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Abstract

In this paper, we analyze the consequences of biotechnology innovations in the United States (U.S.) forest sector (logging) by modeling technology transfer embodied in trade flows and its absorption. A seven-region, seven-traded-commodity version of a dynamic computable general equilibrium model is used to achieve this task. A 0.63% Hicks-Neutral biotechnological progress in the source region (U.S.) has differential impacts on the productivity of the log-using sectors in the domestic as well as in the recipient regions. Since recipient regions' ability to utilize biotechnology innovations depends on their absorptive capacity (AC) and structural similarity (SS), we construct the AC and SS indices based on multiplicity of factors such as human capital endowments, skill content and social appropriateness of the new innovations. The model results show that biotechnological innovations in the U.S. forest sector result in a significant increase in timber production. Following the productivity improvements and its embodied spillover, wood products and pulp and paper sectors in the U.S. register higher productivity growth. The role of AC and SS in capturing technical change is shown to be evident. In the face of growing regulations on timber production from public forests, increasing productivity through biotechnology may be the most effective way to meet the consumer demand for forest products.

Keywords: Total factor productivity; Dynamic Computable General Equilibrium; Capture Parameter; Forestry Biotechnology

1. Forestry Biotechnology: Technological and Economic Aspects

Historically, the U.S. enjoyed significant comparative advantage in industrial wood production based on its vast acreage of old growth forests. As much of these forests have either already been harvested or converted to other land uses, the U.S. can no longer solely rely on its natural forests for industrial timber production. In addition, forest preservation sentiments are growing in the face of rising demand for forest products. For example, a house bill—H.R. 1494 entitled "National Forest Protection and Restoration Act" was introduced into the U.S. Congress in 2001. This bill proposes an elimination of commercial logging from all national forests of the U.S. The essence of this bill is to protect the environment, preserve biodiversity, to avert indirect costs to the recreation and tourism industry, fishing industry, and to stoppage of flooding damage in the process of supplying consumer goods. If passed, this policy is expected to reduce U.S. timber supply by approximately 5 percent. On the other hand, consumption of forest products in the US is expected to increase by 69 percent over the next 50 years [1]. The application of productivity-enhancing activities through genetic improvements and tissue culture is thought to be a viable option to address the above paradoxical situation. The advent of biotechnological innovations and its potential impact on sustained productivity growth in forestry is well documented [2, 3, 4, and 5].

In the literature, two principal sources are identified for increased forest sector productivity—firstly, technical change in logging and second, technical innovations focusing on intensive forest management and plantations for commercial wood production [3, 4 and 5]. The latter source has been dominant with over 33 percent of global industrial wood production coming from plantation forests [4]. Intensively managed tree plantations achieve much higher productivity, particularly with the application of biotechnology for tree improvement, biopesticides for forest management and propagation, and conservation and restoration [6, 7]. Biotechnology is used to achieve desired tree traits such as tolerance for herbicide, insects and faster tree growth. In terms of potential gains in wood production, these innovations contribute to significant cost-savings [8].

The acquisition and effective assimilation of transferred technologies are essential for the development of forest product industries. This has been discussed in the context of agroforestry extension efforts for the adoption and diffusion of technology [9, 10]. Whiteman et al. [11] identified important social factors, such as land tenure security, local participation in the implementation of agroforestry ventures, and attitudes towards acceptance of novel techniques. Based on Rogers' [12] theory of 'Diffusion of Innovations', Whiteman et al. [13] emphasized that an efficient technology transfer process involves development of indigenous knowledge systems and "the ability to understand and apply complex technical knowledge." Thus, extension programs based on social factors and educational attainment play important role in promoting absorptive capacity (AC) to 'adopt' the new technique. Effective adoption of new forestry technologies depends, *inter alia*, on the process of invention, its transmission, 'local adoption' and social acceptance [4 and 14].

