Absorption Capacity, Structural Similarity and Embodied Technology Spillovers in A 'Macro' Model: An Implementation within a CGE Framework

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Absorption Capacity, Structural Similarity and Embodied Technology Spillovers in A 'Macro' Model: An Implementation within a Computable General Equilibrium Framework

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Abstract

In this paper, all technology transfers are embodied in trade flows within a three-region, one-traded-commodity version of the GTAP model. Exogenous Hicks-Neutral technical progress in one region can have uneven impacts on productivity elsewhere. Why? Destination regions' ability to harness new technology depends on their *absorptive capacity* and the *structural congruence* of the source and destination. Together with trade volume, these two factors determine the recipient's *spillover coefficient* (which measures its success in capturing foreign technology). Armington competition between the outputs of the three economies and shifts in their terms of trade loom large in the general equilibrium adjustment.

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Key Words: Absorption Capacity, Capture Parameter, Trade, Technology Spillover, and CGE.

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1. Introduction

The links between international trade, growth and invention are well-established in the literature. Many less developed countries (LDCs) have pursued liberal trade and technology policies and have relied on technologies originating in the industrialised, developed countries (DCs) of the world. Given that the latest state-of-the-art is researched and developed in the DCs, we address the problem of "effective assimilation" and "absorption" of advanced technology in the LDCs.

There is evidence that knowledge spills over from the sources of innovation to the destinations through different channels. Two principal channels through which such transmission of advanced knowledge-capital occurs are (a) International Trade in goods and services and (b) Foreign Direct Investment (of which Joint-Ventures are special case). The literature has highlighted the role of trade in technology spillovers from North to South [Coe, Helpman and Hoffmaister 1995 & 1997), Connolly (1997), Keller (1997), Edwards (1997), Hall and Jones (1998), Padoan (1996)]. This paper is about "embodied" spillovers of knowledge through *international trade* in commodities. Technology transferred via bilateral trade in goods embodying technological advances leads to enhancement of productivity in the receiving countries. Here, we consider the effects of ***'Absorptive Capacity (AC)'*** and ***'Structural Similarity (SS)'*** in fostering technology acquisition. Among the plethora of papers on the determinants of technological innovation, the bulk has been in the context of DCs. The paper by Hans van Meijl and Frank van Tongeren (April, 1997) (henceforth, referred to as MT) is a stepping stone for modelling issues of technology transfer from the countries at the frontiers of technology creation to the relatively laggard recipient countries within the global applied general equilibrium model, GTAP[1]. It is argued that "local" or domestic usability of the foreign technology depends on the destination's capacity to identify, procure and use the diffused state-of-the-art.

[1] The Global Trade Analysis Project's model (GTAP—see Hertel (ed.), 1997) is a multi-regional, multi-commodity, comparative-static model with a global database for 30 regions and 37 commodities (database version 3).

We implement the 'embodied' knowledge spillovers in a highly aggregated version of the GTAP model—that is, a one-traded-commodity, three-region version of GTAP.[2] GTAP, like many CGE models, adopts Armington's (1969) treatment of commodity substitution, so that even if all regions produce the same generic commodity, the substitution elasticity between that commodity produced in region A and the "same" commodity produced in region B, is *not* infinite. Thus, even in a one-commodity version of GTAP the 'Law of One Price' does not hold. Working at the one-commodity level has the advantage of concentrating on inter-regional competition in the goods market without having to deal with the large amount of detail entailed in keeping track also of inter-generic commodity substitution.

We aggregate the GTAP database to one-commodity and three-region (USA, EU, and ROW) database. The generic commodity that is traded internationally will be called "Stuff". Each region produces one tradable good (its own type of "Stuff") and one non-tradable (its own Capital Goods). It is necessary to include a non-tradable in each region because GTAP specifies that capital formation is supplied completely by a domestic industry which does not export. Note, however, that the domestic capital goods industry in any country merely assembles a bundle of traded goods (which include foreign tradables). Consumers absorb Stuff produced at home, as well as the two imported varieties. We consider a Hicks-Neutral general total factor productivity (TFP) shock in the "Stuff" sector originating in one of the three regions, viz. the USA. Such a TFP shock is general output-augmenting by nature. Its impact on productivity in the destinations via an embodiment index, an absorption capacity index, and a structural similarity index, are studied. Section 2 and 3 describe the theoretical premise and the database corresponding to our aggregation respectively. Section 4 documents the GTAP implementation, the closure and the perturbation introduced into the system. Section 5 reports the simulation results. Section 6 concludes.

[2] Various aggregations of the data are available, and in this paper a 3×3 aggregation of the database is the starting point from which a further aggregation is implemented to produce a three region macro model.

2. Theoretical Premise

2.1 Embodied Spillover Hypothesis[3]

Growth and development of the LDCs depend not only on the extent and nature of the foreign technology which is available to them via participation in international trade in goods and services, but also on their capabilities for effectively absorbing the diffused state-of-the-art. Current state-of-the-art technologies created by concerted research efforts are embodied in the commodities produced using the newly created 'ideas'. The knowledge-capital generated at the sources of inventions, spills over to the destinations through bilateral trade linkages. This is the "*embodiment hypothesis*": technical knowledge flows through traded goods. Note that the creation (as distinct from the transmission) of knowledge-capital is beyond the scope of this model.

The adaptability and local usability of the diffused technologies depends on the *Absorptive Capacity* [Cohen and Levinthal[4] (1990)] of the destinations and the *Structural Similarity* [Hayami and Ruttan (1985)] between the trading nations. In the literature, the importance of ***'SS'*** has been discussed especially in the context of agriculture. Here in a single-sector model with one trading sector per region, this focus is not valid. However, the maximum potential for productivity enhancement attainable with a given stock of ideas can be achieved only if both AC and SS are high.[5]

Productivity growth rates of countries are related through international trade linkages and associated "embodied" knowledge-spillovers. In their model, AC is constructed as a binary (source- and destination-specific) index of human-capital-induced absorption capacity of Country A vis-a-vis Country B. They also use a binary index for SS. It is based on the

[3] Our approach is more modest than the approach by Eaton and Kortum (1994, 1996a & b) [henceforth, EK], Grossman and Helpman (1991a & b), Jones (1995). All of these dynamic general equilibrium models have considered the possible interlinkages between invention, technology diffusion, growth and productivity. Eaton and Kortum have developed an empirical dynamic general equilibrium model of technology-diffusion based on a "quality-ladder" approach. Better quality inputs embodying the latest 'ideas' always replace the 'state-of-the-art' currently in practice.

[4] To the best of our knowledge, the role of such factors in assimilating the foreign technology was first emphasised in the literarure by Cohen and Levinthal. Based on their notion of absorption capacity and its importance, some authors like Keller (1997), Nelson (1990), to name a few, have extended the discussion initiated by them.

