# *Endogenous International Technology Spillovers And Biased Technical Change In The GTAP Model*

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**GTAP Technical Paper No. 15**

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## *Abstract*

This paper discusses the implementation of embodied international technology spillovers in the GTAP model. We specify a transmission mechanism for technical knowledge that assumes that knowledge is embodied in traded commodities. The usability of knowledge in the receiving country is dependent on the local absorption capacity (e.g., human capital, knowledge infrastructure) and on structural differences (e.g., factor endowments, climate) between countries. This concept is illustrated first by modeling spillovers embodied in final products and Hicks-neutral technical change. The bulk of the paper deals with factor-biased technical change in agriculture, and its international transmission through traded intermediate inputs. We demonstrate how to implement embodied international technology spillovers in the GTAP model and provide some numerical illustrations which highlight production effects and welfare effects. The GEMPACK implementation, together with additional data, is provided in a set of files which accompanies this paper.

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# *Endogenous International Technology Spillovers And Biased Technical Change In The GTAP Model*

## *1. Introduction*

Technology spillovers are said to exist if one market party receives productivity benefits from technologies developed by others, yet there is no monetary compensation for the technology transfer. Modeling of technology spillovers requires some assumptions on the transmission mechanisms of knowledge between countries. This technical paper shows how to utilize GTAP's bilateral trade flows as a transmission channel for international knowledge transfer.

Knowledge can be transmitted by various channels. For example, a division can be made between embodied and disembodied spillovers. Embodied knowledge spillovers represent knowledge that comes together with commodity purchases or in other words knowledge that is embodied in goods. In contrast, disembodied spillover channels are not linked to commodity flows. Examples are scientific conferences, international journals, patent information etc. There is empirical evidence that both types of spillovers are important for the productivity growth of sectors (see Mohnen (1994) or van Meijl (1995) for a review).[1] In this paper we limit ourselves to embodied knowledge spillovers as the main transmission channel of knowledge.

The approach set forth in this note relates to recent developments in the so-called "new trade" and "new growth" theory. Based on this literature, Coe, Helpman and Hoffmaister (1995) identified four technology transmission channels in particular. First, international trade enables a country to employ a larger variety of intermediate products and capital equipment, which enhances the productivity of its own resources. Second, international trade provides channels of communication that stimulate cross-border learning of production methods, product design, organizational methods, and market conditions. Third, international contacts enable a country to copy foreign technologies and adjust them to domestic use. Imitation is widespread and it has played a major role in the growth of high performing economies such as Japan and the Newly Industrialized Countries (NICs). Finally, international trade can raise a country's productivity in the development of new technologies or the imitation of foreign technologies, thereby indirectly affecting the productivity level of its entire economy.

Empirical support for our approach is provided in Coe and Helpman (1993) and Coe, Helpman and Hoffmaister (1995) who estimated the existence of international technology spillovers embodied in trade flows and found a statistically significant influence of knowledge developed in foreign countries on the

[1] Despite the fact that there are many empirical papers that measure the existence of spillovers, only Sterlacchini (1989) and van Meijl (1997) estimate the influence of both embodied and disembodied spillovers on productivity growth. Both authors find a statistically significant influence for both kinds of intersectoral spillovers on the productivity growth of sectors.

productivity level of a country. Their estimates suggest that countries enjoy substantial benefits from R&D done by their partners. In a recent paper Sjoholm (1996) shows the relevance of trade as a transfer mechanism. The volume of international trade is a robust explanatory variable for cross-border patent citations in his regression equations. In this paper we focus on international trade as the carrier of knowledge. Of course there are other important channels, most notably foreign direct investment (FDI), from which we will abstract in this work.

We distinguish between two types of spillovers in this paper: spillovers embodied in final products and spillovers embodied in traded intermediate inputs. The first type relates to transfer of knowledge through an imitation and 'reverse engineering' process, that may for example occur in consumer electronics. In this case, we shall assume that imports of improved final products lead to Hicks-neutral productivity improvements in the production of that particular commodity in the receiving country. Here, no distinction is drawn between the carrier of knowledge and the commodity that it affects via innovation.

On the other hand, spillovers through trade in intermediate inputs are more complex. In this case, the carrier of knowledge (the intermediate input) is distinguished from the commodity that is affected by the innovation (the commodity that uses the intermediate input in its production). We shall assume that imports of improved intermediate inputs will lead to improvements of productivity of that intermediate input in the production of a specific commodity, or set of commodities. For example, imports of improved fertilizers make fertilizers more productive in the production of grain. On top of that, we shall assume that imports of improved intermediate inputs will also have a broader effect on production techniques in the sense that they also alter the productivity of land and labor.

The remainder of this paper is organized as follows. Section 2 provides, first of all, the theoretical background for our modeling of international technology spillovers and it specifies a transmission mechanism for international technology spillovers. Sections 3 and 4 discuss the actual implementation of these ideas in the GTAP model. Section 3 contains a discussion on modeling spillovers embodied in final products and Hicks neutral technical change in the GTAP model and gives some numerical illustrations to show the working of the spillover function. Section 4 focuses on the implementation of technology spillovers through trade in intermediate inputs. This is followed by presentation and analysis of several illustrative simulations to show the production and welfare effects of the introduction of such spillovers in the GTAP model. The first appendix to this note describes the aggregation and additional data used in these simulations while the second appendix gives details on the actual GEMPACK implementation, which should be general enough for others to build on the ideas introduced here.

# *2. General embodiment hypothesis*

Our basic spillover formulation endogenously relates technological change in a region or country to technological change in a foreign region or country which may be Hicks-neutral or input augmenting. Our main assumption is that the receiving region can only benefit from technological change which is occurring elsewhere if it acquires the commodities in question from the region where the technological change occurs initially. International trade is therefore the vehicle of knowledge spillovers, and the *size of trade linkages* plays an important role in technology transfer. If we think of technology as being embodied in commodities, so that a certain amount of knowledge is embodied in each unit of the commodity being used, then the size of the knowledge flow is directly related to the volume of imports.

Coe and Helpman (1995) have used this in empirical work to estimate international spillover effects, but we extend this spillover concept by considering not only the amount of knowledge received by trade flows, but also the *effectiveness* of this amount of knowledge in the receiving region. We distinguish two main constraints to effective use of foreign technologies. First, *the absorption capacity* is important because the destination region must be able to absorb the knowledge which is developed in the source region. The ability to absorb knowledge is dependent on the level of human capital, the research capacity, the knowledge infrastructure, own innovation capacity, etc. If a country has a low absorption capacity it will only be able to partially understand and utilize the foreign technology. Second, the *structural similarity* of countries in terms of current production characteristics is important for the effectiveness of a certain amount of knowledge because knowledge is partly country-specific, particularly in agriculture. See for example Schultz (1964) and Hayami and Ruttan (1985) who notice that for agricultural techniques the international diffusion process is even more difficult than for manufacturing industries because "agricultural technology is highly *location specific* and techniques developed in advanced countries are not, in most cases, directly transferable to less developed countries with different climates and different resource endowments" (Hayami and Ruttan, 1985, p.59).

Our spillover hypothesis may be summarized in an equation that relates productivity growth rates between two regions. Productivity growth in the receiving region is determined by the following transmission equation:

$$a_s = E_{rs}^{1-\delta_{rs}} \cdot a_r \quad 0 \le \delta_{rs} \le 1 \quad 0 \le E_{rs} \le 1$$
$$\delta_{rs} = \delta(H_{rs}, D_{rs}) \tag{1}$$

Where $r$ denotes the region of origin of the productivity growth, $s$ denotes the destination region; $a_r$ and $a_s$ denote productivity growth rates respectively the regions of origin and destination, respectively. These parameters are directly related to the parameters in the production function of the GTAP model, (see section 4.2). $E_{rs}$ is an index of the *amount* of knowledge which is embodied in trade linkages between the two regions. $\delta_{rs}$ is a function of an absorption capacity index $H_{rs}$ and an index of structural similarity $D_{rs}$.[2]

The particular functional form of the spillover equation implies that: (i) region $s$ cannot benefit from productivity growth in region $r$ if there are no trade linkages between the two regions, (ii) the maximum rate of productivity growth that can be achieved in region $s$ equals the exogenous productivity growth in region $r$, (iii) the marginal returns of increasing trade linkages (in terms of productivity growth) to region $s$ are positive, but diminishing. This feature reflects the notion that relatively large marginal gains can be achieved by moving from a state of very low interactions to a situation which allows knowledge

[2] Coe and Helpman (1995) have used a similar type of specification of the embodiment index for embodied neutral technology change. However, their specification did not include the absorption capacity and structural similarity effects.

to move more freely between regions. In contrast, the marginal gains are lower if two regions are already close- knit.[3]

Generally speaking, the index $E_{rs}$ is taken to be a function of the domestic use in region *s* which is satisfied by imports from region *r*. We elaborate on the specification of this index below. In section 3.1 we consider the case where knowledge is embodied in final product and in section 4.3 we specify an alternative index for the case where knowledge is embodied in intermediate inputs. The initial productivity growth in region *r*, $a_r$ is viewed as the result of an R&D process which is not modeled explicitly here, and which is taken to be exogenous. In the GTAP model, the innovation is visible to producers in the sense that they take the productivity effect into account in their cost minimizing input choice. Productivity parameters appear in the cost function because they alter the 'effective' input prices facing firms.

*The absorption capacity index: $H_{rs}$:* The absorption capacity index ($H_{rs}$) relates the absorption capacity of the destination region ($h_s$) to the absorption capacity of the country of origin ($h_r$) and reflects the destination region's relative ability to use the new technology. We use the following specification for the absorption capacity index:

$$H_{rs} = min\left[\ 1, \frac{h_s}{h_r}\ \right] \tag{2}$$

This particular form of the absorption capacity index incorporates the notion that there are no obstacles to absorbing a foreign technology if the destination region has a larger amount of human capital than the source region, while absorption is more difficult if the absorption capacity in the destination region lags behind the source region. In the latter case, we believe that the destination region may not have sufficient expertise to permit it to understand and adapt the new technology

The absorption capacity in equation (2) has been quantified using information on years of schooling from the well known Barro & Lee (1993) data set (see Appendix 1). The idea is that it takes trained and educated persons to absorb knowledge produced in other countries.

*The structural similarity index: $D_{rs:}$* A part of the newly created knowledge is country specific and is only useful for the specific structure of the innovating country. Therefore, the more similar the structure of the countries the higher the expected usefulness of the received knowledge. We calculate an index of structural similarity using the equation:

$$D_{rs} = exp[\ -\left|\ (l_r - l_s)/d\ max\ \right|\ ] \tag{3}$$

Where $l_s$ and $i_r$ denote indicators of structural characteristics (e.g. land/labor ratios) the source region (*r*) and destination region (*s*) respectively, and $d^{max}$ is the largest absolute difference in the indicator found between all pairs of regions. This formulation scales the differences in the indicators on the unit interval.

[3] Alternative functional forms could incorporate increasing returns in the initial phase of trade interaction and decreasing returns when trade volumes are larger. Such a specification (e.g. through a logistic function) would then incorporate the notion of an initial hurdle below which technology transfer is very difficult, and above which technology can flow more freely between regions. In contrast, our specification implies no initial hurdle and countries learn most from the first contacts with innovating countries.

Furthermore, the function takes the value one if the two countries are identical, and declines exponentially towards zero as they become more different.

In our empirical application, we focus on grains production. The associated index of structural similarity in equation (3) has been quantified using FAO data on land and labor intensities (see Appendix 1).

*The interaction between structural characteristics and local absorption capacity:* Simply being smart (a high absorption capacity, $H_{rs} \to 1$) is not sufficient to benefit fully from foreign technologies because a part of the foreign technology is location specific. On the other hand, a perfect match in terms of structural characteristics ($D_{rs} \to 1$) is not sufficient to enable full transfer of agricultural knowledge developed in another country because a country must also be able to understand and absorb the knowledge. In order to incorporate the notion that both absorption capacity and structural similarity need to be present, we combine the measures $H_{rs}$ and $D_{rs}$ multiplicatively to yield the parameter $\delta_{rs}$ which determines effectiveness of foreign knowledge:

$$\delta_{rs} = H_{rs} \cdot D_{rs} \tag{4}$$

The multiplicative specification implies imperfect substitutability between absorption capacity and structural similarity. It is not possible to fully offset the impact of dissimilar structural characteristics by virtue of a high absorption capacity.

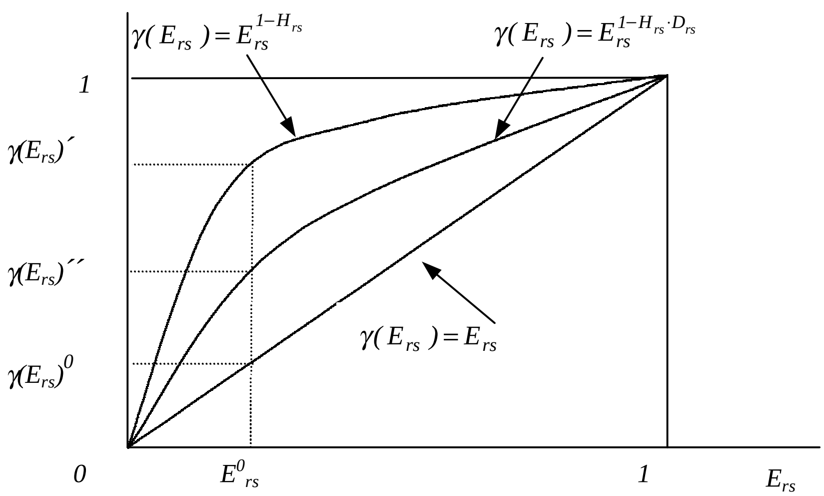
Combining (1) and (4) and rewriting this equation in terms of relative productivity growth rates, we arrive at the following specification for our spillover coefficient:

$$\gamma(E_{rs}) = a_r / a_s = E_{rs}^{1-H_{rs} \cdot D_{rs}} \tag{5}$$

The spillover coefficient, $\gamma(E_{rs})$, represents that portion of technical progress in the innovating country $r$ that spills over to the receiving country $s$. As can be seen from equation (5), this coefficient is dependent on three main effects: the relative amount of knowledge that is embodied in trade flows from the innovating country ($E_{rs}$), its absorption capacity ($H_{rs}$) and the degree of structural similarity ($D_{rs}$) with the innovating country. The $E_{rs}$ index is endogenously determined in the model while the $D_{rs}$ and $H_{rs}$ indices are exogenous.