The issue of absorption has been stressed in the literature in the context of biotechnology as well. In particular, Fontes [15] stressed the role of new biotechnology firms and skilled young professionals as "disseminators of new technology and translators of competencies to user sectors." Also, Fontes [15] emphasized the crucial role of 'hybrid entrepreneurs' (i.e., the professionals with technical expertise) for facilitating the transfer of such technology and its absorption. However, to the best of our knowledge, there has been fewer analysis on the role of absorptive capacity (AC) in the transfer and use of biotechnology in the forestry sector. We do so here by constructing an operational definition of AC and applying it within an empirical general equilibrium framework. Success in assimilation of transferred technology depends on the skill content of the labor force and has been ascribed to 'AC' of the recipients. The importance of AC in technology acquisition has been discussed at length in the development economics literature by Cohen and Levinthal [16], Pack and Westphal [17], Nelson [18], Nelson and Pack [19], Lall [20], and World Bank's [21] World Development Report—to name a few.

As biotechnology research opens up new opportunities for sustainable forest management and yield-enhancing activities, transmission of such technology and its effective assimilation are crucial for productivity enhancement in the forestry sector. In the integrated world of global trade, cross-border technology flows occur via intersectoral spillovers and trading intermediates. These traded intermediates, embodying technical improvements, when used in the production of final products, deliver potential technological benefits to the user sectors. Typically, in the context of transfer of biotechnology one could envisage the productivity improvements in the logging sector and its transfer to other sectors via usage of traded timber as intermediate inputs in the production of user sectors viz., wood products, pulp and paper products. Such a transfer of forestry biotechnology from the logging sector (i.e., source) to the user sectors would lead to a rise in industrial wood productivity. As more of world's industrial wood is produced in plantation forests, sophisticated forestry biotechnology delivers benefits due to higher productivity of planted forests. This is reflected in lower costs of production in wood, pulp and paper sectors. This, in turn, will lead to lower relative prices faced by the consumers of such products. As relative prices of the demanded goods fall after the spillovers of innovations, scope of application for cost-effective biotechnology in forestry is substantial.

As such, a simulation analysis of biotechnological inventions and its repercussions requires a multi-sectoral and multi-regional structure. Therefore, we use a modified Global Trade Analysis Project (GTAP) model,[2] a general equilibrium framework, to analyze the consequences of a biotechnology innovation in the U.S. forest sector. Section 2 sets out the conceptual framework for the study. Section 3 documents the aggregation in the database. Section 4 describes the implementation whereas section 5 documents the simulation experiment. Section 6 explains the simulation results. Section 7 concludes.

2. Underlying conceptual framework.

2.1 Brief survey of the literature for trade-induced technology transmission.

Advanced technologies are primarily developed in the more industrialized countries. The relatively "laggard" or developing countries largely depend on the growth of foreign technologies for their own development, based on not only the extent and nature of the technologies but also on their competence for effectively assimilating the diffused technologies. Technologies that are developed at the source regions will spill over to the destination regions through bilateral and multi-lateral trade linkages. International trade in commodities has shown to be an efficient facilitator for propagating technologies embodied in those goods. Research findings of Coe, et al. [23], Dietzenbacher [24], Eaton and Kortum [25], Connolly [26], Keller [27, 28], and World Bank [21] provide substantial empirical evidences for this "embodiment hypothesis". All these studies have found substantial trade-related spillovers accruing to the developing economies with their total factor productivity (TFP) responding positively to liberalized imports of manufactured products and a higher level of education of the labor force. Eaton and Kortum [25] have explored trans-border technology flows and productivity differentials across countries in multi-country, empirical, general equilibrium model with particular focus on technology flows between five leading innovative Organisation for Economic Co-operation and Development (OECD) economies. World Bank [21] has documented the relevant country experiences in acquiring technology via traded intermediates with particular emphasis on the role of AC and structural similarity (SS). Amacher et al. [14] have studied the aspects of household and community adoption of new forestry technologies in a province in Pakistan and have found that household characteristics such as income levels, factor endowments and extension forestry programs facilitate adoption of new forestry innovations. Role of structural and technological congruence in aiding technology adoption in agriculture has also been studied [29, 30, 31].