[5] This aspect of "*effective* absorption" has not been studied by the authors cited above in footnote 3.

similarity of factor proportions in the two regions (but unlike AC, SS is symmetric). These two indexes conjointly determine the 'productive efficiency' parameter for effective assimilation of the technology by the recipient countries.[6]

Our model differs in several details. *Firstly*, we restrict ourselves to a one-sector ('tradable' Stuff) technology for production. 'Stuff' is produced in a world divided into three regions. Like "ectoplasm" in the one sector Neo-Classical growth model, 'Stuff' is easily transmutable from consumable to investment goods. *Second*, unlike MT where AC is a binary index involving both 'source' and 'destination', we make the 'AC' factor destination-specific only. The 'SS' factor retains its 'binary' affix, though. *Third*, as will become evident below, we have modified MT's 'embodied spillover function'.

It is argued that domestic usability of the transmitted foreign technology depends mainly on the *recipient's* capability to identify, procure and utilise the diffused technology. This simplification reflects our desire to keep the model simple by concentrating on first-order effects. It seems likely that if region 'C' is good at absorbing technology from region 'A', it will be equally good at absorbing technology from another region 'B' which (from C's point of view) is structurally similar to 'A'. Thus, the AC factor is made destination-specific only (unlike in MT where they carry both source and destination affixes). The basic spillover equations are rationalised in the next section.

2.2 Production Technology and Spillover Function

2.2a Production Technology

The production technology tree in the GTAP model uses a ***nested*** production function. Here we specialize the notation for use with the one-traded-commodity version.

At the top level, a composite output Y_r is produced in region 'r' with a Leontief fixed proportion technology using intermediate inputs $Q_{r.}$ and a primary input composite $Q^V_{r.}$. $Q_{r.}$ is intermediate input demand for Armington composite "stuff" by any region 'r'. Each $Q_{r.}$ is

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

produced in a CES production nest using domestic stuff and a composite of foreign 'stuff' distinguished by country of origin (using the Armington assumption). Thus, we can write the CES production function for the intermediate input nest as

$$Q_{r\cdot} = A_r \{\delta^D_r (Q_{rr})^{-\beta_{r\cdot}} + (1-\delta^D_r)(Q^F_r)^{-\beta_{r\cdot}}\}^{-1/\beta_{r\cdot}} \qquad (2.1a)$$

where 'r' is the region using the domestically sourced tradable stuff Q_{rr} and the foreign inputs composite of stuff $Q^F_{r\cdot}$. δ^D_r is the distribution parameter (positive constant). $\beta_{r\cdot} \neq -1$ is the substitution parameter. The superscripts 'D' and 'F' are used to identify domestic and foreign components respectively. The substitution elasticity between domestic and foreign stuff is $[1/(1+\beta_{r\cdot})]$.

For notational convenience, in Q_{rs} the first subscript refers to the using region and the second one refers to the foreign source of Stuff. For example, let the three regions in our implementation be A, B and C so that $r,s \in \{A, B, C\}$. Then, if r=C is the 'using' region, and s=B or A, $Q_{rr}=Q_{CC}$ is the domestically sourced 'stuff' in C while Q_{CA} and Q_{CB} are Stuff imported by C from B and A respectively.

Q^F_r is produced in region 'r' using the Stuff imported from other regions, say, 's' and 't'. Let Q_{rs} and Q_{rt} be respectively the intermediate input demand for Stuff from 's' and 't' by using region 'r'. This leads us to write the CES production nest for Q^F_r as below:

$$Q^F_r = A^F_r \{\delta^F_r (Q_{rs})^{-\beta_{rF}} + (1-\delta^F_r)(Q_{rt})^{-\beta_{rF}}\}^{-1/\beta_{rF}} \qquad (2.1b)$$

where $s,t \neq r$; $s \neq t$. δ^F_r is the distribution parameter associated with this production nest. The elasticity of substitution in 'r' between imported stuffs is $[1/(1+\beta_{rF})]$. If $\beta_{r\cdot}=\beta_{rF}$, (2.1b) is equivalent to writing $Q_{r\cdot}$ as a CES function in 'stuff' from all three sources.

Primary factor composite Q^V_r is produced combining the primary factors land (T), labor (L), and capital (K). Q^f_r is the demand for primary factor 'f' in region 'r' where $f \in \{L, K, T\}$. The production technology is CES as given below:

$$Q^{V}_{r} = A^{V}_{r} \{ \sum_{f} \delta^{V}_{rf} (Q^{f}_{r})^{-\rho_r} \}^{-1/\rho_r} \qquad (2.2)$$

where δ^{V}_{rf}'s are distribution parameters (positive constants) (with $\sum_{f} \delta^{V}_{rf} = 1, \ \forall r$) and ρ_r is the substitution parameter. The substitution elasticity between primary factors in region 'r' is $[1/(1+\rho_r)]$. In the above equations, A_r, A^{F}_{r} and A^{V}_{r} are technical progress parameters.

$Q_{r.}$ and Q^{V}_{r} are combined using a fixed proportion technology with no scope for substitution between intermediate inputs and the primary factors. However, as seen above, there is scope for substitution between domestic and imported varieties of Stuff, as there is between L, K and T. At the top level the (Leontief) production function is:

$$Y_r = [AO]_r \min \{ A^{O}_{r} Q_{r.} , Q^{V}_{r} \} \qquad (2.3)$$

where Y_r is the flow of final output and A^{O}_{r} is an intermediate input augmenting technical change parameter. $[AO]_r$ is the Hicks-Neutral Technical Progress (HNTP) parameter.

2.2b Spillover Equation and Productivity Shock

The spillover hypothesis (as documented in Section 2.1 above) is captured by a technology-transmission equation incorporating destination-specific AC and source- and destination-specific SS. Exports from source 'r' to destination 's' determine an "**Embodiment index**'' E_{rs}. The latter, together with AC_s and SS_{rs} determine the value of a "**Spillover Coefficient**" $\gamma_s(E_{rs}, AC_s, SS_{rs})$ via the spillover function γ_s.

The details of this chain are now explained, starting at the top. Note that there is only one source of 'exogenous' technological improvement in the current treatment, so that 'r' is unique.[7] Stuff produced using the improved technology *embodies* this technological improvement. Exports of 'Stuff' from 'r' to the trade partners 's' transmit these embodied technological advances but do not necessarily lead to enhancement of productivity in the recipient sectors of the client countries ***unless*** they are utilized as an input to production. We

7 An implication of the uniqueness of 'r' is that equations carrying an r-subscripted variable on the right do not necessarily require an 'r' subscript to appear on the left.

define an "Embodiment Index" E_{rs} (where $0 \leq E_{rs} \leq 1$) that is proportional to the amount of embodied knowledge received via bilateral trade linkages between 'r' and 's' so that

$$E_{rs} = X_{rs}/Y_s \qquad (2.4)$$

where X_{rs} is the bilateral exports of Stuff from source 'r' to the clients 's' and Y_s is the domestic production of Stuff in 's'. E_{rs} , thus, measures the amount of *embodied* knowledge obtained via bilateral exports from 'r' to 's' per unit of output of Stuff produced in client 's'.[8] The recipient-specific AC-index AC_s (where $0 \leq AC_s \leq 1$) and the binary structural similarity index SS_{rs} (where $0 \leq SS_{rs} \leq 1$) interactively determine a "capture parameter" θ_s measuring the efficiency with which the knowledge embodied in bilateral trade flows from source 'r' is *captured* by the recipients 's' :

$$\theta_s = AC_s . SS_{rs} \qquad (2.5)$$

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

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

where primes indicate the first (′) and the second (″) derivatives with respect to E_{rs}. We consider an exogenous TFP improvement in the technology for producing "stuff" in region 'r'. Specifically, the shock is a Hicks-neutral improvement in the productivity of each primary factor there. Figure 1 shows the way in which technological knowledge embodied in trade flows affects the spillover of productivity from a source to a destination region.