The combined impact of these three effects is illustrated graphically in figure 2.1. We assume that the innovating country $r$ achieves a certain rate of technical progress and study the part that spills over to the receiving country $s$. This yields the spillover coefficient, $\gamma(E_{rs})$, which is depicted on the vertical

Figure 2.1: The value of the spillover coefficient




axis in figure 2.1. This depends on the relative amount of embodied knowledge, $E_{rs}$, as determined by the strength of the bilateral trade relations between the two countries $(E_{rs})$ is depicted on the horizontal axis). If we set $H_{rs}$, or $D_{rs} = 0$), then the spillover coefficient varies linearly with the amount of embodied knowledge spillovers, i.e. equation (5) becomes $\gamma(E_{rs}) = E_{rs}$. For example, when the amount of embodied knowledge spillovers is equal to $E^0_{rs}$ then the obtained spillover coefficient is equal to $\gamma(E_{rs})^0$ in figure 2.1. However, the relative level of the absorption capacity $(H_{rs})$ of country $r$ to country $s$ influences the usefulness of embodied knowledge and therefore the spillover coefficient. If the absorption capacity of a country is high, a small amount of embodied knowledge enables a country to achieve a higher rate of technical progress than expected on the basis of the linear relation. Taking into account this absorption capacity in figure 2.1, shifts the curve from $\gamma(E_{rs}) = E_{rs}$ to $\gamma(E_{rs}) = E_{rs}^{1-H_{rs}}$. Given the same level of embodied knowledge spillovers, $E^0_{rs}$, the spillover coefficient now increases from $\gamma(E_{rs})^0$ to $\gamma(E_{rs})'$. Finally, we can bring in the structural similarity effect $(D_{rs})$ which implies that a part of the created knowledge is country specific, and therefore of less value in the receiving country. Consequently, the curve shifts downwards to $\gamma(E_{rs}) = E_{rs}^{1-H_{rs}\cdot D_{rs}}$ which implies that the obtained spillover coefficient declines from $\gamma(E_{rs})'$ to $\gamma(E_{rs})''$.

# *3. Modeling spillovers embodied in final products and Hicks-neutral technical change in GTAP*

In this section we implement the spillover function specified in the GTAP model. In section 3.1 we introduce spillovers embodied in final products that cause Hicks-neutral technical change in the GTAP model. Section 3.2 provides some numerical simulation examples with the GTAP model to illustrate the workings of our spillover formulation. We assume that spillovers are embodied in traded final products and illustrate the influence of the embodiment, absorption capacity and structural similarity effects on the value of the spillover coefficient.

Spillovers related to trade in final products might naturally occur in consumer electronics. The acquisition of improved foreign computers, television sets etc. may be followed by a 'reverse engineering' process which leads to productivity improvements in the domestic consumer electronics sector.

## *3.1 Spillovers embodied in traded final products*

To implement the spillover equation (5) in GTAP, we have to define the embodied knowledge index ($E_{rs}$). In this section it is assumed that knowledge from sector *i* in the innovating country comes along with final products of sector *i* that are exported from country *r* to *s*. The embodied knowledge index becomes (see, also Bernstein and Mohnen (1994), Coe, Helpman and Hoffmaister (1995)):

$$E_{irs} = \frac{X_{irs}}{\sum_k X_{irk}} \tag{6}$$

where $X_{irs}$ represents exports of product *i* from country *r* to country *s*. Equation (6) therefore represents the share of total exports of commodity *i* from country *r*, that is shipped to country *s*. Note that $\sum_k E_{irk} = 1$, and therefore (abstracting from the *H and D indices)* the initial productivity change $a_r$ is fully distributed over trading partners. The knowledge simply 'leaks away' to others. In section 4 below we will use import shares instead of equation (6). Equation (6) is used here in order to forge a link with other studies that have used such a formulation. Also, this illustrates the point that there is more than one way to implement these ideas.

Using (6), the spillover equation (5) becomes

$$a_{is} = \left( \frac{X_{irs}}{\sum_k X_{irk}} \right)^{1-H_{rs} \cdot D_{rs}} \cdot a_{ir} \tag{7}$$

In GEMPACK this is achieved by adding a new equation to GTAP.TAB:

```
EQUATION ao_eq
!Hicks-neutral tech change related to trade flows !
(all, i,SPILL_COMM)(all, r, SPILL_SRC)(all, s, SPILL_DEST)
ao(i, s) =
VXMD(i,r,s)/sum(k,SPILL_DEST,VXMD(i,r,k))] ^(1-spilldelta(s,r)*absflex)
                                * spillflex
                                * ao(i,r);
```

It relates Hicks-neutral factor productivity growth ao(i, s) in sector *i* of region *s* to the initial TFP shock ao(i,r) in the same sector in region of origin *r*. Productivity growth is transferred through trade in the same commodity *i*, using the proportion of total exports to all `SPILL_DEST` regions from the `SPILL_SRC` region of origin to the region of destination as weight. The export shares are based on the GTAP variable VXMD(i,r,s) that represents exports of commodity *i* from region *r* to region *s* measured in FOB prices[4].

The term `spilldelta(s,r)` is the product of the absorption ($H_{rs}$) and structural similarity ($D_{rs}$) coefficients which determine the effectiveness of embodied foreign knowledge. The value of this coefficient is calculated outside the model (see data Appendix) and read from a datafile. Also note the roles of the binary parameters `ABSFLEX` and `SPILLFLEX.` Setting `SPILLFLEX` to zero switches the entire spillover equation off. Setting `ABSFLEX` to zero sets the term (`1-spilldelta(s,r)`) to unity, thereby neutralizing the effects of absorption and structural similarity. (See section 4 below for data sources and empirical estimates of $H_{rs}$ and $D_{rs}$.)

The following new sets and coefficients have to be included in the GEMPACK implementation of the standard GTAP model (file: GTAP.TAB, including welfare decomposition).

***Sets***

The spillover framework requires the specification of four new sets:

(1) the source regions of spillovers, i.e., the region which makes the initial invention:

`SPILL_SRC`

(2) the destination regions of spillovers, where does the knowledge go?

`SPILL_DEST`

(3) the commodity whose production function is affected by spillovers:

`SPILL_COMM`

***Parameters***

The additional parameters fall into two categories:

1. New model coefficients.

- `SPILLDELTA` the parameter which determines the effectiveness of foreign knowledge in the spillover receiving region:

2. Simulation control parameters to (dis-) activate certain features of the spillover implementation.

- `SPILLFLEX` to switch embodied spillovers on or off. This facilitates study of the impact of technical change in a single country without spillovers.
- `ABSFLEX` to turn the human capital/structural differences effect on or off. With the help of `ABSFLEX` the combined effect of the absorption parameters can be isolated.

[4] Hence we are excluding trade- and transport margins from our embodiment index

## *3.2 Numerical examples with the spillover function*

This section illustrates spillovers embodied in final products, and it highlights the features of our spillover equation. A technology shock in an innovating country *($a_{ir}$)* will automatically induce a technology shock in the receiving country ($a_{is}$) which is dependent on the trade relations, the absorption capacity and the structural similarity index.

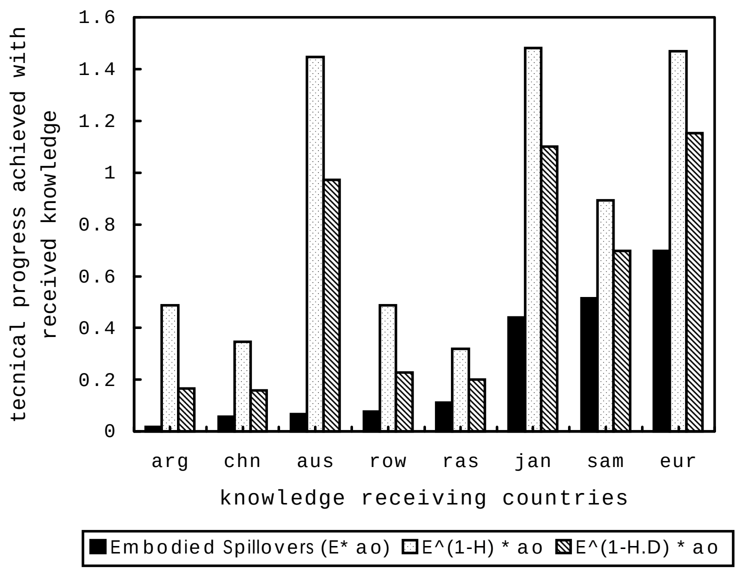



Figure 3.1 Knowledge spillovers received by other countries when there is a 2% Hicks neutral technical change in the machinery industry in North America (NAM).

We introduce an innovation in sector *i* in country *r* by increasing its total factor productivity (TFP). In particular we introduce a 2% TFP shock in the machinery sector in North America (NAM). Three simulations are performed to study the spillover function. First, we assume a linear relation between $E_{rs}$ and spillovers. Second, we introduce the absorption capacity effect and thirdly, we include both the absorption capacity as the structural similarity effect. The simulation results are depicted in figure 3.1. For example the technology shock of 2% in North America in machinery induces technical change of 0.70% in the machinery sector in the European Union (EUR) when the spillover coefficient varies linearly with the amount of embodied spillovers. The spillover coefficient ($\gamma_{NAM,EUR}$) is simply the export share amounting to 0.35 and this is multiplied by the rate of TFP growth in the originating country. Including the absorption capacity implies that the amount of embodied spillovers becomes more valuable and the spillover coefficient increases to 0.735 which induces 1.47% of technical change in the European machinery sector. However, the land/labor ratio of EUR is much smaller than that of NAM which implies that these countries are structurally different. Therefore, the knowledge produced in NAM is of less value in the EUR.[5] This effect brings the spillover coefficient back down to 0.52, so the rate of technical

[5] In this paper we focus mainly on the agricultural sector where similarities in land/labor ratios can be seen as a proxy for the structural similarity of countries. In the section where we focus on the machinery sector this proxy could be improved upon by also taking account of the industrial structure of the machinery sector.

change is 1.03. If one compares these effects over countries it is striking that most trade in machinery of NAM is with Europe, South America (SAM), Japan and the NIC's (JAN). These countries receive therefore the largest amount of embodied spillovers. Like Europe, AUS and JAN have a high absorption capacity that increases the value of embodied knowledge. The structural similarity is highest with Australia and Argentina (ARG) which implies that knowledge produced in NAM is most useful in these countries.

# *4. Modeling spillovers embodied in inputs and biased technical change*

## *4.1 Biased technical change: the case of agriculture*

The previous section abstracted from the nature of the technical change in agriculture. In this section, we discuss the process of technical change in agriculture and elaborate on its "factor-bias" and "location-specific" nature. Learning in the agricultural sector occurs primarily through acquisition of improved inputs, which may be adapted to fit into local circumstances. The following quotation from Timmer (1988) nicely describes the issue of technical change in agriculture:

> "Most technical change in agriculture involves improvements in the biological processes by which plants and animals grow and yield output useful to society or in the mechanical functions that are necessary for the biological processes to carry on more efficiently than in natural setting. Primitive agriculture uses natural biological materials and processes in combination with human labor and management to bring in a crop or livestock product. Modern agriculture uses scientific knowledge to reshape the biological materials so that each plant and animal is more productive, and it increasingly substitutes machines for labor" (Timmer, 1988, p.303).

*Technology embodied in inputs:* According to Timmer most agricultural innovations tend to be embodied in physical inputs (p. 302-304 and p. 312). The main kinds of inputs that carry technology are hybrid seeds, fertilizers and insecticides on the one hand and agricultural machinery on the other hand. The consequences of such technological progress for the productivity of agricultural imports in the receiving regional are rarely uniform. Rather they represent "factor biased technical change."

*Factor biased technical change:* The concept of factor biased technical change was first introduced by Hicks (1932) to describe techniques that facilitate the substitution of other inputs for a specific production factor. He called techniques that facilitated the substitution of other inputs for labor "labor saving" and those designed to facilitate the substitution of other inputs for land "land saving". According to Earl O. Heady (1949) and Hayami and Ruttan (1985, p.75) *biological-chemical* innovations, such as hybrid seeds, fertilizers, and pesticides all tend to be yield increasing and thus substitute for land. In Hicks' terminology they are land saving. *Mechanical* technology can also have a yield effect when it permits more timely cultivation and an extension of multiple cropping, cultivation of soils, or the use of irrigation pumps, but most mechanical technology is designed to make agricultural work less physically burdensome and to save the amount of labor to produce a unit of output: i.e. they substitute machines for labor and are therefore labor saving.

*International transfer of agricultural technology-Location specificity:* Abramovitz (1986) and Baumol et al. (1989), stress that the international diffusion of techniques doesn't happen automatically. Countries must be able to understand and work with the new techniques. Countries must have a sufficient "absorption capacity". However, Schultz (1964) and Hayami and Ruttan (1985) point out that for agricultural techniques the international diffusion process is even more difficult because "Agricultural technology is highly *location specific* and techniques developed in advanced countries are not, in most cases, directly transferable to less developed countries with different climates and different resource endowments" (Hayami and Ruttan, 1985, p.59). This location specificity implies that the absorption capacity stressed by Abramovitz and Baumol et al. becomes even more important in agriculture because countries must be able to adapt techniques to local structural characteristics. This was stressed by Griliches (1957) in his seminal article on hybrid corn that indicated that the diffusion of this innovation among geographical areas in the US was achieved through the development of locally adapted varieties.[6] Therefore, the key elements in the process of international spillovers are the absorption capacity, structural characteristics of countries and the interaction between these elements.

*Structural characteristics:* The assumption of direct transferability of the technology is not adequate in the case of the diffusion of agricultural technology because ecological conditions and factor endowments among countries severely restrict the direct transfer of agricultural technology. Focusing on grain crops, the major distinguishing factors between regions are land and labor intensities. Following Hayami and Ruttan (1985) we took land/labor ratios as indicators of structural similarity of land use patterns. The associated dissimilarity index ($D_{rs}$) is region specific, but not sector specific. Additional indicators which might be employed in future applications include regional climate- and soil quality indicators, as in Darwin et al. (1995). (Appendix table A2.4 shows the data used to construct this index).

*Local absorption capacity:* The levels of human capital and indigenous research capacity are critical factors in the innovation and diffusion process (see, e.g., Lucas 1988). A country should have a sufficient level of education among the population (e.g., farmers and those working in the input supply industries) so that they are able to adapt new technologies. Furthermore, the level of scientists, technicians and local research capacity is important for the transfer of scientific knowledge and to perform adaptive indigenous research based on the prototype technology from abroad.