Spillovers can readily be traced in a multisectoral, multi-regional framework, as is shown in studies by van Meijl and van Tongeren [31], Dietzenbacher [24], Keller [27]. Meijl and Tongeren [31] have taken productivity growth in innovating country (e.g., North America) as exogenous and analyzed the effective utilization and resultant productivity growth in the destination regions (e.g., China) via transmission of knowledge through traded inputs, human capital and structural similarity between donor and the recipients. Since the productivity growth rates of countries are related through international trade linkages and associated “trade-embodied” technology spillovers, Meijl and Tongeren’s model [31] incorporates the essential elements of AC and SS factors to determine the domestic usability of foreign technologies. AC is constructed as an index of human-capital-induced absorption capacity of the participating trade partners. SS is specified as a binary index based on similarity of factor proportions in the two regions. Together with trade volume, these two indices jointly determine the 'productive efficiency' parameter.[3] Domestic usability of the transmitted technology depends mainly on the recipient's capability to utilize the diffused technology. The simplified 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 the first approximation) be equally good at absorbing technology from another region 'B' which (from C's point of view) is structurally similar to 'A'. The trade-induced technology transmission mechanism implemented here is based on Das' earlier work [32, 33] in a static GTAP framework. Unlike Meijl and Tongeren [31] and Das [32, 33], our modeling framework here is dynamic. The basic spillover equations and necessary modifications made are described in the following sub-sections.

2.2 Theoretical framework for trade-embodiment and technology spillover equations

Technology embodied in foreign and domestic intermediate inputs spills over to all other economic sectors and affects their total factor productivity. That is, following an exogenous Hicks-neutral technological improvement in one sector of a region (for example, the logging sector in the U.S.), all other sectors in the source and trading regions experience trade-induced endogenous TFP improvement.[4] The embodiment index is defined in terms of input-specific trade intensity. Following Das [32, 33], we adopt two different specifications for technology transmission equation: the first applies for the trade-induced spillover between the source and destination regions, while the second captures the endogenous domestic spillover to other sectors in the source region itself.

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

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

In equation (1), F_{irjs} is the imports of 'i' from source 'r' used by sector 'j' in recipient 's'. For the source sector 'i', the definition for the spillover coefficient is given by:

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

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 absorptive capacity index AC_s, (with $0 \le AC_s \le 1$) and the binary structural similarity index, SS_{rs}, (with $0 \le SS_{rs} \le 1$); 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,

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

It should 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 used 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_{ijs}), the regional composition of imports for individual using sectors in 's' is not known. Therefore, we make a pro-rata assumption— that an imported input is proportionally distributed across all user sectors.[5] 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':

$$F_{irjs}/F_{ijs} = F_{irs}/F_{is} \qquad (3)$$

where F_{is} 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 of 'i' by sector 'j' by 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.

In the source region, the benefits of a technological change (exogenous) in a particular sector are enjoyed by the other sectors both directly via the usage of locally produced intermediate inputs with the embodied technology, and indirectly via the relative price changes of foreign intermediates. Thus, new technology embodied in the intermediate inputs is dispersed to the other domestic sectors such that the exogenous TFP improvement in the source sector endogenises the TFP improvement in the receiving sectors via a domestic spillover effect. The relevant sectoral embodiment index [E_{ijr}] for 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'. The relevant capture parameter for the source country is defined in terms of the human capital-induced AC only, where we assume that the higher is AC in 'r', the higher will be the domestic sectoral spillover effect. 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-induced capture-parameter for source 'r'.

2.3 Productivity shock

The productivity transmission equation for the recipient 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 (i.e., Hicks-neutral technical progress parameters) in source and destinations [$i \neq j$, $r \neq s$]. For the source region ‘r’, the transmission equations, where i and j ($i \neq j$) are the innovating sector and the receiving sectors respectively, is given by

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

However, in our simulation design, the source of TFP improvement is *uniquely* in sector ‘i’ in the single donor region ‘r’.