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8 However, it is to be noted that in MT, E_{rs} is defined as the ratio of bilateral trade flows (X_{rs}) from 'r' to 's' in any final product sector and total bilateral trade flows ($\sum_s X_{rs}$) to all destinations 's' from the source 'r'. This ratio shows the spillover to the recipients as a proportion of aggregate 'global' spillovers from source to the client countries. This seems to neglect the public good character of knowledge capital. We have modified this definition as described in the text.

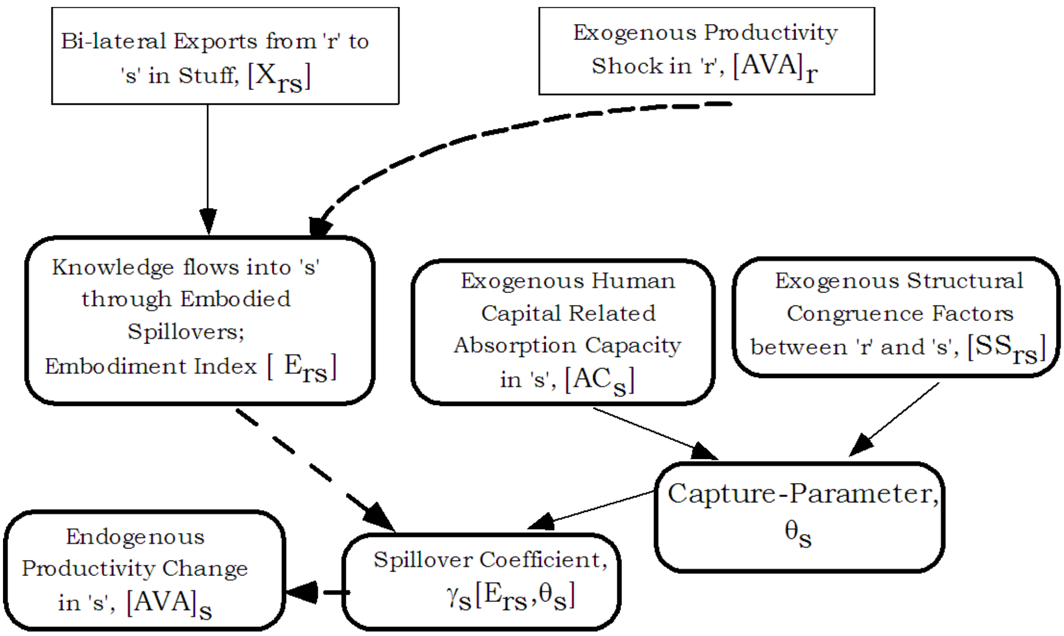

Figure 1: Flowchart for the transmission mechanism in the model.

The improvement in productive efficiency leads to value-added augmenting technical change in 'Stuff'. Hence, A^V_r in the value-added nest of the production tree [see equation (2.2)] is the appropriate technological change parameter for considering HNTP. In GTAP notation, this is AVA(r). The transmission equation showing how the productivity improvement in 'r' affects productivity in 's' is as follows:

$$ava(s) = \gamma_s(E_{rs}, \theta_s).\ ava(r) \qquad (2.6)$$

where ava(s) and ava(r) are respectively the percentage improvements in the productivity 'levels' (HNTP parameters, AVA) in the value-added nest of the production function of regions 'r' and 's' (the convention in the GTAP-system of notation being that the lower case variables represent the percentage-changes in the corresponding 'level' variables). This transmitted improvement is higher, the higher are the values of AC_s and SS_{rs}.

More specifically,

$$\gamma_s(E_{rs}, \theta_s) = E_{rs}^{1-\theta_s}\ ,\ 0 \le \theta_s \le 1 \qquad (2.7)$$

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

$\frac{\partial \gamma_s}{\partial \theta_s} = [-\gamma_s(E_{rs}).\ln E_{rs}] > 0$ and $\frac{\partial^2 \gamma_s}{\partial \theta_s^2} = [(\ln E_{rs})^2 . E_{rs}^{1-\theta_s}] > 0$ i.e., γ_s is a convex function of θ_s.

Thus, the γ_s function shows *increasing* marginal returns to θ_s.[9]

Substitution of (2.7) into (2.6) shows that, all told, the equation governing the technological spillover is given by

$$ava(s) = E_{rs}^{1-AC_s . SS_{rs}} . ava(r) \qquad (2.8)$$

Substitution of (2.4) into equation (2.8) yields the fundamental spillover equation for implementation in GTAP as

$$ava(s) = [X_{rs}/Y_s]^{1-AC_s . SS_{rs}} . ava(r) \qquad (2.8a)$$

Being '*neutral'* in nature, the exogenous HNTP shock uniformly reduces the input requirements associated with producing a given level of output of Stuff.

3.The GTAP Database and Aggregation

The aggregation procedure involves working in several steps with necessary computer files for performing the task. All these files are documented in details in the *Appendix*. The MODHAR programme available in the Windows version [WINGEM] of GEMPACK (**G**eneral **E**quilibrium **M**odelling **Pack**age) was run interactively to create a HAR (**H**eader **AR**ray) file named SET1BY3.HAR from a text file (SET1BY3.TXT) defining the elements of the sets. We refer to our one-traded-commodity, three-region model as 1×3GTAP. The aggregated database comprising trade, production and input-output data was produced by running Mark Horridge's programme **"DAGG"** on the 3×3GTAP bilateral and input-output data in Version 3 of the database. The procedure is described in details in the *Appendix.*

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[9] With the determinants AC and SS of θ_s both bounded in [0,1] and *strictly exogenous*, this should not present any computational problem in our GE model.

The additional parameters introduced in the parameter file are HK(s) and SS(r, s). HK(s) represents AC_s as described in Section 2. Their values are set arbitrarily. *Assuming* that the EU is more 'similar' to the US in both SS and AC than to the ROW, higher values are assigned for these exogenous variables in case of EU as compared to ROW; that is, $AC_{EU} > AC_{ROW}$ and $SS_{EU,US} > SS_{ROW,US}$. The *Appendix* documents them as appended in the TABLO file.

4.GTAP Implementation

5.2 Additional Equation

The economic model is the one described in Hertel (ed.) [1997] with an additional behavioural equation, two new parameters and two new coefficients, plus some additional national accounting identities coded by Philip D. Adams.