The most preferred proxy of a country's absorption capacity for foreign agricultural technologies would employ sector-specific information on schooling levels of those in the farming and agribusiness sectors, in conjunction with information on local knowledge infrastructure. The number of engineers, agricultural extension workers, level of schooling of farmers and similar indicators of the local level of schooling all can be expected to have a significant impact on absorption capacity of new technologies. Such indicators are at our disposal on a global scale. Consequently, we opt for an aggregate regional measure of absorption capacity. Therefore, our H-indices are region-specific, but not sector-specific. Table A1.4 in the Appendix 1 displays the results.

*The interaction between structural characteristics and local absorption capacity:* Structural differences between countries limit the usefulness of agricultural knowledge in countries with a different structure. Local absorption capacity can increase the usefulness of this knowledge by breeding plant and

[6] Public research institution and private agricultural supply firms played a key role in this adaptation process.

animal varieties locally to adapt them to local ecological conditions and modifying imported machinery designs in order to meet climatic and soil requirements and factor endowments of the economy. Hayami and Ruttan (1985) hypothesize that the most serious constraints on the international transfer of agricultural technology are limited experiment station capacity in the case of biological technology and limited industrial capacity in the case of mechanical technology. The inelastic supply of scientific and technical manpower represents a critical limiting factor in both cases.

## *4.2. Biased technical change in the GTAP production structure*

This section discusses the implementation of biased technical change in the GTAP production structure. It also provides some analytical results which facilitate interpretation of numerical simulation results.

### *4.2.1 General specification*

The production function in the GTAP model follows the 'nesting-approach', which is well established in applied general equilibrium modeling. At the top level, commodity output is a Leontief-composite of primary inputs and intermediate inputs. The primary inputs branch is a Constant Elasticity of Substitution (CES) composite of labor, land and capital. Each intermediate input is a CES-composite of domestic and foreign inputs, the latter are distinguished by country of origin (Armington assumption). Each of the composite intermediate inputs is required in fixed proportions. At each branch, the production function contains shift parameters which allow for modeling of Hicks-neutral as well as biased technical change. For the purposes of this note the domestic part of the GTAP production structure may be formalized for each activity as:

$$\frac{Y}{A_o} = min[\, A_{i1} Q_{i1} ,..., A_{in} Q_{in} ; Q_v \,] \tag{8}$$

Where Y denotes output, $Q_{ij}$ denote intermediate inputs, and the primary input composite $Q_v$ is given by the CES-composite:

$$Q_v = [\, \Sigma( A_e Q_e )^{-\rho} \,]^{\frac{-1}{\rho}} ;\; e = \{land, labour, capital\} \tag{9}$$

The parameter $A_o$, is a Hicks-neutral technical change term. $A_{i1}$ .$A_{in}$, and $A_e$ denote output-per unit input coefficients and input share parameters, respectively. Biased technical change is modeled by varying these $A$-parameters. $\rho$ ($-1 < \rho < \infty$) is a substitution parameter.

The particular nested production function does not allow for induced effects (in the Hicks sense) between primary factors on one hand and intermediate inputs on the other hand. This is a consequence of the assumption of no substitutability at the top level, i.e. the composite primary factor and each of the intermediate inputs are required in fixed proportions to output. However, technical progress often occurs in the form of new technology packages, which combine improved productivity of intermediate inputs with productivity improvements of primary factors. We concentrate here on *two prototypical patterns* related to agriculture: the first combines improved productivity of fertilizers and other chemical inputs with improved productivity of land (land saving), while the second combines improved productivity of machinery with improved productivity of labor (labor saving).

In order to incorporate this feature into GTAP, we choose to link directly productivity growth in intermediate goods to productivity growth of primary factors. While this feature is clearly inferior to a more flexible specification of the production function, which would allow for inclusion of fertilizers, land and labor into one 'nest' in the production function, it does incorporate the basic notion of technology packages which improve productivity of several inputs simultaneously.

The new equation links productivity growth rates linearly:

$$a_e = \beta\, a_{ij} \quad j = \{\text{chemicals, machines}\} \tag{10}$$

Where $\beta$ is a simulation parameter, and $a_e$ and $a_{ij}$ denote proportional rates of change of the parameters $A_e$ and $A_{ij}$ . In our simulations, $a_{ij}$ will be endogenously determined by the spillover equation (5). Some implications of this assumption are discussed below.

#### *4.2.2 Biased technical change in a partial equilibrium setting: some analytical results*

In this section we discuss the effects of biased technical change in the nested production function. We use a simplified representation of the production tree, using only two primary factors and one intermediate input. We allow for technical change in only one of the primary factors and in the intermediate input. Furthermore, we confine ourselves to a single industry, partial equilibrium setting, without international trade. We abstract from general equilibrium effects arising through changes in factor prices.

*The Basic Model:* With one intermediate input and two primary factors, land and labor, the production function is simplified to:

$$Y = \min\{A_i Q_i, Q_v\} \tag{11}$$

$$Q_v = \{(A_a Q_a)^{-\rho} + Q_l^{-\rho}\}^{-1/\rho}$$

where

$Y$ = output of final good

$Q_i$ = input of the intermediate input

$Q_v$ = composite primary input

$Q_a$ = input of land

$Q_l$ = input of labor

$A_i$ = intermediate input augmenting technical change parameter

$A_a$ = land augmenting technical change parameter

$\rho$ = substitution parameter , $-1 < \rho < \infty$

This formulation allows for biased technical change through variations of the parameters $A_i$ and $A_a$, which are both initially set to unity. Note that the elasticity of substitution between the intermediate input $Q_i$ and any of the primary inputs is assumed to be zero. Cost minimization under given factor prices results in a set of factor demand equations:

$$Q_i \cdot A_i = Y \tag{12}$$

$$Q_l = Y\left(\frac{P_v}{P_l}\right)^{\sigma} \tag{13}$$

$$Q_a \cdot A_a = Y\left(\frac{P_v}{P_a / A_a}\right)^{\sigma} \tag{14}$$

where σ = 1/ (1 + ρ) is the elasticity of substitution between land and labor. Factor price of land, labor and intermediate input are respectively $P_a$ , $P_l$ , and $P_i$ , and the price index for primary factors is given by:

$$P_v = \left[ ( P_a / A_a )^{1-\sigma} + P_l^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \tag{15}$$

In order to close our simplified model, we introduce a zero-profit equation and a market clearing equation for the final product, assuming perfect competition on the output market. Under constant returns to scale the zero-profit condition becomes $Y[P - P_i/A_i - P_v] = 0$, where $P$ denotes output price. Market clearing requires that demand for the final product equals output. Using the inverse final demand function $P = P(Y)$, $(P' < 0)$ , the zero profit equation becomes:

$$Y\ [\ P(Y) - P_i / A_i - P_v\ ] = 0 \tag{16}$$

*Technical progress in intermediate inputs: T*echnical change in intermediate inputs is modeled by shocking the parameter $A_i$. An increase in $A_i$, implies that less of the intermediate input is required per unit of output. Holding output constant, we observe a decrease in the demand for intermediate inputs, via equation (12).

There is an additional, higher-order effect which affects the demand for primary factors through changes in output. This is most easily seen by inspecting the zero-profit condition in equation (B.16). Assuming constant primary factor prices $P_i$ and $P_v$ in partial equilibrium, a change in $A_i$ has to be offset by a change in $P$ in the opposite direction to satisfy the zero-profit condition. This is achieved by raising output which translates through the downward sloping demand function $P(Y)$ into a lower price for the final good.

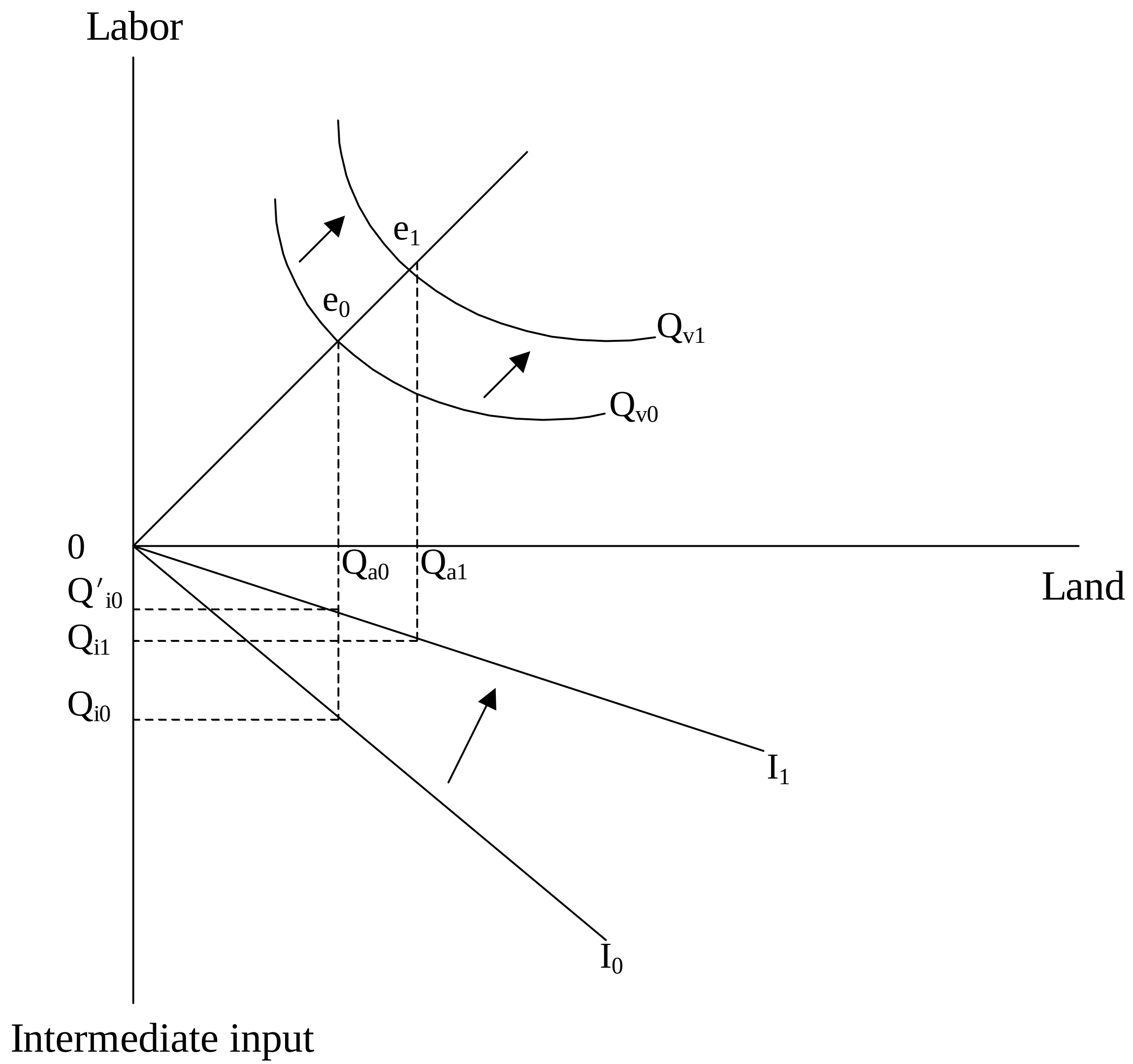



Figure 4.1 Innovation in an intermediate input

The two effects, which may be labeled the *direct factor saving effect*- and the *expansion effect*, are illustrated in figure 4.1. The top half of the figure shows how the primary factors land and labor can be combined to yield a given level of the composite primary input $Q_v$ . The isoquant is convex to the origin, indicating the substitution possibilities implied by the CES function in equation (11). The bottom half of the figure shows that the intermediate input is combined in fixed proportions with land. The ray $OI_{0,}$ emanating from the origin shows all cost minimizing combinations between land and the intermediate input, given factor prices. It represents the firm's expansion path.[7] Movements away from the origin in either the top- or the bottom half of the figure correspond to higher levels of output.

Given primary factor prices, the initial equilibrium is at point $e_0$, where demand for land is equal to $Q_{a0.}$ Demand for the intermediate input is found by moving downward to the ray $OI_0$ and left to the vertical axis, yielding $Q_{i0}$.

An increase in $A_i$ causes the ray $OI_0$ to rotate towards the horizontal axis: With higher productivity, less intermediate input is required at all levels of output, and hence the ratio of land to intermediate inputs declines as well. At the given level of output and combined primary factor demand, the reduced demand for intermediate inputs equals $Q'_{i0}$. This reduced level of intermediate inputs leads to a cost reduction at the given level of output equal to $P_i(Q'_{i0} - Q_{i0})$. Industry equilibrium is restored by expanding output. This is indicated by the new isoquant corresponding to the composite primary input level $Q_{v1}$. At the new output level the demand for intermediate inputs increases relative to the reduced level $Q'_{i0}$, but lies below the initial equilibrium value. Hence, we find that the combined factor saving and expansion effects result in: (1) a reduction of intermediate input demand due to the direct factor saving effect, (2) an increase in primary factor demand due to the expansion effect, and (3) as a result, the percent reduction in intermediate input demand is smaller than the productivity growth rate.[8]

*Primary factor technical change:* Turning to the effects of primary factor-saving technical progress, we shall see that this is not quite as clear cut as before, since the effects depend on the substitution possibilities between primary factors. An increase in land productivity is modeled by varying the parameter $A_a$ . Assuming, as before, constant factor prices, the initial effect of increased productivity is a decrease in the demand for land. The increased productivity parameter decreases the *effective price* for land, $P_a/A_a$ , which passes through to the factor price index $P_v$ thereupon leading to a decrease in the relative price of land.

Comparative static effects on factor demand are most conveniently analyzed by linearizing the system of equations (12) - (14) around the initial equilibrium. We adopt the convention that lower case letters indicate a percentage change in the corresponding uppercase variable, so that z = 100%*$dZ/Z$.

[7] The expansion path is given by $\dfrac{Q_i A_i}{Q_a A_a} = \left(\dfrac{P_a / A_a}{P_v}\right)^{\sigma}$

[8] Obviously these conclusions will be qualified if we allow factor prices to change in a general equilibrium setting. Specifically, the primary factor ratios will then not be constant, as we assumed here, but will change as a consequence of substitution between primary factors in response to changing factor price ratios.