3. Methodology and Database: Sectoral and Regional Aggregation

Version 4 of the GTAP database (i.e., GTAP Sectoral Classification, revision 1 (GSC1)) distinguishes 45 regions and 50 sectors. A reduced dimension involving a seven region-seven sector aggregation of Version 4 of the GTAP database is used to calibrate the model. Table 1 presents the regional and sectoral aggregations used in this implementation. It comprises bilateral trade flows, protection and transport data accounting for regional interlinkages and also input-output databases for multi-sectoral linkages within regions. McDougall et al. [36] documents the detailed database. The starting period of our simulation is 1995.

[**Insert TABLE 1 here**]

4. A Dynamic GTAP Implementation

A modified dynamic GTAP model [GTAP-Dyn] is used to simulate the effect of the technology shock. GTAP–Dyn is a multi-regional, multi-sectoral dynamic computable general equilibrium global trade model developed by Ianchovichina and McDougall [37] and Ianchovichina et al. [38] based on the standard, static GTAP model as documented in Hertel [22].

In our model, technological change in the logging sector at the source, i.e., the U.S., is treated exogenously, and the intermediate goods from this sector are the primary vehicles for technology transfer. Such a technological innovation entails induced productivity enhancements when the output of the logging sector is used as intermediate inputs in other sectors especially wood products and paper products and publishing. Thus, we specify a TFP improvement in the U.S. logging sector and trace the ensuing changes in the recipients via trade and sectoral feedback. In the current experiment, we assume technological innovation in the unique source sector 'i', i.e., the logging sector, and the unique source region ‘r’, i.e., the U.S.

With regards to the absorption capacity parameter, we define it in terms of skill-intensity of the labor force. Thus, the skill-unskilled labor payment shares for all the regions are calculated and used as proxies for AC parameter in our model. As per our calculation, α_r in equation 7 is proxying AC_r for any region ‘r’ and AC_{US} is the highest of all the regions followed by those of WEU and CAN. For SS parameter, we proceed in two steps: (i) calculating the land/labor ratios from the GTAP database; (ii) based on these calculations, we find that U.S., WEU, CAN and JPN have similar range of values and hence, assume that they are more similar structurally as opposed to SEA and SAM. This leads us to assign higher values for the former group of four regions and lower values to the other two regions. Thus, the economic model includes structural equations plus additional technology flow equations (6) and (7), the modified equation for TFP appended to the standard dynamic GTAP model, and additional coefficients and parameters for AC and SS.[6] The model is solved recursively using customized windows program RunGDYN.[7]

We develop a baseline forecast of the world economy for the year 1996 to 2017 based on the macroeconomic scenario developed mainly by the World Bank’s Global Economic Prospects historical and forecast data [39]. The baseline forecast corresponding to this particular aggregation is constructed on the basis of macro and policy forecasts based on Walmsley et al. [39]. The base case scenario represents a plausible state of development of the world economy over 1996-2017. There are seven periods of varying lengths—the last five periods being of four years' length each while the first two periods are each of one-year length. The reason behind using one-year period length at the start is to validate the effects of TFP change taken from history (in 1996) in very near-term whereas the last five periods are of uniform length.

Given the base case scenario, the global economy as a whole shows an increase in regional and consequently in global trade for almost all the products. Overall, there has been an increase in the production of goods during the base period with some differences in performance across the regions. Base line projections provide annual average percentage increases in regional as well as global production, exports and imports of such products.[8] It is to be noted that the baseline projections represent performances in the forestry sector without any additional technological change.