Equation (2.8a) in the notation of the GTAP-system of equations is:

$$\text{ava(i,s)= [VXWD(i,r,s)/VOW(i,s)]}^{(1\text{-}AC_s.SS_{rs})}\text{. ava(i,r)} \qquad (2.8b)$$

where i $\in$ TRAD_COMM. TRAD_COMM contains traded commodity 'Stuff' only, VXWD(i,r,s) is the value of exports of tradable commodity 'i' from 'r' to 's' evaluated at world *'fob'* prices [i.e., X_{rs} in equation (2.8a)]; VOW (i,s) is the value of output of tradable commodity 'i' in 's' evaluated at world *'fob'* prices [i.e., Y_s in (2.8a)]. The model is encoded in TABLO language for GEMPACK software as reported in the *Appendix.* In our implementation, we define one region at a time as the source of invention—set named 'SRC'. The countries other than the source belong to the set named 'REG_NOT_SRC'. These two sets are subsets of the set of all regions–REG. Table 1 gives the encoding of the spillover equation only (i.e., equation (2.8b)) in TABLO[10] language.

TABLE 1: Key Technology Spillover Equation in the TABLO Source file

```
Equation MOD_EMB_SPLOVER
!This equation gives the Embodied Spillovers via Trade in the recepients!

(all, i, TRAD_COMM) (all, r, SRC) (all, s, REG_NOT_SRC)
ava(i,s)=[(VXWD(i,r,s)/VOW(i,s))^(1-HK(s)*SS(r,s))]*ava(i,r);           (2.8b′)
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The *Appendix* documents the changes made in the GTAP96.TAB by defining some additional coefficients, variables and necessary equations.

5.2 Closure and Shock

All savers face a common price, PSAVE (which is the numeraire in the standard closure of the model), for the savings commodity. The allocation of savings commodity depends on the specification of the closure. Here it is assumed that the aggregate capital stock is exogenous in all regions and that regional and global nett investment move together. While no reallocation of regional shares in global investment is permitted, inter-industry capital mobility within a region is allowed. This is known as the ***medium-run***, or ***partial long-run equilibrium*** standard closure in the GTAP literature. In all standard closures of GTAP, the regional labor endowments are exogenous, while in the current closure new investment does not add to the capital stock available in the solution period[11]. Hence the productive capacities of all regions are unaffected in the period to which the simulation results apply. However, as investment is a component of final demand, it affects economic activity in the solution period via its impact on the demand. In the case of our 1×3 macro aggregation of GTAP, these compositional influences are limited to the sourcing of "Stuff" from different regions in the assembly of locally-specific capital goods.

Below we consider an arbitrary 2% TFP shock in the USA in the "Stuff" sector. In the closure used here, prices, quantities of all non-endowment commodities, and regional

[10] TABLO is an algebraic language for writing economic models and for defining the associated sets, equations, coefficients, and variables for subsequent solution specifically compatible with the GEMPACK software suite (see Harrison and Pearson, 1996).

[11] We use 'solution period' and 'snapshot' period interchangeably to mean the period (occurring some time after the shock) for which the simulation is run and solution is obtained. The solution is presented as the percentage deviation in the snapshot period in a variable of interest *relative* to its value *in that period* in a base-case or control scenario in which no shocks occur.

incomes are *endogenous*, while policy variables, other technical change variables, and population [POP(r)] are *exogenous* to the model.

5. Analysis of Simulation Results

5.1 Macroeconomic Effects in Each Region

Table 2 summarises the impact of the perturbation on the macro variables.

TABLE 2 Simulated regional effects of technological change in the USA on selected macroeconomic variables[(a)]

Percentage change in:	USA	EU	ROW
1. Technological Change [TFP]	2.00	1.07	0.05
2. Output of STUFF [qo]	2.00	1.07	0.05
3. Supply price of STUFF [ps]	-0.30	-0.19	+0.12
4. Output of sector CGDS [qcgds]	0.08	0.19	0.25
5. Price of investment goods [pcgds]	-0.26	-0.17	+0.09
6. Real Value-added in Stuff [qva] (in conventional units)	0.00	0.00	0.00
7. Price of Value-added [pva] (in conventional units)	1.68	0.86	0.19
8. Real Value-added in Stuff [in constant efficiency units]	2.00	1.07	0.05
9. Price of Value-added [in constant efficiency units]	-0.31	-0.20	+0.14
10. Nominal GDP [NA_gdpinc] from Income Side (market prices)	1.67	0.86	0.19
11. Nominal GDP from Expenditure Side [NA_gdpexp] (market prices)	1.67	0.86	0.19
12. Nominal GDP at Factor Cost [NA_gdpfc]	1.68	0.86	0.19
13. Real GDP from Income side [NA_realgdpinc] (at market prices)	1.99	1.06	0.06
14. Real GDP from Expenditure side [qgdp] (at market prices)	1.99	1.06	0.06
15. Real GDP at Factor Cost [NA_realgdpfc]	2.00	1.07	0.05
16. Price Index of GDP [NA_prigdpin] from Income side (market prices)	-0.31	-0.20	+0.14
17. Price index of GDP from expenditure side[NA_prigdp] (market prices)	-0.31	-0.20	+0.14
18. Price Index of GDP at Factor Cost [NA_prigdpfc] [(a)]	-0.31	-0.20	+0.14
19. Price index for GNE [NA_prigne]	-0.28	-0.18	+0.10

(a) These values are for percentage changes of level variables from their control values (post- shock). Figures are rounded to 2 or 3 decimal places. The shock is a 2% increase in TFP. (a) Figures for row 18 are obtained by modifying the existing equation for it in GTAP National Accounts module and incorporating into it the 'Tec_Chg' variable as documented in the Appendix. These are the same as figures in row 9 after this adjustment has been made.

With fixed supplies of land, labor and capital and no factor-bias, a 2% TFP-shock in 'Stuff' in the USA leads to an increase in output in that sector and real GDP at factor cost of exactly 2%. After the HNTP shock, we *effectively* have 2-percent more of each factor after allowing for the improvement in its quality. Thus, in the snapshot period, one-hundred input-hours of composite *real* value-added are equivalent to one hundred and two quantity units of composite value-added measured in terms of constant efficiency units applicable in the base-period. Hence, there has been no change in the usage of primary factors of production (as measured in conventional units) between the base case and the shocked solution. This leads to a zero percentage change in value-added (not quality adjusted) by factors of production [row 6, Table 2]. However, real value-added (measured in constant efficiency units) increases in all three regions.

The increase in productive efficiency of the 'raw' primary composite input (measured in conventional units) leads to an increase in its marginal productivity (MP)—i.e., 2.00, 1.07, and 0.05 per cent for USA, EU and ROW respectively [12]. Since factors are paid according to their marginal products, these increases in MP lead to increases in the price of value-added and their constituents in all three regions. Being neutral in nature, this TFP improvement causes equal percentage increases in the real rewards of all primary factors within any given region.