Combining the linearized versions of equations (13) and (15) (see Appendix 3) and rearranging results in:

$$q_a = y - a_a [1 - \sigma(1 - S_a)] \tag{17}$$

where we assume constant factor prices. The coefficient $S_a$ is the cost share of land in total primary factor cost, and the parameter $a_a$ denotes the percent change in the parameter $A_a$, i.e. the change in land productivity.

This expression highlights the various effects acting on land demand in response to technical change. Specifically we may disentangle the change in factor demand into *direct factor saving effect*, the *expansion effect* and the *substitution effect.* The substitution effect was not present in the previous analysis of changes in the intermediate input due to the fixed proportions technology at that level in the production function.

The *direct factor saving effect* following an increase in $a_a$ is a decrease in demand for land: $-a_a * 1 < 0$. The *substitution effect* follows from the second bracketed term in the above equation: $a_a * \sigma(1-S_a) > 0$. This term takes into account the ease of substitution and cost shares. The substitution effect works in the opposite direction as the factor saving effect. As the (effective) relative price of land declines, the more land relative to labor is demanded. Depending on the size of the elasticity of substitution $\sigma$ and the cost share of the primary input, the net result may either be an increase or a decrease of demand for labor. In particular, we may note that the larger the elasticity of substitution, i.e. the more readily primary factors can be substituted for each other, the more advantageous the technical change is for the factor which is subject to the productivity shock. In addition, a small cost share works in favor of the technically progressing factor, since this offers greater scope for substitution away from non-land inputs.

From (17) we may derive the following implications for the sign of the substitution effect at given levels of output:

$$\begin{aligned} q_a &> 0 \ \text{ if } \sigma > \frac{1}{1 - S_a} \\ q_a &= 0 \ \text{ if } \sigma = \frac{1}{1 - S_a} \\ q_a &< 0 \ \text{ if } \sigma < \frac{1}{1 - S_a} \end{aligned} \tag{18}$$

In addition, the factor share of land relative to that of labor inputs will increase (decrease) if the elasticity of substitution is greater (smaller) than one: $q_a - q_e = -a_a[1-\sigma]$, where $q_e$ refers to the quantity of labor. This result is obtained by linearizing the factor demand equation for labor and combining with equation (17). [9]

[9] These latter insights are by no means novel, see Hicks (1932).

The final effect to be considered is the *expansion effect* which enters through the term y. This effect is analogous to the case of productivity improvements in intermediate inputs. The expansion effect occurs through the conditions for industry equilibrium, which increases demand for all factors simultaneously.

*Linking intermediate and primary factor technical change:* Technical change in both types of inputs is analyzed by combining the previous two subsections. Our modeling of embodied spillovers assumes that knowledge about improved techniques is acquired through the use of more productive intermediate inputs from abroad. The higher productivity of intermediate inputs is coupled with productivity changes in primary inputs through the linkage equation $a_a = \beta a_i$. Hence, we study the combined effects of technical change in both types of inputs. The methodology employed in the foregoing paragraphs provides the tools to analyze these combined effects.

The relative change in demand for the intermediate input is found from linearizing equation (12). This linearized version again illustrates the expansion- and factor saving effects for intermediate goods:

$$q_i = y - a_i \tag{19}$$

From (17) And using the linkage equation $a_a = \beta a_i$ we obtain the effect on demand for land:

$$q_a = y - \beta\, a_i\, [1 - \sigma(1 - S_a)] \tag{20}$$

The relative change in demand for land may be positive or negative, depending on the size of the elasticity of substitution and the cost share.

Subtracting (19) from (20), the change in relative factor intensities becomes:

$$q_a - q_i = a_i\, [1 - \beta(1 - \sigma(1 - S_a))] \tag{21}$$

From (21) it may be noted that even if a productivity growth in intermediates always leads to an increase in the optimal land-intermediate ratio. The reason for this result, even when $\beta=1$, is that land may be substituted for labor after a rise in productivity of land, while there are no substitution possibilities for intermediate inputs.

## 4.3 Spillovers embodied in traded inputs and primary factor biases

*Introducing spillovers embodied in traded chemical and mechanical inputs in GTAP*

With knowledge embodied in inputs, as opposed to embodiment in final products, the embodied knowledge index ($E_{irs}$) takes a different form. In this section we assume that technological progress in sector *i* in the innovating country comes along with the innovative inputs produced by sector *j* that are exported from country *r* to *s*. The embodied knowledge index becomes the import share in production:

$$E_{irs} = \frac{X_{jirs} / Y_{is}}{X_{jirr} \;\, / Y_{ir}} \tag{22}$$

where $X_{jirs}$ represents the imports of input *j* used in sector *i*, that are shipped to the destination country *s* from the source country *r*, $Y_{is}$ is production of sector i in country *s*, $X_{jirr}$ are domestic inputs of sector *j* delivered to sector *i* in country *r*. This index measures the relative amount of embodied knowledge per unit of output that a sector *i* in the destination country receives from the innovating foreign input producing sector *j* relative to the amount of knowledge per unit of output that the domestic sector *i* receives in the country of origin. The denominator of equation (22) represents the ‘domestic’ input-output coefficient of inputs from the innovating sector *j* in production of activity *i* in the country of origin. The numerator is an input-output coefficient of foreign-sourced inputs from the innovating sector *j* in production of activity *i* in the destination country.

The ideal embodiment index would directly incorporate the amount of innovative inputs *j* used in production of commodity *i* sourced from the innovating region *r*. However, the GTAP database does not directly contain that information, and consequently we opted for a simplifying approximation. The amount of innovative inputs used in activity *i* sourced from the innovating region *r* is approximated by:

(total firm imports of innovative input by region *s* from region *r*) * (activity *i*’s share of total imports into *s* of innovative input)

From the GTAP database we can obtain total imports of traded commodities specified by region of source and region of origin, valued at importer’s market prices `VIMS(j,r,s)`. This flow has to be adjusted in two respects: (a) subtract the part which is used for respectively private household and government household use, and (b) add taxes levied on imported goods in order to obtain values in purchaser (agents) prices.

In order to make these adjustments we define some auxiliary coefficients. First denote `VIMSF(j,r,s)` as the total source specific imports of the innovative input *j* by firms from region *r* to region *s* at market prices:

```
VIMSF(j,r,s)=VIMS(j,r,s)-{VIGM(j,s)+VIPM(j,s)}*VIMS(j,r,s)/VIM(j,s)
```

This formula subtracts from total source specific imports government, `VIGM(j,s)`, and private household, `VIPM(j,s)`, imports. Since the latter are not available by region of origin, we approximate them by assuming that the regional composition of imports does not differ across usage categories. This is achieved by applying the regional import shares `VIMS(j,r,s)/VIM(j,s)`, where VIM(j,s)denotes the value of aggregate imports of *j* in to region *s* at market prices.

Next, we add flow specific taxes on intermediate inputs in order to obtain the flow in purchaser (agent’s) prices. The tax on use of imported intermediate good *j* in industry *i* in region *s*, `IFTAX(i,j,r)`, is calculated as a derivative of the database within GTAP94.TAB. Since this value flow is not source region specific, we are again using region *r*’s share in total imports as weight to allocate the tax bill across using sectors. Firm’s source specific imports of good *j* in purchaser prices are denoted `VIASF(j,r,s)`:

```
VIASF(j,r,s) = VIMSF(j,r,s)
                + sum(k,prod_comm, IFTAX(j,k,s))* VIMS(j,r,s)/VIM(j,s);
```

After having calculated the total source specific imports of good *j* by firms, we need to determine which share is used by each using sector *i*. Sector specific use is approximated by using sector *i*’s share in total (not source region specific) imports of good *j* at agent’s prices, `VIFA(j,i,s)`. This share equals:

```
SHRIFA(j,i,s) = VIFA(j,i,s) / sum(k, prod_comm, VIFA(j,k,s))
```

The numerator of equation (23) is now readily obtained as:

```
SIINT(j,i,r,s) = VIASF(j,r,s) * SHRIFA(j,i,s) / VOA(i,s)
```

Where `VOA(i,s)` denotes the value of output of sector *i* in region *s* in agent's (producer) prices. The coefficient `STINT (j,i,r,s)` denotes source *r* specific cost share of imported intermediate input *j* used in sector *i* in region *s*, valued at agent's prices. Finally, the denominator of equation (23) is calculated as:

```
SDINT(j,i,r) = VDFA(j,i,r) / VOA(i,r)
```

Where `VDFA(j,i,r)` denotes domestically produced intermediate inputs *j* used in sector *i* region *r*, the source region of the innovation. The coefficient `SDINT(j,i,r)` represents the cost share of domestic intermediate input *j* in sector *i* in region *r*, valued at agent's (purchaser) prices. Combining terms we arrive at the spillover equation, given here for the case of chemicals:

```
EQUATION af_chem_eq
 ! intermediate input augmenting tech change related to trade flows in
   chemical inputs !
(all, j, INVCHE) (all, i, SPILL_COMM) (all, r, SPILL_SRC)
(all, s, SPILL_DEST)
  af(j, i, s) = {SIINT(j,i,r,s) / SDINT(j,i,r)}
                  ^(1-spilldelta(s,r)*absflex)
                   * spillflex
                   * af(j, i,r);
```

The simulation control parameters `ABSFLEX` and `SPILLFLEX` fulfil the same role as before in equation `ao_eq`.

For completeness' sake we also give the corresponding equation for embodied spillovers in mechanical (machinery) inputs. The treatment is completely symmetrical to chemical innovations. The only difference is that *j* is in the set `INVMAC`.

```
EQUATION af_mac_eq
 ! intermediate input augmenting tech change related to trade flows in
    machinery inputs
(all, j, INVMAC) (all, i, SPILL_COMM) (all, r, SPILL_SRC)
 (all, s, SPILL_DEST)
     af(j, i, s) = {SIINT(j,i,r,s) / SDINT(j,i,r)}
                  ^(1-spilldelta(s,r)*absflex)
                  * spillflex
                  * af(j, i,r);
```

*Introducing primary factor biases in GTAP*

As said before this note concentrates on *two prototypical patterns* related to agriculture. First, innovations in the chemical/fertilizer sector induce land saving technical progress and second, innovations in the machinery sector induce labor saving technical change.

Chemical innovations that cause a primary factor bias of the land saving kind is incorporated by the equation:

```
EQUATION afe_land_eq
! land augmenting tech change related to intermediate input augmenting
change !
```

```
(all, i, ENDWS_COMM) (all, j, SPILL_COMM) (all, r, REG) (all, k, INVCHE)
   afe(i, j, r) = BETALAND(r) * af(k, j, r);
```

where the coefficient `BETALAND(r)` is the factor bias coefficient for land saving chemical innovations.

Machinery innovations that cause labor saving innovations are incorporated by the equation:

```
EQUATION afe_labor_eq
!labor augmenting tech change related to intermediate input augmenting
change!
(all, i, ENDWL_COMM) (all, j, SPILL_COMM) (all, r, REG) (all, k, INVMAC)
   afe(i, j, r) = ALFALAB(r) * af(k, j, r);
```

*Summary of modifications to GTAP*

The following tables provide a summary of the new equations and auxiliary coefficients added to GTAP94.TAB in order to capture some of the features of technology spillovers.

Summary: five new equations

| Name | Dimension | Identifier |
|---|---|---|
| ao_eq | SPILL_COMM x SPILL_DEST | Hicks-neutral tech change related to trade flows |
| afe_land_eq | ENDWS_COMM x SPILL_COMM x REG | land augmenting tech change related to intermediate input augmenting change |
| afe_labor_eq | ENDWL_COMM x SPILL_COMM x REG | labor augmenting tech change related to intermediate input augmenting change |
| af_chem_eq | INVCHE x SPILL_COMM x SPILL_DEST | intermediate input augmenting tech change related to trade flows in chemical inputs |
| af_eq | INVMAC x SPILL_COMM SPILL_DEST | intermediate input augmenting tech change related to trade flows in machinery inputs |

Summary: five auxiliary coefficients

| Name | Dimension | Identifier |
|---|---|---|
| VIMSF(j,r,s) | TRAD_COMM x REG x REG | Value of firm's imports of tradeable commodity *j* from source *r* to destination *s*. Valued at importer's market prices. |
| VIASF(j,r,s) | TRAD_COMM x REG x REG | Value of firm's imports of tradeable commodity *j* from source *r* to destination *s*. Valued at agent's (purchaser) prices. |
| SHRIFA(j,i,s) | TRAD_COMM x PROD_COMM x REG | Sector *i*'s share in use of imported intermediate good *j* in region *s*. Valued at agent's (purchaser) prices. |
| SIINT(j,i,r,s) | TRAD_COMM x PROD_COMM x REG x REG | Source specific cost share of imported intermediate input *j*, imported by sector *i* in region *s* from region *r*. Valued at region *s* agent's (purchaser) prices. |
| SDINT(j,i,r) | INVMAC x SPILL_COMM SPILL_DEST | Cost share of domestic intermediate input *j*, used by sector *i* in region *r*. Valued at agent's (purchaser) prices. |

## *4.4. Numerical examples*

In this section we assume knowledge spillovers in agriculture are embodied in traded inputs which cause factor biased technical change and study the production and welfare effects of such spillovers. We assume that an innovation occurs in either the chemicals (CRP) or the transport and machinery (TRM) sector in EUR or NAM. This innovation induces a 10% increase in the productivity of chemicals or machinery in the production of grain (GRO). The innovation may ($\beta_{labor}$ or $\beta_{land}$ = 0.5 or 1) or may not ($\beta_{labor}$ or $\beta_{land}$ = 0) lead to factor biased technical change.

*Spillover coefficients:* First, we study the value of the spillover coefficients, i.e. equation (5) with $E_{irs}$ taken from (23), for different sectors and countries of origin. Table 4.1 shows the post-simulation values of spillover coefficients for innovations in the chemical and transport sector in Europe and North America ($\beta_{labor}$ or $\beta_{land}$ = 1). The first column shows that an innovation in the chemical sector in Europe leads to a spillover coefficient of 0.24 for Australia. This means that the 10% increase in the productivity of chemicals in grains in Europe translates into a 2.4% increase in the productivity of chemicals in grains in Australia. The value of the spillover coefficient in Japan and the NICs (JAN) is larger and equal to 0.77, which implies that the productivity level of chemicals in the grain sector increases with 7.7% in JAN. The spillover coefficient is higher in JAN despite the fact that the amount of embodied knowledge (i.e. trade intensity) is higher in AUS than in JAN ( E index is 0.09 in AUS and 0.02 in JAN). This is caused by the structural similarity effect, which is equal to 0.394 in AUS and 0.94 in JAN. This is implying that the relative factor endowments in AUS are more different from EUR than those from JAN (the absorption capacity in both countries is maximal and equal to 1).