We consider the policy experiment where biotechnology shock originates in the forestry sector in the source country i.e., the U.S. and is transmitted to other regions and sectors through international trade linkages. In particular, policy experiment is conducted in the first period, 1996, based on the history of technical change in the forestry sector. However, we compare the baseline projections to the alternative policy simulation in the near-term (1996) and longer run (2017). Since our major interest is on the forestry (FOR), wood products (LUM) and paper products and publishing (PPP) sectors, our discussions will focus on these three sectors only. Also, we emphasize mainly on the regional impacts in the U.S., Canada and WEU on the reasoning that they are the major players in the international market for forest products.[9]

5. Policy experiment: policy shock and policy closure

The particular policy shock is based on the TFP improvement in the U.S. logging sector. According to Sedjo [p.21, 8], aggregate productivity in the U.S. has registered annual average growth rate of 0.5 to 1 percent during 1935-80. According to Parry [5], the average annual growth in TFP in the logging sector was 0.3 percent between 1980-1992. Since we do not have data for all the periods being simulated in our experiment, linear extrapolation method is used to extrapolate the growth rates over a 22-year period encompassing the simulated period, i.e., 1996-2017. This extrapolated growth rate of 0.63 percent is used as the TFP shock in the experiment. We shock the total factor productivity coefficient of the U.S. in the logging sector by 0.63 percent in 1996 and simulate the inter-sectoral technology spillovers across different regions. Since the policy experiment of our interest is conducted in the first period, we consider the policy impact in 1996 to be effective in unison with the base period shocks such that the 'pure' policy effect would be the differential impacts between the base-case and various policy scenarios.

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

Following the shock, the region-wide TFP index registers an improvement in the U.S., Canada and WEU and consequently it translates into increments in sectoral outputs and TFP growth. Figure 1 shows an increase in real GDP at factor cost in all the regions with higher percentage increases for the U.S., Canada and WEU.

[**Insert FIGURE 1 here**]

As the technological shock is factor-neutral, all primary factors become equally productive after the shock and its transmission. Thus, the regional index of real value-added correspondingly register an equivalent TFP improvement with differences in performances being driven mainly by the differentials in technology transfer and its capture—based on our constructed AC and SS indexes.

[Insert TABLE 2 here]

As will be evident from Table 2, the capture of transmitted biotechnology shock depends on the magnitudes of sectoral embodiment indexes and spillover coefficients vis-à-vis source and the destination regions. Since the policy shock occurs in the first period, we quote the base-period values of such indexes. It is evident from Table 2 that the aggregate embodiment index in Canada is the highest among the trading regions due not only to higher volume of trade flows from the U.S. but also to the relatively higher magnitude of spillover coefficients (see columns 2 and 3). The U.S., with the highest magnitude of its capture-parameter (θ_r) and domestic spillovers and being the largest supplier of logging products in the domestic market, is able to capture most of the productivity gains from the domestic technology spillover to other sectors. Canada has lower magnitudes of capture-parameter (θ_r) as compared to the WEU, but registers higher spillovers of biotechnological improvement due to a higher magnitude of its trade-embodiment index (see Column 2, Table 2). Thus, on the whole, trade-induced productivity enhancements contribute to increase in real output in these regions. On the other hand, in the case of developing composite regions SAM and SEA the magnitudes of the capture-parameter is very low (see column 4, Table 2). This is reflected in the relatively smaller values of embodiment indexes and spillover coefficients in these regions as compared to the developed regions the U.S., WEU and Canada (see column 3, Table 2). Therefore, the transmitted productivity gains are of lower order of magnitude for SAM and SEA.

We observe that the factor-neutral TFP shock makes all primary factors more productive so that their marginal productivity improves by equal percentage changes after the perturbation. In the policy experiment, after the TFP shock and its resultant transmission of productivity gains, productive efficiency of composite value-added increases. Consequently, marginal productivity of all the primary factors improves and in almost all the regions price of value added in efficiency units increases. Opposite is the case with the WEU, which experienced lesser productivity gains; this is due to the fact that it is the largest supplier to its domestic market. However, all the sectors experience differential TFP growths depending on the values of sectoral embodiment indexes and spillover coefficients as presented in Table 3.