We observe that there has not been full transmission of technical change from the source to the destinations–EU and ROW. Table 3 suggests that the value of the spillover coefficient depends more strongly on θ_s than on E_{rs} *alone*. Thus, whilst trade is the prime vehicle for transmission of knowledge-flows, AC_s and SS_{rs} (and hence, θ_s) are critical for *'effective'* transmission of technology from 'r' to 's'. This is supported by the fact that even when E_{rs} has lower values, the magnification of them by θ_s can lead to a high rate of capture of the technological improvement. Thus, EU with higher values of both AC_s and SS_{rs}, does better than ROW at capturing the TFP improvement occurring in the USA despite ROW

[12] The percentage changes in marginal (physical) productivities can be verified from computed GTAP variables as follows. In the levels, the value of the MPs of factors should equal their prices:

$$P_{stuff} * MP_f = P_f \quad (\text{where } f \in \{L, K, T\})$$

We have computed GTAP results for the percentage changes in P_{stuff} and in each P_f—p_{stuff}, p_L, p_K, and p_T (say)—in each region. Then, for example, we can use the above relationship to compute the percentage change in the marginal physical product of labour by:

$$\% \text{ change in } MP_L = (\{[P_f^{(initial)} * (1+p_f/100)] / [P_{stuff}^{(initial)} * (1+p_{stuff}/100)]\}-1)*100$$
$$= 100* [\{(p_f/100)-(p_{stuff}/100)\}/(1+p_{stuff}/100)]$$

Note that this accurate calculation is *not* replicated by simply subtracting 'p_{stuff}' from 'p_l'.

having a higher value of E_{rs}. Consequently, in Table 2 we see a greater improvement in technology in EU (1.07) as compared to that in ROW (0.05).

TABLE 3 Values of embodiment-index, spillover coefficient and capture-parameter (a)

GTAP Regions	Embodiment Index (E_{rs})	Spillover Coefficient (γ_s)	Capture-Parameter (θ_s)
EU	0.014	0.540	0.855
ROW	0.020	0.023	0.030
USA	1.000	1.000	1.000

(a) Values shown relate to the pre-shock situation.

Stuff being the *only* sector whose production involves value-added, its share in total value-added is *unity* in *all* three regions. As the TFP improvements cause real value-added by factors of production (quality adjusted) to increase by the same percentages, the percentage change in real GDP at factor cost in each region is equal to the respective TFP shock (see rows 1 and 8, Table 2). Also, the price indexes for value-added in 'Stuff' (row 9 of Table 2) and for GDP at factor cost (row 18) are identical. Changes in real nett indirect taxes (which are of fairly small magnitude) account for the wedges between real GDP at market prices and real GDP at factor cost.

Now, the recorded NA_gdpfc (row 12, Table 2) is calculated on the basis of price and quantity indexes of value-added measured in conventional units [*pva*]. These are taken as *given* from the GTAP results. As the *real* value-added measured in constant efficiency units (i.e., '*quality-adjusted*') increases in all regions by the same percentage as the TFP improvement, the effective price of value-added has to adjust accordingly so that the *nominal* value-added measured in *constant efficiency units* matches the GTAP results. The increases in real value-added (measured in constant efficiency units) of about 2 and 1 percent respectively in USA and EU lead to falls in the corresponding price indices of about 0.3 and 0.2 per cent (rows 8 and 9, Table 2). In case of ROW, the small rise in real value-added (with least TFP improvement) is not enough to depress the corresponding price given the attendant general equilibrium effects (to be discussed below)—in fact, it rises (0.14 per cent) there.

5.2 Inter-regional Competition Effects

Table 4 shows that, region by region, there have been increases in *nominal* regional household income [*y(r)*] and its uses (rows 1, 7, 5 and 4).

TABLE 4 Simulated regional effects on sources of final demand[(a)]

Percentage change in:	USA	EU	ROW
1. Regional household income [y (REG)] (Nominal)	1.91	1.00	0.21
2. Price index of GDP from expenditure and income sides(market prices)	-0.31	-0.20	+0.14
3. Regional household income [u (REG)] (Real)	2.19	1.17	0.12
4.Regional nett savings demand [qsave] (Real and nominal) [(b)]	1.91	1.00	0.21
5. (Real) Public consumption [ug (REG)]	2.20	1.19	0.09
6. Nominal Public consumption [yg(r)]	1.91	1.00	0.21
7. Nominal Private household expenditure [yp(REG)]	1.91	1.00	0.21
8. (Real) Private household consumption [up (REG)]	2.19	1.18	0.10
9. Gross National Expenditure (NA_realgne] (Real)	1.92	0.99	0.14
10. Price index for GNE [NA_prigne]	-0.28	-0.18	+0.10
11. McDougal Terms-of-trade (McDougal_TOT)	-0.35	-0.21	+0.17
12. Aggregate export price index of stuff [pxw]	-0.30	-0.19	+0.12
13. Aggregate import price index of stuff [piw]	+0.05	+0.02	-0.05
14. Real value of exports [qxw]	1.71	1.19	0.05
15. Real value of imports [qiw]	1.01	0.50	0.46
16. Change in trade balance [DTBAL] [(c)]	+1508.26	+3233.6	-4741.86
17. Consumer price index [ppriv]	-0.277	-0.179	+0.104
18. Government aggregate purchase price index [pgov]	-0.285	-0.189	+0.110
19. Real GDP from Expenditure and Income sides (market prices)	1.99	1.06	0.06
20. *Real* Gross regional investment [qcgds]	0.08	0.19	0.25

(a) Figures in this table are rounded to 2 or, 3 decimal places.
(b) This is the same in 'nominal' terms as there has been no %-change in its price PSAVE.
(c) Since the trade balance can pass through zero, percentage changes are avoided in the case of this variable. The change reported here is an ordinary change (million US $) changes of level values.

We first explain post-shock *differential impacts on nominal income* [*y(r)*] which is the sum of primary factor payments and receipts from various transactions taxes *nett* of depreciation. Table 5 breaks up the component-wise effects on *y(r)*. Earlier discussion shows that the HNTP shock increases '*pva*' and its components (row 7, Table 2). The increase in *y(r)* has primarily been caused by the uniform increases in primary factor payments in all regions (row 2, Table 5).

TABLE 5 Simulated effects on nominal regional income[(a)]

Percentage change in:	USA	EU	ROW
1. Nominal Regional Household income [y(REG)]	1.908	1.000	0.206
2. Contribution of Endowment income [pfac]	1.721	0.936	0.193
3. Contribution of Physical Depreciation	0.000	0.000	0.000
4. Contribution of pcgds to cost of replacing depreciated capital (*nominal* changes)	+0.031	+0.024	-0.013
5. Contribution of Output tax revenues	0.143	0.004	0.011

(a) Figures in this table are rounded to 3 or, 4 decimal places. Figures in row 1, when rounded to 2 decimal places, yield the same figures as in row 1 of Table 4. We do not report here the figures for all component-wise effects from tax receipts. Figures of very small magnitude (< 0.00003) are excluded.

We now turn to the discussion of impacts on sources of various income-uses.

5.2.a Region-wide impact on sources of final demands