Table 4.1: Value of spillover coefficient

| | Innovation in chemicals EUR | Innovation in chemicals NAM | Innovation in machinery EUR | Innovation in machinery NAM |
|---|---|---|---|---|
| AUS | 0.24 | 0.37 | 0.49 | 0.65 |
| NAM | 0.28 | -- | 0.36 | -- |
| ARG | 0.75 | 0.06 | 0.59 | 0.01 |
| EUR | -- | 0.10 | -- | 0.07 |
| JAN | 0.77 | 0.06 | 0.65 | 0.02 |
| RAS | 0.31 | 0.07 | 0.23 | 0.05 |
| SAM | 0.53 | 0.19 | 0.26 | 0.08 |
| CHN | 0.52 | 0.16 | 0.43 | 0.09 |
| ROW | 0.71 | 0.04 | 0.66 | 0.06 |

*Source:* GTAP simulations, author's calculations

We get an indication of the source country effect for a specific country when we compare columns one and two in Table 4.1. It is apparent that the value of the spillover coefficients from different countries of destination is very different across countries of origin (i.e. EUR and NAM). For, example the spillover coefficient for JAN is equal to 0.06 when the innovation occurs in NAM and equals 0.77 in the case of Europe. Furthermore, it is striking that almost all spillover coefficients are higher when Europe is the source country (the notable exception is AUS which is structurally most similar to NAM). The reason is that EUR: (a) exports a larger part of its chemical products, (b) has a lower level of human capital, and (c) exhibits structural characteristics (i.e. land-labor ratios) which are less extreme than those of NAM.

The spillover coefficients when the innovation originates in the machinery sector are given in columns three (innovation in EUR) and four (innovation in NAM). A comparison of columns one and three or columns two and four indicates that the source sector is also an important determinant of the spillover coefficients. Thus, for example, the impact of an innovation (i.e. productivity growth) in the EUR machinery sector on Australia is twice as large as the same amount of productivity growth in EUR chemicals. In these comparisons, the differences in spillover coefficients are only caused by the amount of embodied knowledge in trade flows, because the productivity of this knowledge is identical across sectors of origin.

*The impact of technical change in chemicals used for grains production:* Assume an innovation in the chemical sector in EUR that leads to a 10% increase in the productivity of chemicals in grains. This may also induce land augmenting technical change in the grains sector. The land-bias coefficient ($\beta_{land}$) is equal to 0, 0.5 or 1. The impact on grain production in the various countries is illustrated in figure 4.2. Without land augmenting technical change ($\beta_{land}$=0) the innovating country EUR achieves the highest growth rate (0.17%) in grains production. Countries that also achieve a positive rate are JAN, CHN, ROW and SAM. These countries have a rather high spillover coefficient (see Table 4.1) and use relatively more chemicals per unit of output. This is important because the technical change is chemical augmenting (see Table 4.2). Countries that lose from the European innovation are ARG, which has a relatively high spillover coefficient but a low cost share of chemicals in grains, and the countries with both a low spillover coefficient and a low chemicals cost share (i.e. AUS, NAM, RAS). These findings are also consistent with the induced innovation theory that the relatively land-abundant countries (e.g. AUS, NAM, ARG) use relatively fewer chemicals than countries where land is scarce (e.g. CHN, SAM, ROW, JAN), since chemicals are primarily land-augmenting. In case of chemical-augmenting technical change, the latter countries may be able to get higher growth rates in their agricultural sector if they receive enough knowledge spillovers.

Next, we introduce directly the land-augmenting characteristics of enhanced chemicals in the model by putting the land-bias coefficient equal to 0.5 or 1. The implications for the growth rates in grain production are given in figure 4.2. If we compare the growth rates of grain production obtained with a land-bias to the growth rates obtained without such land-bias we see some significant differences. First of all, -and quite surprising- we see that the innovating country, EUR, obtains a lower growth rate with a land-augmenting technical change linkage than in the case without this linkage and it achieves a lower growth rate than the “imitating” countries. Second, the Asian countries, with a low land/labor ratio, gain more with the land-augmenting linkage. Third, NAM and AUS, with a high land-labor ratio obtain higher reduction in their output growth rates and fourth, Argentina moves from a situation of negative to positive growth in production.

**Innovation in Chemicals**

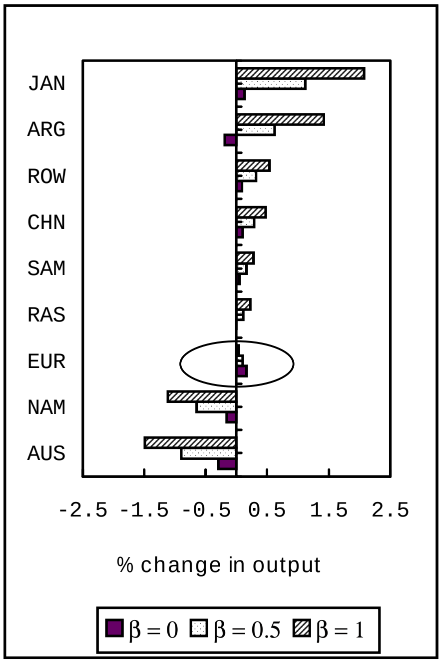



Figure 4.2: Innovation in Europe
Growth in production

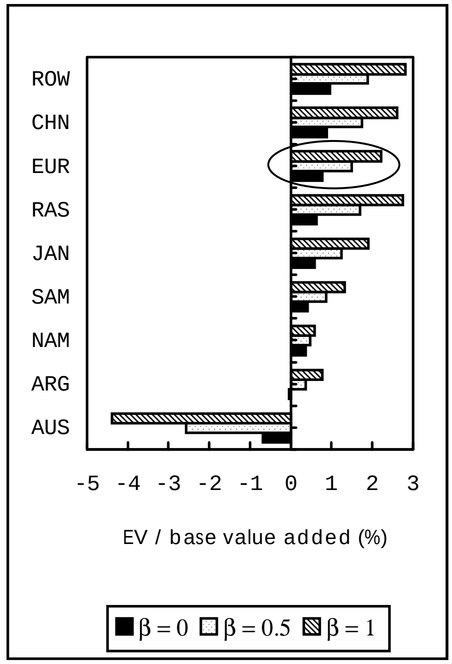



Figure 4.3: Innovation in Europe
Change in Welfare

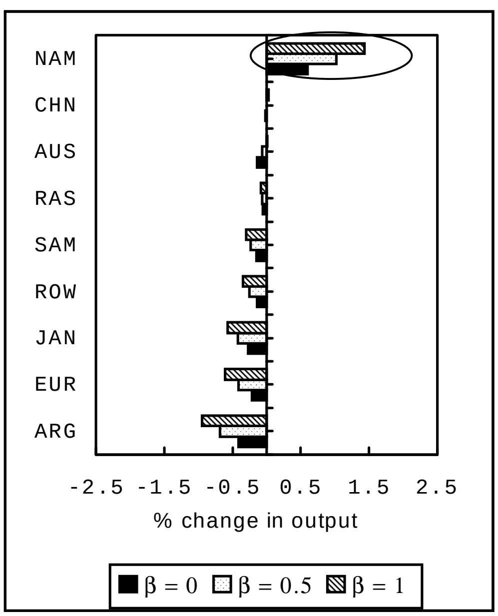



Figure 4.4: Innovation in North America
Growth of output

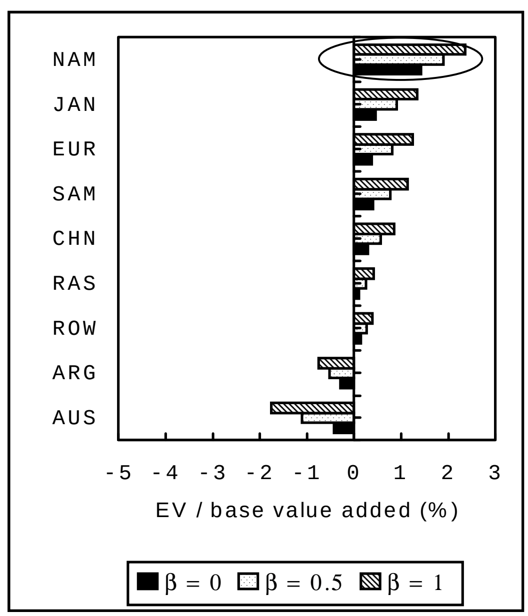



Figure 4.5: Innovation in North America
Change in welfare

Table 4.2: Value of cost shares and factor shares in gross value added

| | Cost share of chemicals in grains | Land share (grains) | Cost share of machinery in grains | Labor share(grains) |
|---|---|---|---|---|
| AUS | 0.15 | 0.29 | 0.01 | 0.56 |
| NAM | 0.17 | 0.20 | 0.38 | 0.38 |
| ARG | 0.13 | 0.28 | 0.01 | 0.47 |
| EUR | 0.12 | 0.13 | 0.32 | 0.64 |
| JAN | 0.34 | 0.38 | 0.01 | 0.48 |
| RAS | 0.19 | 0.35 | 0.10 | 0.50 |
| SAM | 0.23 | 0.21 | 0.02 | 0.46 |
| CHN | 0.3 | 0.29 | 0.09 | 0.59 |
| ROW | 0.23 | 0.23 | 0.08 | 0.61 |

These four observations can be explained by combining the value of the spillover coefficient (see table 4.1) with cost shares of land (see table 4.2). The innovating region EUR, has a relatively low land share in costs and therefore its advantage from land-augmenting technical change is relatively smaller than in other countries.[10] Furthermore, the spillover coefficients are relatively high for the other countries when an innovation occurs in EUR, which implies that other countries can achieve also a high growth in their land-augmenting technical change. However, these countries have a higher land-share in their costs and therefore obtain a larger gain. This effect is most striking for JAN which has the highest land share and the highest spillover coefficient and therefore achieves the highest growth rate. Argentina gets a positive growth instead of negative growth because it spends a relatively large part of its costs on land and it has a high spillover coefficient, whereas in the case with only chemical augmenting technical change it had a relatively low share of chemicals in costs. These results illustrate that the innovating country will not always achieve the highest growth rate in the case of factor biased technical change, because a certain type of technical change may be even more suitable for other countries. In most cases the production factor whose productivity increases is a scarce factor in this country.

The welfare effects (equivalent variation as percentage of base value added in grains sector, evaluated in 1992 US$) are depicted in figure 4.3. In contrast to the grain production growth rates, Europe ranks high among the group of countries that experience a welfare gain (with or without land augmenting technical change). This high increase in EUR and the other countries is mainly due to the contribution

[10] Of course, this result hinges crucially on the cost share of land in grains production. Cost shares in GTAP are obtained from a diverse set of economic studies for the farm sector as a whole (Hertel an Tsigas, 1997). As a consequence, one should take these findings with a “grain of salt”.

of technical change to welfare, see Huff and Hertel (1996). With biased technical change ($\beta_{land}$=0.5) the contribution to welfare of technical change is higher in JAN than in EUR. However, EUR gets a higher total welfare change because the contribution of allocation effects is negative in JAN and positive in EUR. The negative effect in JAN is caused by factor movements into the distorted grains sector, while the allocative gain in EUR is caused by factor movements out of the distorted grain sector. Another effect of technical change in the grains sector is that the world price of grains declines, which has negative terms of trade effects for the large grain exporters such as AUS and NAM. In AUS, this negative terms of trade effect dominates the positive technical change effect in these regions. In NAM the negative terms of trade effect is more than compensated by a positive allocative efficiency effect (factors move out of the distorted grains sector) and technical change.

Figure 4.4 gives the simulation results for the growth rate of production in grains when the innovation in the chemical sector occurs in North America (NAM). The innovating country NAM obtains a positive and high growth rate in grains, while output growth in all other countries is negative. The main explanation for this result is that the spillover coefficient is low for the other countries (see table 4.1). With biased technical change, the growth becomes more negative for almost all countries, except for AUS and SAM because they have a relatively high spillover coefficient and a relatively high land share in costs.

Figure 4.5 shows the welfare effects for the various regions. While all innovation-receiving countries obtained a negative growth in the production of grains, almost all countries achieve a positive change in their welfare. With full factor biases, $\beta_{land}$ = 1, the innovating country NAM obtains an increase in welfare of 729 m$, which amounts to 2.4% of value added in grains. This can be decomposed into its main components: the positive contribution of technical change (1210 m$), the negative terms of trade effect (-246 m$: the world grain price declines and NAM is a large exporter) and the negative allocative effect (-234 m$: factors move into the distorted grains sector). The main contributors to the positive welfare effect in JAN, 713 m$, or 1.3% of value added, are the allocative efficiency effect (355 m$ because factors move out of the distorted/subsidized grain sector) and the terms of trade effect (207 m$: lower world grain prices are beneficial for JAN which is a larger importer of grains). Europe obtains a welfare increase of 503 m$, equaling 1.2% of grains value added, which is mainly caused by the positive allocative efficiency effect (432m$).

*Impact of technical change in machinery used in grains production:* Next, we study the effect when an innovation occurs in the transport and machinery sector. Figure 4.6 shows the simulation results for the growth rate of the production of grain in all countries when an innovation occurs in NAM. Australia's gains in this case are quite striking. This result is driven by the high spillover coefficient to AUS, 0.62, which is caused by relatively high machinery imports into Australia from NAM and the structural similarity between both countries (both have high land/labor ratios). Without a labor bias, the innovating country achieves the highest growth rate (0.16%). However, when the machinery also directly makes labor more productive, AUS clearly the highest growth in grains because labor has a relatively high share in costs. Therefore, the relatively labor scarce country (high land/labor ratio), AUS, obtains the highest growth rate in the production of grains.