[Insert TABLE 3 here]

As expected, the U.S. enjoys the largest share of benefits from domestic spillover and sectoral TFP growth is the highest in all three sectors as compared to other regions (column 4, Table 3). The value of capture parameter magnifies the values of spillovers thereby resulting in higher TFP growth in the U.S. Similar considerations apply for TFP growth in Canada and the WEU. In the case of the WEU with lower magnitudes of θ_r, the resultant sectoral TFP growth is, as to be expected, lower as compared to the other two regions. The sectoral TFP improvement resulted in higher percentage increase in the output of all the regions in the near term (see column 5, Table 3). On the contrary, in case of developing regions, SEA and SAM, because of lower values of capture parameter and spillover coefficients, the TFP improvements are modest.

The differential sectoral performances are also reflected in inter-regional competition in the altered trading environment following the policy shock. The differential transmitted productivity gains are reflected by relative price changes, leading to changes in the terms-of-trade and correspondingly, competitiveness of the sectors and regions. Table 4 summarizes the regional aggregate trade performance over the policy period.

[**Insert TABLE 4 here**]

It is evident that the overall TFP enhancement acts as an export supply shifter in all the regions with variations in regional performance being driven by regional and sectoral differences in technology capture and resultant productivity improvements. This is reflected in percentage increases of regional aggregate exports and imports for the U.S., WEU and Canada (see row 4, Table 4). From row 1, Table 4, we see that the terms-of-trade improves for major beneficiaries of TFP improvement–the US and Canada, leading to an increase in real exports from the U.S. and Canada. The U.S., having reaped most of the benefits from the technology shock and its associated spillovers to other sectors, is able to register a decline in the relative prices of exportable whereas for Canada, it was of smaller order of magnitude despite an increase in aggregate export price. Consequently, the terms-of-trade improved for these two regions. Opposite happens in case of the WEU whose terms-of-trade deteriorated owing to lesser transmitted productivity gains. However, as the technology shock is overall productivity enhancing, aggregate real exports increase in all three regions. Also, supporting evidence from Table 5 shows a decline in world export price indexes for the three sectors due to technical change, resulting in higher global exports in these commodities. Following the shock, the world export prices fell by 0.23

percent, 0.22 percent and 0.07 percent for logging, wood products, and paper products respectively. This leads to an increase in global trade in the forestry sector products.

The results indicate that the public/private sectors in the U.S. and Canada have a major role to play in promoting biotechnological innovations in the forestry sector so as to generate higher outputs in this sector. Through trade promotion, these benefits are transmitted to the trading partners like Canada and the WEU as they have adequate capacity to absorb the technology. It is important to note that as growing environmental concerns has led to more forest set-asides, the higher volume of trade following the technical change and trans-border spillover enables the countries to meet their growing demand for forest products.

[**Insert TABLE 5 here**]

We infer from Table 5 that the changes in the relative prices in all the three sectors are higher for both Canada and the WEU as compared to the U.S. As a result, there is an increase in regional aggregate exports of all three sectors from the U.S. to all the destination regions. We find that the percentage increases in regional exports of all three sectors from the U.S. increased, whereas exports from Canada declined (see Table 5). This is due to the fact that relative prices in these product categories have moved in favor of the U.S. For Canada and the WEU, the fall in the price of the forestry sector is negligible and hence, the decline in price in these two regions has not translated into an increase in export demand.

In the base-case, there is free trade between the U.S. and Canada, while very low but varying tariffs exist in the lumber, and pulp and paper product sectors in some regions. Since there is no further trade liberalization in forest products between base and policy periods, the scope of technology-induced TFP improvement via further trade flows in forest products is low. Therefore, we observe that the differentials in the capture of potential benefits from technology transmission altered the trading environment by opening up the scope for regional and sectoral competition through relative price changes. From the discussion of policy effects, we have seen that regional differences in transmitted TFP improvements have led to differences in productivity growth performances across regions and sectors in near-term (i.e., policy period 1996). Similar explanation also applies in the case of isolating the policy effects *per se* in longer term.