In GTAP, each region's demands for private expenditure [PRIVEXP (r)], public expenditure [GOVEXP (r)] and saving [SAVE (r)] are determined by maximisation of a per capita Cobb-Douglas utility function subject to the constraint that these three items totally exhaust the regional income [INCOME(r)]. Under this specification, their *fixed shares* of income result in the equality of percentage increases in *nominal* demand for the income uses with the percentage increases in total *nominal* income.

Given the equality of percentage changes in the *nominal* variables[13] PRIVEXP and GOVEXP in each region, we observe that the corresponding *real* variables in each region move together but *not* strictly in proportion to each other (see rows 5 and 7, Table 4). The changes in *real* consumption expenditures are attributed to the differential impacts of movements in *pgov* (the aggregate government purchase price index) and *ppriv* (the consumer price index or, CPI)—the divergence being caused by the diverse purchase patterns of the private and public 'households'[14]. Back-of-the-envelope calculation shows that changes up(r) and ug (r) are almost exactly the differences between percentage changes in *nominal* PRIVEXP and GOVEXP (rows 6 and 7, Table 4) and *ppriv* and *pgov* respectively

[13] In terms of the TABLO file, strictly speaking, PRIVEXP and GOVEXP are coefficients which are equal to the levels values of the variables 'yp' and 'yg'. The latter one is added in the original TABLO file for computational conveniences.

[14] According to base-period data, the share of domestic Stuff in government consumption is 96% for USA, 99% for EU and 97% for ROW. This is higher than that in the private sector's consumption —95% for USA, 96% for EU, and 93% for ROW. As well, the regional composition of imported Stuff differs between the two categories of consumption.

(rows 17 and 18, Table 4).

The percentage increases in real private and public consumption demand for composite Stuff are larger than the corresponding increases in domestic supply in every region (rows 5 and 8, Table 4 and row 2, Table 2). In spite of the small percentage increments in the market price of composite imports in USA (0.05) and EU (0.02), this leads to increases in private household *import demands* of 1.35 and 0.7% in USA and EU respectively[15]. The much larger fall in the price of *domestically sourced* Stuff—0.3 percent in USA and 0.19 percent in EU—causes the relative price of domestic- vis-a-vis foreign-sourced Stuff to fall by 0.35 and 0.21 percent in USA and EU respectively. Given the *expansionary effect* on demand (*qp*) for composite Stuff due to the general increase in consumption demand, this leads to substitution in favour of domestic 'Stuff' in USA and EU and reinforces the expansion effect. This is reflected in increases of 2.2 and 1.2 per cent in private consumption demand for domestic Stuff in USA and EU respectively.

As opposed to this, in the case of ROW, a decline in the price of composite imports by 0.05 percent and a rise of 0.12 percent in the price of domestic Stuff causes the relative price of domestic Stuff to increase by 0.17 percent. This leads to substitution in favour of imported stuff with a relatively larger percentage increase (0.5) in demand for foreign composite Stuff as compared to that in domestic stuff (0.07). Since Armington elasticities are the same across uses and regions, similar considerations apply in the case of public consumption. The aggregate utility index [*u(r)*] proxies regional *real* income. In the model, percentage changes in the sub-utility indexes for the public [ug(r)] and private [up(r)] household consumption are equal to the percentage changes in *real* quantities purchased by the representative government and private households respectively. The Cobb-Douglas utility

[15] The share of imports by public and private sectors *together* in aggregate imports of tradable Stuff are 38% for USA, 21% for EU and 22% for ROW. The rest of aggregate imports of Stuff are used as intermediate inputs by firms producing Stuff and CGDS. Firms' demand for composite Stuff as intermediate inputs also changes and this, in turn, affects changes in aggregate region-wide imports of Stuff. We do not discuss this at least for the time-being.

function is *self-dual*[16] as it generates a unit cost function of the same functional form as the *primal*. Following this property, the income deflator [*incdeflator(r)*] for *y(r)* is defined as the sum over the products obtained by multiplying the Cobb-Douglas *price indexes* for each income use viz., *ppriv(r)*, *pgov(r)* and *psave* with their corresponding region-wise shares in total income[17]. Table 6 reports the values of the shares—i.e., PRIVEXP/INCOME, GOVEXP/INCOME, SAVE/INCOME and the *incdefaltor(r)*. Row 4 in Table 6 shows that *incdeflator(r)* preserves the same ranking, sign and order of magnitude as the *ppriv* and *pgov* (rows 17 and 18, Table 4). Subtracting row 4 of Table 6 from row 1 of Table 4, we reproduce, almost exactly, the results on *real income* (row 3, Table 4).

TABLE 6 Budget shares of each income use category and incdeflator [(a)]

Values of:	USA	EU	ROW
1. PRIVEXP/INCOME	0.7711	0.7017	0.6926
2. GOVEXP/INCOME	0.2108	0.2158	0.1515
3. QSAVE/INCOME	0.0181	0.0825	0.1559
4. incdeflator	-0.27	-0.17	+0.09

(a) The shares are calculated from base-period data and hence these are base-case values; under the Cobb-Douglas specification, these are *unchanging* parameters.

Now, the GDP deflator (***pgdp***) is weighted sum of percentage changes in the index of the price of the domestic absorption (***NA_prigne***), in the export price index (***pxw***), in the price index for exports to the international transportation sector (***pm***) and in the aggregate import price index (***pim***)—the weights being the shares in GDP of gross national expenditure (**GNE**), of exports (**VXWD**), of sales to the global transport sector (**VST**), and of imports

[16] The duality between production and cost function is *formally* analogous to the duality between utility and expenditure function—this implies that minimization of total outlay on public and private consumption and saving subject to the specified level of utility will give the same demand equations for these income uses. For a discussion on *'self-duality'* between Cobb-Douglas production and cost function, see Varian (1984) Microeconomic Analysis, 2nd edition, pp. 62-64, and 69-73.

[17] The mathematical expression for *incdeflator (r)* is:

incdeflator (r) = [PRIVEXP (r)/INCOME (r)] ∗ ppriv (r) + [GOVEXP (r)/INCOME (r)] ∗ pgov (r) + [SAVE (r)/INCOME (r)] ∗ psave.

With PSAVE being the *numeraire* in the model, psave = 0 so that the last term in the equation vanishes to yield the price index for income in general.

(**VIWS**)[18]. *pgdp* includes the change in the price of *exportable* Stuff (*pxw*) with a *positive weight* that includes exports rather than just domestic consumption—as in the case of *NA_prigne*. Also, *pgdp* includes '*pim*' with a *negative weight*. Hence, the percentage increase '*pim'* and the percentage fall '*pxw*' lead to a more negative change in *pgdp* than *NA_prigne*. Now, the consumption deflators include the price of imports with *positive weight*. These consumption deflators are included in *NA_prigne* and thus, it includes the import price index with a positive weight.