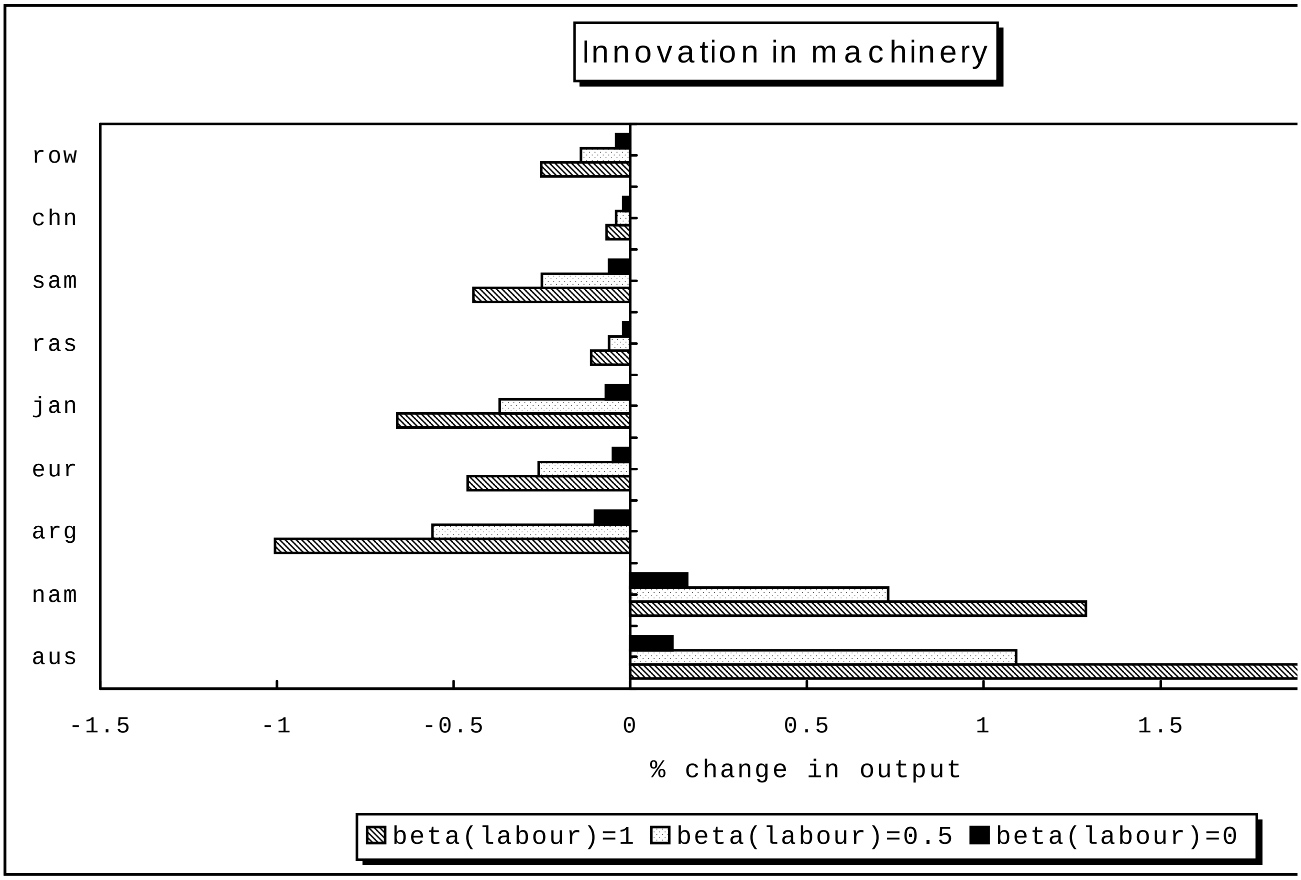



Figure 4.6 Innovation in North America, Growth of output

Reviewing the simulation results with endogenous spillovers and biased technical change, we may draw some conclusions. The magnitude of the spillover coefficient is the first determinant of possible output gains. The spillover coefficient interacts with input cost shares to determine the size of the cost reduction that can be achieved by technical change. However, in the multi-region, general equilibrium setting, those regions which are best able to economize on relatively scarce production factors as a result of the technical change, may be able to increase their output (at the same or lower cost) more than proportionately, thereby gaining a competitive edge over exporters on the world markets. This effect is magnified by the introduction of primary factor biases.

Due to the complexity of the welfare effects of technical change in a realistic, general equilibrium setting, there is less than perfect correlation between output effects and welfare effects. Net welfare effects are positive in most countries. Positive welfare gains are observed both in the original innovating countries as well as in countries which receive new technologies for free. On the basis of these net welfare gains, there is little basis for arguing for protection of domestic agricultural knowledge systems. Decomposing net welfare effects into allocative- and terms-of trade effects shows that factor movements into distorted agricultural sectors may lead to negative welfare consequences. Finally, it is hardly surprising that net exporters of the commodities in question experience negative terms-of-trade effects following technical change.

# *5. Concluding remarks*

This note describes a method to implement trade-related international technology spillovers in the standard GTAP model. The approach presented here takes full advantage of the bilateral trade data incorporated in the GTAP data set. We endogenize technology spillovers by making productivity growth a function of the volume of bilateral trade. In addition, we introduce two limiting factors associated with the effectiveness of foreign knowledge: human capital related- absorption capacity and production related- structural similarity between innovating and receiving countries.

We present two alternative formulations of technology spillovers. The first assumes that knowledge about improved production technology is incorporated in final products, and that the acquisition of improved foreign products improves domestic productivity in producing these particular final products in a Hicks-neutral manner. The process that we have in mind here is learning through imitation. This formulation may be best applicable in areas such as consumer electronics.

The alternative formulation assumes that knowledge travels together with traded intermediate inputs. With this formulation we try to capture some essential elements of technical change in agriculture. Domestic farmers improve productivity by buying more productive foreign inputs, such as fertilizers and agricultural machinery. We also introduce land- and labor biases that are often associated with technical change in agriculture. Our treatment of primary factor biases, however, takes the standard Leontief -CES production structure of the GTAP model as given, and incorporates factor biases in a rather crude way. Numerical simulations reveal that primary factor biases are quite important for the size of spillover effects, and more attention to this point is warranted.

In order to specify the spillover mechanisms we choose a specific (concave) functional form relating the spillover coefficient to its underlying determinants. Clearly our choice of this functional specification influences the numerical outcomes, and may be changed if desired. There is also ample scope for improvement in the measurement our absorption capacity and structural similarity indices. These parameters depend on the specific research goal and types of innovation being studied. Spillovers in, say, consumer electronics require a different parameterization than spillovers in agriculture.

Numerical simulations with the GTAP model show the consequences of our spillover hypothesis in a general equilibrium setting. These simulations can be used to generate more specific hypotheses that can be subjected to further econometric testing. The simulations show that the effects of technology spillovers on both the innovating and the receiving economies depend on specific conditions, such as cost shares, and substitution elasticities, as well as existing domestic and trade distortions.

# *Appendix 1: Data Used in the Study*

## *A1.1 Classification*

Our focus on technology spillovers in agriculture prompted an aggregation into 9 regions and 12 sectors. The regional aggregation displayed in table A1.1 attempts to maximize within-region homogeneity with respect to grain crops production patterns. The regional grouping is discussed more thoroughly below.

Table A1.1 Regional aggregation used

| Identifier | Original version 3 regions included |
|---|---|
| 1 AUS Australia | Australia, New Zealand |
| 2 NAM North America | Canada, United States of America |
| 3 ARG Argentina | Argentina |
| 4 EUR Europe | European Union 12, Austria Finland and Sweden (EU3), EFTA |
| 5 JAN Japan and NICs | Japan, Republic of Korea, Singapore, Hong Kong, Taiwan |
| 6 RAS Rest of Asia | Indonesia, Malaysia, Philippines, Thailand, India, Rest of South Asia |
| 7 SAM South America | Mexico, Central America and Caribbean, Brazil, Chile, Rest of South America, Middle East and North Africa |
| 8 CHN China | China |
| 9 ROW Rest of World | Central European Associates, Former Soviet Union, Sub Saharan Africa, Rest of World |

The sectoral aggregation shown in table A1.2 focuses on primary agricultural production and agricultural processing industries. Note that the aggregation distinguishes the two important groups of agricultural inputs chemical (crp), such as fertilizers, and transport equipment and machinery’s (trm).

We used the GTAP aggregation procedure which not only aggregates basic flows, but also takes care of calibrating parameters of production- and consumption functions. On the production side, the key parameters to be aggregated are substitution elasticity’s in CES-nests of primary inputs land, labor and capital and Armington substitution elasticity’s. On the consumption side, the substitution - and expansion parameters of (non-homothetic) CDE expenditure functions are fitted to the aggregated data. See McDougall (1997) for a description of parameter estimates.

Table A1.2: Sectoral aggregation

| Identifier | | | Original version 3 sectors included |
|---|---|---|---|
| 1 | gro | grain crops | paddy rice, wheat, grains |
| 2 | ngc | non grain crops | non grain crops |
| 3 | lst | Livestock | wool, other livestock |
| 4 | fof | forestry &fisheries | forestry, fisheries |
| 5 | min | mining & extraction | coal, oil, gas, other minerals |
| 6 | pcf | processed food | processed rice, meat products, milk products, other food products |
| 7 | opa | other processed agriculture | beverages and tobacco, lumber, pulp paper |
| 8 | tex | textiles | textiles, wearing apparels, leather etc. |
| 9 | crp | chemicals | chemicals, rubbers and plastics |
| 10 | trm | transport equipment and machinery | Transport industries, machinery and equipment |
| 11 | omf | Other manufacturing | petroleum and coal, nonmetallic minerals, primary ferrous metals, nonferrous metals, fabricated metal products, other manufacturing |
| 12 | svc | Services | electricity water and gas, construction, trade and transport, other services (private), other services (govt), ownership of dwellings |

## *A1.2 Structural similarity and human capital data*

For the spillover application reported here we used a specific operationalization of the absorption parameter (*H*) and the structural similarity index (*D*). Our formulation attempts to be general enough to allow for different specifications of the empirical content of these key parameters, depending on the problem being studied.

The absorption parameter has been quantified by using information on schooling years from the well-known Barro & Lee (1993) data set.[11] The most preferred proxy of a countries absorption capacity for

[11] The data have been downloaded from World Bank's Internet site. The Barro & Lee and other data sets are found at the following URL: http://www.worldbank.org/html/prdmg/grthweb/dataset.htm

foreign agricultural technologies would employ information on schooling levels in agricultural sectors in conjunction with information on local knowledge infrastructure. The number of engineers, agricultural extension workers, level of schooling of farmers and similar indicators of the local level of schooling all can be expected to have a significant impact on absorption capacity of new technologies. In addition, the index could be made sector specific. Such indicators have not been at our disposal however, and consequently we opted for a more aggregate measure of absorption capacity. From the 129 countries in the Barro & Lee data set we calculated population weighted average years of schooling for each region in table A1.1. The results of this procedure are displayed in table A1.3.

The highest average years of schooling are observed in NAM, followed by AUS. The figure for EUR seems to be on the low side, but is explained by the few years of schooling in Mediterranean countries. On the whole, Asian countries have fewer years of schooling on average, which hampers their ability to benefit from technologies developed in for example NAM. From Table A1.3 we can calculate our measure of absorption capacity as $H_s = \min[1, h_s / h_r]$, where $h_s$ and $h_r$ denote respectively the average years of schooling in the region of destination and region of origin of an innovation.

The results of this calculation are presented in table A1.4. For example, this table shows that an innovation which is sourced in NAM, can almost fully be absorbed in AUS, since NAM's average years of schooling is only slightly higher than that in AUS, while the same innovation is less than fully absorbed in ARG, since ARG's average years of schooling lags behind that in NAM. RAS, SAM and CHN are least able to absorb an innovation developed in NAM. Observe also that our definition of the absorption index implies that an innovation which is developed in a region with low average years of schooling can easily be absorbed in a region with a higher average. Compare for example columns 'NAM' and 'EUR'

Table A1.3: Average years of schooling in the 9 regions

| AUS | NAM | ARG | EUR | JAN | RAS | SAM | CHN | ROW |
|---|---|---|---|---|---|---|---|---|
| 10.5 | 11.6 | 8.13 | 8.2 | 9.3 | 4.2 | 4.7 | 5.9 | 6.6 |

*Source:* Barro and Lee (1993) database, author's calculations

Table A1.4: Absorption parameters

| | Region Of origin of innovation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Destination Region | AUS | NAM | ARG | EUR | JAN | RAS | SAM | CHN | ROW |
| AUS | 1.000 | 0.905 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| NAM | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| ARG | 0.774 | 0.701 | 1.000 | 0.991 | 0.874 | 1.000 | 1.000 | 1.000 | 1.000 |
| EUR | 0.781 | 0.707 | 1.000 | 1.000 | 0.882 | 1.000 | 1.000 | 1.000 | 1.000 |
| JAN | 0.886 | 0.802 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| RAS | 0.400 | 0.362 | 0.517 | 0.512 | 0.452 | 1.000 | 0.894 | 0.712 | 0.636 |
| SAM | 0.448 | 0.405 | 0.578 | 0.573 | 0.505 | 1.000 | 1.000 | 0.797 | 0.712 |
| CHN | 0.562 | 0.509 | 0.726 | 0.720 | 0.634 | 1.000 | 1.000 | 1.000 | 0.894 |
| RPW | 0.629 | 0.569 | 0.812 | 0.805 | 0.710 | 1.000 | 1.000 | 1.000 | 1.000 |

*Source:* author's calculations

Turning to the structural similarity index, we may again note that our quantification is implementation specific and liable to improvements if so desired. Focusing on grain crops, the major distinguishing factors between regions are land and labor intensities. This approach follows closely Hayami and Ruttan (1985). Additional indicators which might be employed in future applications include regional climate- and soil quality indicators. For the current application we used FAOSTAT[12] data to compile land/labor ratios in wheat production. The total number of persons employed in agricultural production is available from this source. We used GTAP labor shares to obtain an estimate of persons employed in grain production only. Wheat acreage is directly available from FAOSTAT. Table A1.5 shows the resulting figures.

The index of structural similarity is subsequently calculated using the equation $D_{rs} = \exp[- |(l_r - l_s) / d_{max}|$, where $d_{max}$ equals the difference in land/labor ratios between AUS and CHN. That is, $d_{max} = 122.9$. Table A1.6 shows the results. By construction, the matrix of indices is symmetric.