[**Insert TABLE 6 here**]

Table 6 shows the percentage changes in supply prices and outputs of the three sectors and regions of our interest. It is evident from Table 6 that the outputs of FOR, LUM and PPP in the U.S. register the highest percentage increases as compared to the other regions. This is due to the fact that the U.S. captures most of the potential productivity benefits relative to other regions. However, results are mixed across sectors—owing to the differences in sectoral TFP growth. Looking at Table 6, it is evident that the U.S. reaps the maximum potential from TFP improvements and cost-savings as reflected in lower prices and higher output for all the three forest sectors over the longer term. Prices in the WEU fall too, but not as much as in the case of the U.S. and Canada. Since the WEU supplies almost 97 percent of the domestic demand for forest products (as per the GTAP database), the region is relatively insulated from the trade-induced gains. The declining cost following the TFP improvements is largely attributed to a decline in price of composite value-added and its constituents in any concerned region.

The decline in the relative prices for all three forest sectors in the case of Canada is not as much as compared to its biggest competitor, the U.S. As the relative prices in Canada and the WEU increase relative to the U.S., the demand for these products from these regions declines. The decline in the output of lumber products and a much smaller increase in the output of other forest products are attributed to very low percentage increase in sectoral TFP growth for Canada (see Table 3). As its capture parameter and spillover coefficients are high, Canada is able to appropriate the benefits from productivity improvement in the short-term, but is not able to continually sustain an increase in output over the longer term. Thus, it is imperative that the public/private sectors should not only be investing in forestry-related biotechnology research but also be fostering skill-formation for assimilating such research output. The results imply that the benefits from technical change originating in developed countries like the U.S. can be reaped by other trading regions if there is adequate human capital to assimilate and absorb such benefits.

Since the policy shock is factor-neutral, the shares of value-added and its components in any sector do not change between the baseline and the policy period. Labor and capital are perfectly mobile across sectors as relative prices vary across the commodities after the shock. With almost no change in factor proportions, there has been negligible impact on the relative factor prices of mobile factors across sectors in a particular region. With intersectoral and regional mobility of capital as well as skilled and unskilled labor, the TFP improvement and its transmission resulted in uniform percentage increases in returns to respective factors across sectors in a region. Due to lesser magnitude of the transmission productivity gains, the cost reduction is not fully reflected in higher yields in these sectors. In general, TFP improvement and its transmission have generated increased trade for the world economy as a whole. This is reflected in the increase in the volumes of global merchandise exports in FOR, LUM and PPP over the entire period of simulation (see Figure 2).

[**Insert FIGURE 2 here**]

7. Conclusions

In this paper, we simulated a 0.63 percent total factor productivity improvement in the U.S. in the logging sector and studied regional disparities in capturing transmitted productivity gains. We found that the technological progress can have different impacts on productivity improvements of trading partners depending on the absorptive capacity and structural similarity of the source and the destination regions. The simulation results show that biotechnological innovations in the U.S. logging sector and its spillover to other regions result in a significant increase in global timber production and global welfare. The role of absorption capacity and structural similarity in capturing technical change is also evident. The higher values of capture parameters in the U.S., Canada and WEU allow these regions to realize a higher percentage increase in the productivity growth and sectoral output. On the other hand, the relatively laggard regions, SEA and SAM, experience relatively less pronounced productivity improvement. Higher skill-intensity induced absorptive capacity facilitates transfer of biotechnological inventions across regions that are structurally congruent to each other. Given the increase in productivity and output growth, changes in price relativities between the regions alter the trading scenario. In particular, the U.S., Canada and WEU experience declines in relative prices of exportable as compared to other regions. This is reflected in changes in regional terms-of-trade, which moved in favor of the U.S. and Canada. This suggests that public policy promoting technical education and human capital formation are crucial for harnessing the potential benefits of biotechnology research in both the source and recipient regions. It seems that there is no disagreement about the potential of biotechnological innovations in furthering productivity. In the face of fixed land supply, increasing productivity through biotechnology may be the most effective way to meet growing consumer demands for forest products.

