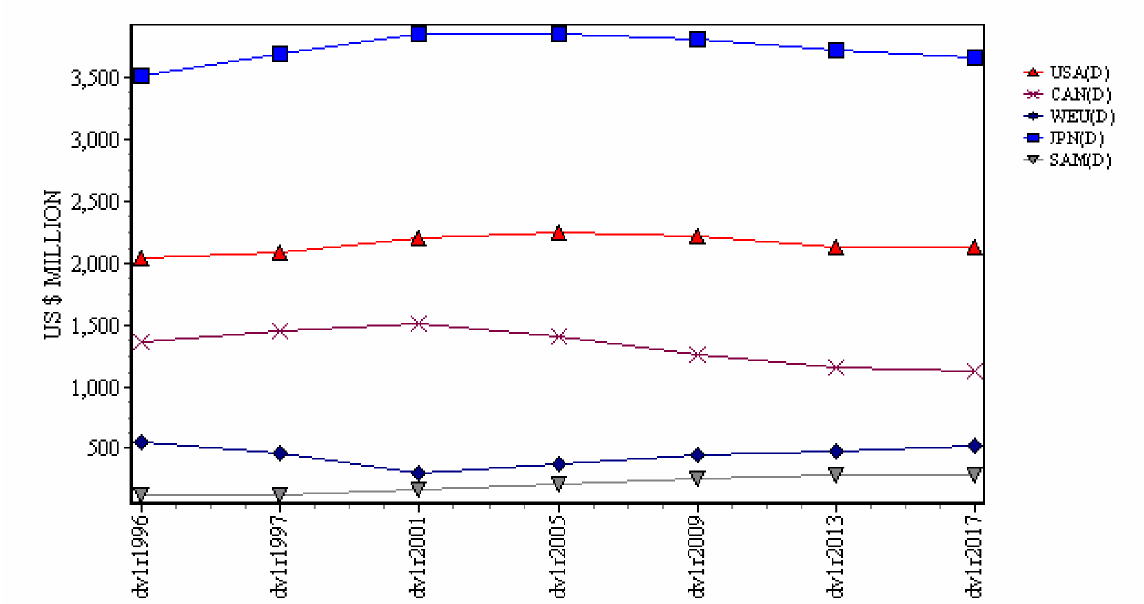

Figure 4: Simulated impact of a TFP shock in Forestry sector in USA on regional welfare, 1996-2017.

7.Summary of Findings

Following the technology shock, we calibrate: (i) regional disparities in capturing transmitted productivity gains; (ii) the impact on global commercial timber supplies, wood products production, and the pulp and paper supplies in the long-run; (iii) future production of timber, wood, and pulp and paper products across regions. The model results show that biotechnological innovations in the logging sector result in a significant increase in timber production. Also, results show that sectors that use forest products intensively register higher output growth especially in USA experiencing much higher benefits of TFP change. In the face of fixed land supply, increasing productivity through biotechnology may be the most effective way to meet the consumer demand for forest products. This has been supported in the studies by Simpson (1999) and Sedjo (1997, 1999a&b). As forestry industry is in the process of transition towards intensive plantation based forest management, the importance of biotechnology research for improving productivity in the face of a shrinking land base can in no way be ignored. Considering land-saving technical change is one area where the research could be extended in future.

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