Table A1.5: Land/labor ratios (hectares per person)

| AUS | NAM | ARG | EUR | JAN | RAS | SAM | CHN | ROW |
|---|---|---|---|---|---|---|---|---|
| 123.6 | 87.1 | 17.1 | 9.18 | 1.4 | 1.3 | 2.0 | 0.7 | 1.1 |

*Source:* FAOSTAT, author§s calculations

Table A1.6: Structural similarity index

| | Region Of origin of innovation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Destination Region | AUS | NAM | ARG | EUR | JAN | RAS | SAM | CHN | ROW |
| AUS | 1.000 | | | | | | | | |
| NAM | 0.743 | 1.000 | | | | | | | |
| ARG | 0.421 | 0.566 | 1.000 | | | | | | |
| EUR | 0.394 | 0.530 | 0.940 | 1.000 | | | | | |
| JAN | 0.370 | 0.498 | 0.880 | 0.940 | 1.000 | | | | |
| RAS | 0.370 | 0.498 | 0.879 | 0.939 | 0.999 | 1.000 | | | |
| SAM | 0.372 | 0.501 | 0.884 | 0.944 | 0.995 | 0.994 | 1.000 | | |
| CHN | 0.368 | 0.495 | 0.875 | 0.934 | 0.994 | 0.995 | 0.889 | 1.000 | |
| RPW | 0.369 | 0.497 | 0.878 | 0.937 | 0.997 | 0.998 | 0.992 | 0.997 | 1.000 |

*Source*: FAOSTAT, author's calculations

## *A1.3 Regional aggregation*

In addition to providing data for our structural similarity index, the FAO data on land use patterns provide the basis for our regional aggregation. For spillover simulation purposes, the highest information content is achieved by choosing a regional aggregation that maximizes within group homogeneity while maximizing between group heterogeneity. In this way we are able to concentrate on main impacts of structural similarity. The country grouping is obtained by constructing a figure which plots for GTAP

[12] The data have been downloaded from the FAO Database Collection at: http://app.fao.org/lim500/agri_db.pl

regions the logarithm of land/output ratios against the logarithm of labor/output ratios, as in Hayami and Ruttan (1985). On the basis of figure AN.1, regions can be grouped according to their land/labor intensities. The data for this figure are the acreage and employment data used in the previous subsection and agricultural output data which are directly obtained from the GTAP data set. For 9 GTAP regions FAOSTAT does not provide the required information, or the data seemed unreasonable (Former Soviet Union).

Moving from the North-West corner towards the South-East corner of figure A1.1, we move from regions with high land/labor ratios towards regions which are characterized by more labor intensive modes of grain production. Countries lying along the same $45^0$ line experience the same land/labor ratio. On the basis of this figure the 9 GTAP regions in table AN.1 have been formed. The first cluster consists of regions with high land/labor ratios (CAN, USA, AUS). From this cluster we formed 2 groups, viz.(1) NAM, consisting of USA and Canada, (2) AUS, consisting of Australia and New Zealand. New Zealand has been grouped together with Australia despite its significantly lower land/labor ratio. Region (3) Argentina, ARG, is kept apart in order to be able to study spillover effects for a relatively small country which keeps a middle position between the NAM- and AUS regions and region (4) Europe, EUR. EUR also keeps a middle position between the land-abundant regions and the land scarce Asian regions. Region (5), Japan and the NICs, JAN, consists of Japan, Republic of Korea, Singapore, Hong Kong, and Taiwan. (FAOSTAT does not provide data). Region (6) is a heterogeneous group of Asian countries, comprising Indonesia, Malaysia, Philippines, Thailand, India and Rest of South Asia. Region (7) consists of South- and Central American countries augmented with the GTAP region Middle East and Northern Africa. Lacking data for the latter group of countries, it has been added to region (7). Region (8) is formed by China alone, since it is expected to assume an increasingly important position in world agricultural markets. Finally, region (9) is the ‘Rest of the World’, i.e. all regions not explicitly distinguished in the GTAP database. Figure A1.2 shows the resulting 9 regions in terms of their land/output and land/labor ratios.

Figure A1.1: Land/labor ratios in agriculture, GTAP regions

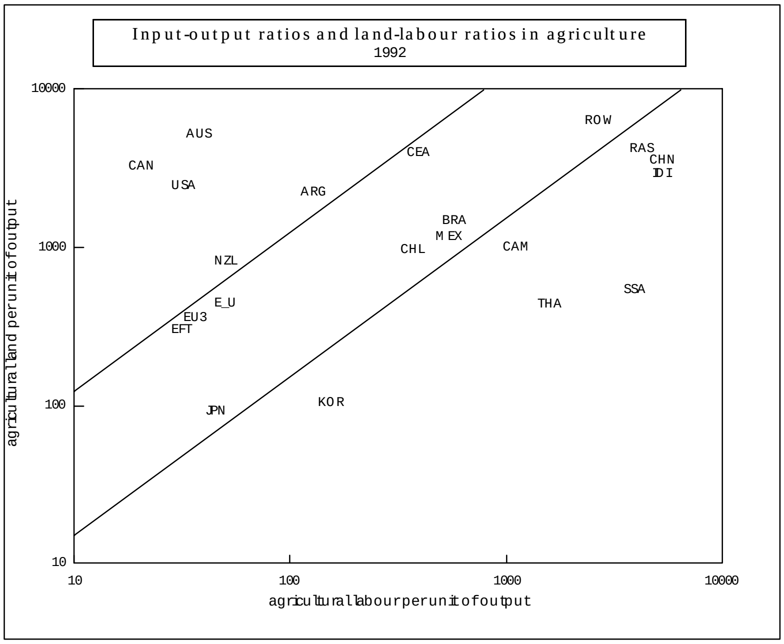
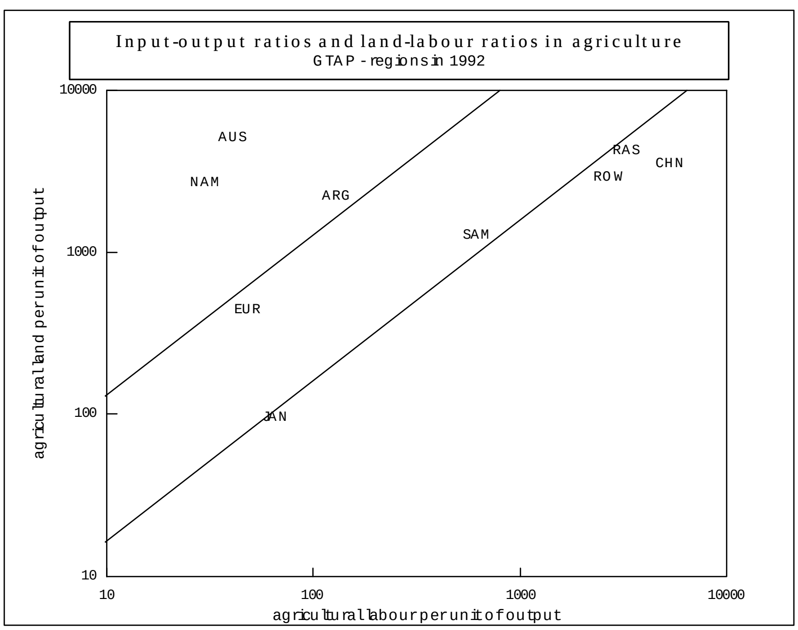



Figure A1.2: Land/labor ratios in agriculture, 9-region aggregation



# *Appendix 2: GEMPACK Implementation*

The GEMPACK code required to implement the spillover features into the GTAP model is packaged in a file called SPILadd_on.tab. The contents of this file can be added at the bottom of your own version of GTAP.TAB. The particular implementation described here has been used with GTAP94de.TAB (version 2.2a August 1995 of GTAP94). This additional code in conjunction with the parameter files provided should generate the same outcomes as in the text.

```
!-----------------------------------------------------------------------------!
! SPILL.TAB                                                                   !
! Spillover equations add-on                                                  !
! HvM & FvT March 1997, basic implementation                                  !
! FvT   Dec 1998   , correction import cost shares, streamline code,          !
!                       add auxiliary coefficients                            !

! This add-on contains GEMPACK code to implement endogenous technology        !
! spillovers as documented in the GTAP technical paper no 15:                 !
! Hans van Meijl & Frank van Tongeren, "Endogenous international              !
!  technology spillovers and biased technical change in the GTAP model"       !
! Add this code at the bottom of GTAP.TAB                                     !
! This spillover code has been used with version 2.2a August 1995 of GTAP94   !
! For applications see: Hans van Meijl & Frank van Tongeren (1998),           !
!  "Trade, technology spillovers and food production in China",               !
!  Weltwirtschaftliches Archiv, 134, 3.                                       !
! Hans van Meijl & Frank van Tongeren (1999),"Endogenous international        !
!  technology spillovers and biased technical change in agriculture",         !
!  Economic Systems Research, 11, 1.
! NOTE: these applications used a slightly different definition of the       !
!      import shares than used in this code. Numerical results will           !
!      therefore differ slightly from those reported in above mentioned       !
!       articles.                                                               !
!-----------------------------------------------------------------------------!

!-----------------------------------------------------------------------------!
!                             New FILES                                       !
!-----------------------------------------------------------------------------!
FILE SPILLSET # File with set specification spillovers #;
FILE (TEXT) SPILLPAR # The file containing spillover parameters. #;

!-----------------------------------------------------------------------------!
!                                New SETS                                     !
!-----------------------------------------------------------------------------!

SET SPILL_SRC # Source regions spillovers #
      MAXIMUM SIZE 10 READ ELEMENTS FROM FILE spillset HEADER "H10"  ;

SET SPILL_DEST # Destination regions spillovers #
     MAXIMUM SIZE 10 READ ELEMENTS FROM FILE spillset HEADER "H11";

SET SPILL_COMM # Spillover commodities #
     MAXIMUM SIZE 10 READ ELEMENTS FROM FILE spillset HEADER "H12";

SET INVCHE # Source sector of chemicals invention #
     MAXIMUM SIZE 1 READ ELEMENTS FROM FILE spillset HEADER "H13";

SET INVMAC # Source sector of machinery invention #
     MAXIMUM SIZE 1 READ ELEMENTS FROM FILE spillset HEADER "H14";
!-----------------------------------------------------------------------------!
!                                 SUBSETS                                     !
!-----------------------------------------------------------------------------!
SUBSET SPILL_COMM IS SUBSET OF TRAD_COMM;
SUBSET SPILL_SRC  IS SUBSET OF REG;
```

```
SUBSET SPILL_DEST IS SUBSET OF REG;
SUBSET INVCHE     IS SUBSET OF TRAD_COMM;
SUBSET INVMAC     IS SUBSET OF TRAD_COMM;

!--------------------------------------------------------------------------------!
! additional coefficients relating to technological spillovers                   !
!                                                                                !
!--------------------------------------------------------------------------------!

COEFFICIENT (all, r, REG)
BETALAND(r)
      ! BETALAND relates input-augmenting tech change in chemicals
        to input augmenting change in land ! ;

COEFFICIENT (all, r, REG)
ALFALAB(r)
      ! ALFALAB relates input-augmenting tech change in machinery
        to input augmenting change in labor ! ;

COEFFICIENT
SPILLFLEX
     ! SPILLFLEX is used to switch embodied spillovers on or off
       SPILLFLEX = 1 -> on, 0 -> off !;

COEFFICIENT
ABSFLEX
     ! ABSFLEX is used to switch absorption effect on or off
       ABSFLEX = 1 -> on, 0 -> off !;

COEFFICIENT  (all, r, REG) (all, s, REG)                         SPILLDELTA(r,s)
       ! SPILLDELTA determines productivity of embodied spillovers
    includes both absorption capacity and structural
         differences effect!;

!--------------------------------------------------------------------------------!
!                   Reading additional model parameters                          !
!--------------------------------------------------------------------------------!

READ BETALAND   FROM FILE SPILLPAR ;
READ ALFALAB    FROM FILE SPILLPAR ;
READ SPILLFLEX  FROM FILE SPILLPAR ;
READ ABSFLEX    FROM FILE SPILLPAR ;
READ SPILLDELTA FROM FILE SPILLPAR ;

!--------------------------------------------------------------------------------!
!Some auxiliary coefficients to facilitate calculation of import cost shares     !
!                                                                                !
!--------------------------------------------------------------------------------!

COEFFICIENT (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)               VIMSF(i,r,s);
  ! firms source specific imports in sector i from region r
    to region s valued at importers market prices.
    This is an approximation which shares out government
    and private household use !
FORMULA (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
   VIMSF(i,r,s) = VIMS(i,r,s)- {VIGM(i,s) + VIPM(i,s)}
                               * VIMS(i,r,s)/VIM(i,s);

COEFFICIENT (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)               VIASF(i,r,s);
  ! total imports by firms in sector i from region r
    to region s valued at agents(purchaser) prices.!

FORMULA  (all,i,TRAD_COMM)(all,r,REG)(all,s,REG)
    VIASF(i,r,s) = VIMSF(i,r,s)
                  + sum(j,prod_comm, IFTAX(i,j,s))
                           * VIMS(i,r,s)/VIM(i,s);
```

```
COEFFICIENT (all, i, TRAD_COMM)(all, j, PROD_COMM) (all, s, REG)  SHRIFA(i,j,s);
     ! sector j share of total firm imports of commodity i
       in region s valued at agent's (purchaser) prices !
FORMULA (all, i, TRAD_COMM)(all, j, PROD_COMM) (all, s, REG)
    SHRIFA(i,j,s) = VIFA(i,j,s) / sum(k, prod_comm, VIFA(i,k,s));

COEFFICIENT (all, i, TRAD_COMM)(all, j, PROD_COMM)
            (all, r, REG) (all, s, REG)                          SIINT(i,j,r,s);
   ! source specific cost share imported intermediate input
i imported by sector j in region s from region r,
     valued at agent's (purchaser) prices !
FORMULA (all, i, TRAD_COMM)(all, j, PROD_COMM)
        (all, r, REG) (all, s, REG)
    SIINT(i,j,r,s) = VIASF(i,r,s) * SHRIFA(i,j,s) / VOA(j,s);

COEFFICIENT (all, i, TRAD_COMM)(all, j, PROD_COMM)(all, s, REG)    SDINT(i,j,s);
    ! cost share domestic intermediate input i in sector j
      in region s,valued at agent's (purchaser) prices !
FORMULA (all, i, TRAD_COMM)(all, j, PROD_COMM)(all, s, REG)
     SDINT(i,j,s) = VDFA(i,j,s) / VOA(j,s);

!----------------------------------------------------------------------------!
! New spillover equations                                                    !
! First comes equation for TFP change                                        !
! Second comes set of equations for intermediate input augmenting and biased !
! tech change                                                                !
!----------------------------------------------------------------------------!
!----------------------------------------------------------------------------!
! TFP change equation                                                        !
!----------------------------------------------------------------------------!
EQUATION ao_eq
! TFP change related to trade flows !
(all, i,SPILL_COMM) (all, r, SPILL_SRC) (all, s, SPILL_DEST)
    ao(i, s) = [VXMD(i, r,s) / sum(k,SPILL_DEST, VXMD(i,r,k))]
                     ^(1-spilldelta(s,r)*absflex)
                                  * spillflex
                                  * ao(i,r);

!----------------------------------------------------------------------------!
! Next two equns relate to: Chemical products land saving                    !
!----------------------------------------------------------------------------!
EQUATION afe_land_eq
! land augmenting tech change related to intermediate input augmenting change!
   (all, i, ENDWS_COMM) (all, j, SPILL_COMM)(all, r, REG) (all, k, INVCHE)
    afe(i, j, r) = BETALAND(r) * af(k, j, r);

EQUATION af_chem_eq
 ! intermediate input augmenting tech change related to trade flows in
   chemical inputs.
   The ratio (cost share imports in s / cost share intermediate in r)
   determines relative amount of knowledge flowing between s and r !

 (all, k, INVCHE) (all, i, SPILL_COMM) (all, r, SPILL_SRC)(all, s, SPILL_DEST)
  af(k, i, s) = {SIINT(k,i,r,s) / SDINT(k,i,r)}
                  ^(1-spilldelta(s,r)*absflex)
                                 * spillflex
                    * af(k, i,r);

!----------------------------------------------------------------------------!
! Next two equns relate to: machinery products labor saving                  !
!----------------------------------------------------------------------------!
EQUATION afe_labor_eq
! labor augmenting tech change related to intermediate input augmenting change !
(all, i, ENDWL_COMM) (all, j, SPILL_COMM) (all, r, REG) (all, k, INVMAC)
   afe(i, j, r) = ALFALAB(r) * af(k, j, r);
```

```
EQUATION af_eq
 ! intermediate input augmenting tech change related to trade flows in
   machinery inputs.
   The ratio (cost share imports in s / cost share intermediate in r)
   determines relative amount of knowledge flowing between s and r !

 (all, k, INVMAC) (all, i, SPILL_COMM) (all, r, SPILL_SRC)
 (all, s, SPILL_DEST)
     af(k, i, s) = {SIINT(k,i,r,s) / SDINT(k,i,r)}
                  ^(1-spilldelta(s,r)*absflex)
                                  * spillflex
                    * af(k, i,r);
! ---------------------------------------------------------------------------!
!                              END OF SPILLOVER MODULE                        !
! ---------------------------------------------------------------------------!
```