There are several directions in which the present research could be further extended. Although we have considered a neutral technical progress, it would be worthwhile to explore the impacts of skill-labor biased technical change favoring the skilled personnel. In this line, modeling the role of human capital and skill formation will give more insights about interplay between absorptive capacity and technological spillovers. We assumed that TFP improvement occurs only in the U.S. forest sector. It is quite likely that other developed countries also experience productivity improvements. As such, the effects of productivity improvement in all developed regions can be studied. Modeling R&D formation in the forestry biotechnology would help us to construct more refined specifications for absorptive capacity and capture parameter. However, our present paper is a step towards research in these directions.

Footnotes

[1] This is based on the paper presented at the 4th Annual Conference in Global Economic Analysis held at Purdue University, West Lafayette, June 27-29, 2001. The generous support and useful suggestions from W. J. Harrison, Hans van Meijl, Ken R. Pearson, Alan Powell, Frank von Tongeren and Terrie Walmsley are acknowledged with usual caveats. Helpful comments from two anonymous referees of this journal are also immensely appreciated. Financial support from the USDA (Initiative for Future Agriculture and Food System) is greatly appreciated. Florida Agricultural Experiment Station Journal Series R-08708.

[2] GTAP is a multi-regional, multi-sectoral global applied general equilibrium trade model suitable for trade policy analysis. For details, see Hertel [22].

[3] Absorption capacity (AC) depends not just on human capital, but also on a constellation of factors such as learning effects and R&D in the recipient countries. In this paper, we do not model technology creation and R&D formation explicitly as an endogenous outcome of the decision-making process of the firm. Rather, we treated it as an exogenous perturbation within the system and traced the impact of its transmission mediated by trade flows. Also, the data on variables like inventions and R&D for composite regions in our model are not easy to obtain. Thus, while defining AC in our model, we have not considered the variables for inventions for sake of simplicity and lack of comparable data. In case of modeling endogenous R&D creation, one needs to take into account the variables for inventions. In case of structural similarity (SS), we define it at the macro/regional/country level rather than focusing on any particular sector per se. We emphasize the role of similarity of factor proportions between the source and the destination countries. The idea is that the more

similar are factor endowments in the origin of technological change and the recipients, the more likely are the accrual of benefits from technology transfer. Given the focus on the role of similarity of regional endowment patterns in facilitating technology transmission, the consideration of land/labor ratios as a proxy for SS does not necessarily undermine our purpose (see [29, 30, 31, 33]). Consideration of forestland usage pattern would have been useful if the analysis would have focused on structural similarity/differences of forest sector itself and the impact of technical progress on changes in land categories across various uses. However, these issues are beyond the scope of our study. Hence, in line with the definition of AC (defined at the regional level), SS is defined analogously.

[4] A technical progress is Hicks-neutral if the ratio of marginal physical products remains unaltered for a given capital-labor ratio. Thus, this type of technical progress makes all the productive inputs equally productive with no bias in favor of non-produced primary factors of production. It is called factor-neutral technical change as it does not save relatively more of any of the factor inputs.

[5] This particular assumption is necessitated by data limitations. However, in the literature on embodied international technology diffusion, this is a common assumption. See OECD [34], *Science and Technology Indicators Scoreboard*, p 105.

[6] Structural equations of the model encoded in TABLO language are not reported here for space limitations. GTAP users interested in the modified equations or other modeling specifics may contact the authors for such details.

[7] 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 [35] for details on GEMPACK simulation software.

[8] The base line projections corresponding to the base-case scenario are not reported here but can be obtained from the authors.

[9] All the results are not reported due to limitations of space but are available from the authors upon request.