TABLE 7 Component-wise effects on pgdp [(a)]

Share weighted values of:	USA	EU	ROW
1. GNE deflator [=NA_prigne* GNE/GDP]	-0.278	-0.180	+0.101
2. Price of exports [=pxw × Exports/GDP]	-0.029	-0.020	+0.025
3. Price of imports [= pim × Imports/GDP]	+0.005	+0.002	-0.010
4. Price of exports for global transportation sector[=pm×VST /GDP]	-0.001	-0.003	+0.001
5. Percentage changes in GDP price deflator [pgdp = (1)+ (2)+ (4)-(3)]	-0.313	-0.205	+0.137

(a) Calculated from base-period data. Figures in row 5 match the figures in row 2 in Table 4 when we do 'rounding' to 2 decimal places.

From Table 7, it is evident that the difference between *pgdp* and *NA_prigne* clearly relates to the percentage deviation of the terms-of-trade (*TOT*) from the control scenario[19]. The fall in TOT in USA and EU does not cause CPI, *pgov* and hence, *NA_prigne* to fall as much as *pgdp*—see rows 1 and 5 in Table 7. This implies that a decline in TOT implies a *rise* in the consumption deflators (which include price of imports) *relative* to *pgdp* (which includes price of exports) in these regions.

[18] The GDP deflator, *pgdp*, can be broken down into the following components as below:
pgdp= NA_prigne*(GNE/GDP)+ pxw*(VXWD/GDP)+ pm*(VST/GDP)—pim*(VIWS/GDP)
It is to be noted that 'pm' and 'pxw' are the same. Nominal domestic absorption, GNE(r) is expressed as: GNE(r)= PRIVEXP(r)+GOVEXP(r)+REGINV(r). Thus, the GNE deflator is:
NA_prigne (r)= ppriv (r)∗ [PRIVEXP(r)/GNE (r)] + pgov (r)∗[GOVEXP(r)/GNE (r)] +
pcgds (r)∗ [REGINV (r)/GNE (r)]

[19] After some algebraic manipulation, we can re-write the expression in Footnote 18 as:
pgdp–NA_prigne=[pxw*{(VXWD+VST)/GNE}]–[pim*(VIWS/GNE)]–pgdp*(TradeBalance/GNE)]
In the case of *balanced trade*, VXWD+VST=VXW=VIWS, this equation becomes:
pgdp–NA_prigne = (VIWS/GNE) (pxw – pim). Also, in case of balanced trade, GNE (r)=GDP (r). Thus, multiplying both sides of the above expression by [GNE/GDP], we re-write it as:
pgdp–NA_prigne = [pxw–pim]∗[VIWS/GDP] = [VXW/GDP] ∗ [pxw–pim]
The variable (pxw – pim), the percentage change in the ratio of export prices to import prices, is a conventional measure of the change in the terms-of-trade. Although the GTAP standard TOT definition also includes the price of the non-traded regional investment goods, QO(CGDS, r), here we use the more conventional definition introduced above.

Similar considerations explain relatively larger percentage changes in *pgdp* relative to *NA_prigne* and the consumption deflators in case of ROW. We now elaborate the trade competition in the wake of relative price divergences.

5.2.b Regional composition of International Trade

Due to the Armington specification of commodity substitution, even in a world with one generic traded-commodity in every region, the relative price divergences (between the three varieties of Stuff) across regions (after the TFP shock) induce changes in regional TOT and open up the scope for inter-regional competition via trade. Consequently, these lead to changes in the regional composition of exports and imports depending, *inter alia*, on the movements in TOT. Looking at the global economy as a whole, we observe that after the shock there has been an increase in the quantity index of *global* merchandise exports and imports of Armington substitutable Stuffs by 0.57%[20]. However, ROW experiences a small percentage rise in the price of domestically produced Stuff as compared to *relatively large* percentage falls in the prices of Stuff exported by USA and EU (as explained in subsections 5.1 and 5.2.a). Thus, the price index of *global* merchandise exports of Stuff *[pxwcom(Stuff)] falls* by 0.02%.[21] Similar considerations explain the percentage fall in the index of world prices of total supplies of Stuff *[pw (Stuff)]*.[22]

Decomposition of region-specific differential TOT effects identifies the forces behind such changes. We follow the decomposition *à la* McDougall (1993)[23] where the percentage change in regional terms of trade [*tot (r)*] is split into two components as below:

$$tot(r) = px(\bullet, r) - pm(\bullet, r) \qquad (5.2.1)$$

[20] The calculation involves multiplying region-wise shares of exports of Stuff in aggregate worldwide exports (at *fob* prices) by the corresponding percentage increases in regional aggregate volume of exports of Stuff and summation over the products thus obtained. ROW has a higher share (62 percent) in total world exports of Stuff than USA (17 percent) and EU (21 percent). Thus, 0.57 = (1.71×0.17)+(1.19×0.21)+ (0.05 × 0.62).

[21] This is calculated as: (0.17 × -0.30) + (0.21 × -0.19) + (0.62 × 0.12)]. The price index of world trade *[pxwwld] falls* by 0.02 percent as well (similar calculations are involved).

[22] The base-case shares of value of output of Stuff of each region at world prices (*fob*) in total world supplies of Stuff are 49, 24 and 27 percent respectively for ROW, USA and EU. Thus, the magnitude is[(0.24 × -0.30) + (0.27 × -0.19) + (0.49 × 0.12)]= – 0.065.

[23] As noted above, we adopt the conventional definition of TOT *à la* McDougall (1993) as opposed to the definition used in standard GTAP theory—the reason being that the TOT definition in the latter includes the price of CGDS which is a purely non-traded sector produced and sold in the local market only.

where $px(\bullet, r)$ is the percentage change in the price received for exports and $pm(\bullet, r)$ is the percentage change in the price paid for imports. Suppose $pxw(i, r)$ and $piw(i, r)$ are respectively the percentage changes of the export and import prices of traded commodity 'i' in any region 'r', and $EXP\_SHR(i, r)$ and $IMP\_SHR(i, r)$ are respectively the export share of commodity 'i' in total export expenditure and import share of commodity 'i' in total import expenditure in any region 'r'. Thus,

$$px(\bullet, r) = \sum_i EXP\_SHR(i, r)\, pxw(i, r) \qquad (5.2.2a)$$

and

$$pm(\bullet, r) = \sum_i IMP\_SHR(i, r)\, piw(i, r) \qquad (5.2.2b)$$

Then the above expression for region r's terms of trade can be written as:

$$tot(r) = \sum_i EXP\_SHR(i, r)\, pxw(i, r) - \sum_i IMP\_SHR(i, r)\, piw(i, r)$$

With further manipulation following McDougall (1993), this expression yields:

$$tot(r) = \sum_i (EXP\_SHR(i, r) - IMP\_SHR(i, r))\,(pw(i) - pxwwld)$$
$$+ \sum_i EXP\_SHR(i, r)\,(pxw(i, r) - pw(i))$$
$$- \sum_i IMP\_SHR(i, r)\,(piw(i, r) - pw(i)) \qquad (5.2.3)$$

where $pw(i)$ is the world price index for total supplies of good 'i' and *pxwwld* is the price index of world trade (average of world prices of merchandise exports). The first term on the right of (5.2.3), *Wpe*, captures the world price effect, whilst the last two terms show the export price effect *(Xpe)* and the import price effect *(Mpe)* respectively.

'*Wpe*' shows that if the world price of commodity 'i' falls/rises relative to the average of all world commodity prices [i.e., $pw(i) \neq pxwwld$], then, depending on the sign of the regional *nett* trade share of good 'i', the direction of movement of regional TOT will be determined. If 'r' is a nett exporter of 'i', and the world price of 'i' in general (i.e., averaged over the sources) inflates relative to all prices, then, *ceteris paribus*, this is good for region 'r'.