**Added features**:
**2.1 New files**
**2.2 New sets**
**2.3 New coefficients**
**2.4 New equations**
**2.5 Command file**

### 2.1 New files

Two new files are introduced to hold respectively additional set specifications and spillover parameters. The layout of the header array file `SPILLSET` and the text file `SPILLPAR` is as follows:

**New file: SPILLSET** a header array file containing additional set definitions

The contents of the new sets is read from the header array file called `SPILLSET`. An example of this file is provided below. In this example North America (NAM) is the innovating region and grains (gro) is the knowledge receiving sector.

Example of a `SPILLSET` file.

---

This is a text file which is used as input into MODHAR to generate a GEMPACK header array file named `SPSETNAM.HAR`

Note:

| | |
|---|---|
| SPILL_SRC | source region of the innovation |
| SPILL_DEST | destination regions for the innovation |
| SPILL_COMM | the produced commodity which is affected by the innovation |
| INVCHE | the spillover carrier of chemical innovations |
| INVMAC | the spillover carrier of mechanical innovations |

```
1 strings length 4 header "H10" long name "SPILL_SRC";
NAM

8 strings length 4 header "H11" long name "SPILL_DEST";
AUS
EUR
ARG
```

```
JAN
RAS
SAM
CHN
ROW

1 strings length 3 header "H12" long name "SPILL_COMM";
gro

1 strings length 3 header "H13" long name "INVCHE";
crp

1 strings length 3 header "H14" long name "INVMAC";
trm
```

**New file: SPILLPAR** a text file containing additional parameters

A number of parameters are read from the text file SPILLPAR. An example of this file is provided below. The text file format has been chosen for flexibility reasons, because it allows quick changes in parameters for simulation experiments.

Example of a SPILLPAR text file

```
! -----SPAR12_9.DAT ---------------------------------!
! this file contains additional parameters for spillover application   !

1 9 real row_order header "beta" long name "BETALAND";
! spillover parameter land augmentation
! AUS NAM ARG EUR JAN RAS SAM CHN ROW
  1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0

1 9 real row_order header "alfa" long name "ALFALAB";
! spillover parameter labor augmentation
! AUS NAM ARG EUR JAN RAS SAM CHN ROW
  1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0

1 1 real row_order header "spif" long name "SPILLFLEX";
! switches embodied spillovers on or off
! 1 = on, 0 = off
1.0

1 1 real row_order header "absf" long name "ABSFLEX";
! switches absorption capacity effect on or off
! 1 = on, 0 = off
1.0

9 9 real row_order header "SPDE" long name "SPILLDELTA";
! absorption coefficient
! destination by source
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1.000 | 0.713 | 0.597 | 0.607 | 0.770 | 0.254 | 0.283 | 0.368 | 0.428 |
| 0.787 | 1.000 | 0.470 | 0.478 | 0.607 | 0.200 | 0.223 | 0.290 | 0.337 |
| 0.463 | 0.330 | 1.000 | 0.976 | 0.678 | 0.426 | 0.474 | 0.616 | 0.717 |
| 0.474 | 0.338 | 0.985 | 1.000 | 0.694 | 0.419 | 0.467 | 0.607 | 0.706 |
| 0.682 | 0.486 | 0.775 | 0.787 | 1.000 | 0.330 | 0.368 | 0.478 | 0.556 |
| 0.102 | 0.072 | 0.220 | 0.215 | 0.149 | 1.000 | 0.802 | 0.492 | 0.378 |
| 0.127 | 0.090 | 0.274 | 0.268 | 0.186 | 0.897 | 1.000 | 0.614 | 0.471 |
| 0.207 | 0.147 | 0.447 | 0.436 | 0.303 | 0.691 | 0.770 | 1.000 | 0.768 |
| 0.269 | 0.192 | 0.582 | 0.568 | 0.395 | 0.593 | 0.662 | 0.859 | 1.000 |

### 2.2 New sets:

`SPILL_SRC` — the source regions of spillovers, i.e. the region which makes the initial invention

`SPILL_DEST` — the destination regions of spillovers

`SPILL_COMM` — the commodity whose production function is affected by spillovers

`INVCHE` and `INVMAC` — carriers of knowledge, i.e. the commodities (respectively chemicals and machinery) which initially experience a technology shock. These are implementation specific. Other transmission mechanisms may be specified if desired.

Note that the maximum size of these sets may need to be adjusted for different regional/sectoral aggregations. Some additional SUBSET declarations are also necessary:

### 2.3 New coefficients (parameters):

`BETALAND` and `ALFALAB` — primary factor bias coefficients for land- and labor augmented technical change, respectively

`SPILLDELTA(s, r)` — parameter determining the effectiveness of foreign knowledge originating in *r* and spilling over to region *s*.

`SPILLFLEX` — simulation control parameter switches embodied spillovers on or off, [0, 1]

`ABSFLEX` — simulation control parameter switches SPILLDELTA on or off, [0, 1]

`VIMSF(j,r,s)` — Value of firm's imports of tradeable commodity *j* from source *r* to destination *s*. Valued at importer's market prices

`VIASF(j,r,s)` — Value of firm's imports of tradeable commodity *j* from source *r* to destination *s*. Valued at agent's (purchaser) prices.

`SHRIFA(j,i,s)` — Sector *i*'s share in use of imported intermediate good *j* in region *s*. Valued at region *s* agent's (purchaser) prices.

`SIINT(j,i,r,s)` — Source specific cost share of imported intermediate input *j*, imported by sector *i* in region *s* from region *r*. Valued at region *s* agent's (purchaser) prices.

`SDINT(j,i,r)` — Cost share of domestic intermediate input *j*, used by sector *i* in region *r*.

Valued at region *r* agent's (purchaser) prices.

**2.3 New equations:**

Five new equations are added:

| | |
|---|---|
| `ao_eq` | Hicks-neutral technical change related to trade flows |
| `afe_land_eq` | land augmenting technical change related to intermediate input augmenting change |
| `afe_labor_eq` | labor augmenting technical change related to intermediate input augmenting change |
| `af_chem_eq` | intermediate input augmenting tech change related to trade flows in chemical inputs |
| `af_mac_eq` | intermediate input augmenting tech change related to trade flows in machinery inputs |

**2.4 Command file**

The final step in preparing for a simulation is the preparation of a command file. In the spillover application this requires some attention since the number of exogenous and endogenous variables is affected by fixing one productivity parameter in one region exogenously and letting other productivity parameters be determined by the spillover equations treated above, while leaving the remaining productivity parameters exogenous.

The following presents a default command file which handles the endogenous / exogenous choice and specifies initial productivity shocks. Most of this command file is common GTAP practice, except for the introduction of new subsets which are introduced in this command file '"n the fly", i.e. not in the model code (*.TAB) itself.

The command file introduces two new sets, which come in handy for the specification of the closure. The set `_COMM NSPILL` is the set of non-spillover commodities and is the complement of the set `SPILL_COMM` which is already defined in the TABLO file.

We also want a set `NINVENT` of non-innovating sectors. The declaration of this set proceeds in three steps. First, we define `NINVENT1` as the set of 'non-innovating, non-chemicals' sectors. Second, we explicitly define `INVMAC` (declared in TABLO file) as a subset of `NINVENT1`. Third, we define NINVENT to be the set of • non-innovating, non-chemicals sectors excluding `INVMAC`.[13]

Hicks-neutral shifters (ao )to be exogenous in the following sets:
- NSPILL_COMM in all regions
- capital goods in all regions
- SPILL_COMM in the source region of innovations

[13] This somewhat clumsy procedure is necessary because GEMPACK does not allow for a declaration such as: NINVENT = TRAD_COMM - (INVCHE + INVMAC) [!! illegal !!]

Primary factor shifters (afe) to be exogenous in the following sets:

- all ENDW_COMM in NSPILL_COMM in all regions
- ENDW_COMM in capital goods in all regions
- primary factor capital in SPILL_COMM in all regions

Intermediate inputs shifters (af) to be exogenous in the following sets:

- all TRAD_COMM in NSPILL_COMM in all regions
- all TRAD_COMM for capital good in all regions
- NINVENT in SPILL_COMM in all regions
- INVCHE and INVMAC in SPILL_COMM in source region of innovation

```
!______________________________spill00.cmf___________________________________!

! default command file for spillover application                       !
!
! Which model
!
Auxiliary files = SPILL ; ! SPILL includes welfare and TOT decompositions!
! Solution method information.
!
method = gragg ;
steps = 2 4 6 ;
!
! files
!
! This is the 12 commodities 9 countries aggregation
file gtapSETS = set12_9.har;
file spillSET = spsetnam.har;
file gtapPARM = par12_9.dat;
file gtapDATA = dat12_9.har;
file spillPAR = spar00.dat;
!
!
! Next is necessary if reusing pivots is to succeed in multi step simulation !
iz1 = no ;
!
Equations File       = SP12_9 ;
          model      = SPILL ;
          version    = 1 ;
          Identifier = GTAP94DE.TAB with 12x9 data and spillovers;
!
! 3. Simulation Specification Section
!
Verbal Description =
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+                                Model SPILL                                    +
+                Experiment ao shock in gro (=GRAINS), NAM                      +
+                with endogenous spillovers to other countries                  +
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++;

XSET NSPILL_COMM     = TRAD_COMM - SPILL_COMM;
XSET NINVENT1 = TRAD_COMM - INVCHE ;
XSUBSET INVMAC is SUBSET of NINVENT1;
XSET NINVENT  = NINVENT1 - INVMAC;

Exogenous pop
          psave
          profitslack incomeslack endwslack
          cgdslack saveslack govslack tradslack
```

```
          ava atr
          to txs tms tx tm
          qo(ENDW_COMM,REG)

          ao(NSPILL_COMM, reg)
          ao("cgds", reg)
          ao(spill_comm, spill_src)

          afe(ENDW_COMM, NSPILL_COMM, reg)
          afe(ENDW_COMM, "cgds", reg)
          afe("capital", SPILL_COMM, reg)

          af(trad_comm, nspill_comm, reg)
          af(trad_comm, "cgds", reg)
          af(NINVENT, spill_comm , reg)
          af(invche, spill_comm, spill_src)
          af(invmac, spill_comm, spill_src);
Rest Endogenous ;

Shock ao("gro",spill_src)       = 10;
Shock af("crp","gro",spill_src) = 0;
Shock af("trm","gro",spill_src) = 0;

! 4. Output File Specification (they are experiment dependent)
!
Save Environment File   spill ;
Solution         File = spill00 ;
Log              File = spill.LOG ;
!
! Updated data files
!
Updated file gtapDATA = spill00.upd;
!
Display file = sp12_9.dis ;
!
! 5. Other Options
!
Extrapolation accuracy file = YES ;
CPU = yes ;
!_____________________________End of Command file.______________________________
```

# *Appendix 3: A Partial Equilibrium Model of Technical Innovator and Factor Bias*

This appendix presents the linearized version of the system of equations (12) - (16). We adopt the convention that lower case letters indicate the percentage change in the corresponding uppercase variable, so that z = 100% *dZ/Z*. The linearized system becomes:

| | | |
|---|---|---|
| $q_a + a_a = y + \sigma[\,p_v - (\,p_a - a_a)\,]$ | : | demand for land |
| $q_i + a_i = y$ | : | demand for intermediates |
| $q_l = y + \sigma[\,p_v - p_l]$ | : | demand for labor |
| $p_v = (\,p_a - a_a)\,S_a + p_l(1 - S_a)$ | : | price of value added |
| $y + p\,S_p - (\,p_i - a_i)\,S_{p_i/a_i} - p_v\,S_{p_v} = 0$ | : | zero profits |
| $y = \varepsilon_p^y\,p$ | : | demand for output |

In the linearized set of equations, $S_a$ denotes the share of land cost in primary factor cost, $\varepsilon_p^y$ denotes the price elasticity of final demand, and

$$S_p = \frac{P}{N} \quad S_{p_i/a_i} = \frac{P_i / A_i}{N} \quad S_{p_v} = \frac{P_v}{N}$$

$$\text{where } N = P - P_i / A_i - P_v$$

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