'*Xpe*' shows that if in any region, the exporters' price of good 'i' falls relative to the world price of 'i' [i.e., $pw\ (i) \neq pxw\ (i,\ r)$], then TOT will deteriorate. Besides the size of the shock, the extent of changes in such relativities [measured by ($pxw\ (i,\ r) - pw\ (i)$)] reflect the degree of product diversification in the market for 'i' (*à la* Armington assumption). With low Armington elasticities, *ceteris paribus*, the spread between the two prices will tend to be larger. By contrast, with a very large substitution elasticity, the absolute difference between $pxw(i,\ r)$ and $pw(i)$ tends to be smaller so that they are almost equal. If there is erosion of competitiveness following a shock, the large Armington elasticity coupled with the loss in competitive edge can lead to big loss of export shares of a region and consequently, can have adverse effect on TOT. That is, there may be a large fall in EXP_SHR(i,r) – IMP_SHR(i,r) between the base case and the post-shock solution.

'*Mpe'* captures the effect of divergences [$piw(i,\ r) - pw(i)$]between the region-specific import price of good 'i' and the world price of 'i' : it shows that if the latter rises more than the former, then TOT will improve if there are no offsetting changes in *'Wpe'* and *'Xpe'*.

In a one-traded-commodity world, since *EXP_SHR (Stuff, r)* is identical to *IMP_SHR (Stuff, r)* and both are equal to *unity*, the first term on the right of *Equation (5.2.3)* for *tot (r)* vanishes, so that this expression simplifies to the following:

$$tot(r) = pxw(stuff,\ r) - piw(stuff,\ r) \qquad (5.2.4)$$

Thus, in Table 8, *'Wpe'* is zero across all regions. The intuition behind this result is that *'Wpe'* is meant to capture *inter-generic-commodity competition,* of which there is none in this one-commodity version of GTAP. Since the share of Stuff in every region's exports is unity, *'Xpe'* shows in its entirety the effect of changes in the *export supply* price of Stuff in a region relative to an index of the average world price of Stuff. Analogously, *'Mpe'* totally captures the effect of changes in the region-specific *import demand* price relative to the world price.

TABLE 8 Decomposition of percentage changes in regional TOT[a]

GTAP Region	World price effect (Wpe) (1)	Export price effect (Xpe) (2)	Import price effect (Mpe) (3)	Total TOT effect [tot(r)] (4)= (1)+(2)−(3)
USA	0.00	-0.23	+0.12	-0.35
EU	0.00	-0.12	+0.09	-0.21
ROW	0.00	+0.18	+0.01	+0.17

(a) We have rounded percentage changes to 2 decimal places.

Table 8 shows that in all three regions, '*Xpe'* is the most important source of the change in TOT. The changes in regional export volumes can be ascribed to two-fold movements: *along* the export demand schedule and *shifts* of the demand curve.

As the individual regions as exporters of Stuff face downward sloping foreign demand curves for their region-specific Stuffs, a fall in the price of exports in USA and EU (as opposed to a rise in the case of ROW) is consistent with percentage rises in exports from USA and EU which are larger than the percentage expansion of exports from ROW to both of these regions—see row 14 in Table 4. In part, this has been caused by the movements *along* the export demand curve governed by the changes in price relativities between regions. Now, the expansion in activity level (i.e., increase in regional aggregate import demand) in each region results in outward *shifts* of the regional export demand curves. These changed trading conditions entail allocation of demand for *aggregate* composite imports of Stuff by a region across different sources of imports depending on *relative price* changes. Given the expansionary effect on demand for *all* imports of Stuff [*qim (stuff,r)*] by any region 'r' due to the increase in *intermediate input demand* for it by firms producing Stuff and CGDS as well as that in *final demand* by the public and private sectors (explained before in subsection 5.2.a), changes in relativities between the price of imported Stuff from any source 'k' (*pms (stuff,k,r)*) and the aggregate import price index (*pim (stuff, r)*) confronting 'r' determine changes in source-specific import demand by any region.

As products are differentiated by origin, divergences between the export prices for Stuff produced in any region and the average world price for Stuff have given rise to changes in TOT. Taking any region 'r' as the destination of exports of Stuff from two sources viz., 's' and 'k', *given* the Armington elasticity, the expansionary effect on aggregate imports of stuff (*qim (stuff, r)*) and the import share of 'k' in aggregate imports of 'r', then import of Stuff from 's' to 'r' [*qxs (i,s,r)*] depends on the changes in relativities between the price of imports of stuff from 'k' vis-a-vis that from 's'[24]. We discuss the change in *composition* of bilateral export sales which is contingent on these shock-induced relative price effects.

Aggregate imports into the USA increase by 1.0108 percent. In USA, the market shares of EU and ROW in aggregate imports of tradable Stuff are 18 and 82 percent respectively. A relatively large decline (0.183%) in the price of imported Stuff from EU to USA as compared to a rise (0.104%) in case of imports from ROW to USA causes a 2.2 percent increase in imports of Stuff in USA from EU, whereas imports from ROW to USA rise by 0.75 percent only. Given identical Armington elasticities across all regions (all equal to 5), this translates into an increase in demand for Stuff from EU even though initially EU has a lower export share in USA than ROW.

In the case of EU, aggregate imports increase by 0.4951 per cent, while the market shares of USA and ROW in total imports are 20 and 80 percents respectively. The decline in '*pms'* for USA (0.29%) as opposed to an increase (0.1%) in case of ROW translates into a relatively larger increase of exports from USA (2.1%) to EU than in case of ROW (0.10%).

In its own market, ROW (a composite region) supplies 52 % of its total import demand whereas USA and EU supply 22 and 26 % respectively[25]. USA and EU export respectively 73 % and 83 % of their total bilateral exports (i.e., excluding exports to the

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[24] In GTAP, we assume that imports of region 'r' from region 's' are exactly the same as the exports of region 's' to 'r'. Hence, the percentage change in demand for exports of 'i' from 's' to 'r' can be expressed as:
qxs(i, s, r)=qim(i, r)– ESUBM∗MSHRS (i, k, r)∗[pms (i, s, r)–pms(i, k, r)] , where k ≠ s.
where MSHRS (i, k, r) is the share of imports from 'k' to 'r' in aggregate imports from both 'k' and 's' to 'r' and ESUBM (=5 in the database) is the Armington elasticity for imports from sources 'k' and 's'. Thus, we can write MSHRS (i, k, r)+ MSHRS (i, s, r)=1.

[25] For ROW as composite region supplying in its own market, the equation in Footnote 24 can be modified as below:
qxs (i, s, r)= qim (i, r)–ESUBM∗MSHRS (i, k, r)∗[pms (i, s, r) – pms (i, k, r)]
– ESUBM∗MSHRS (i, j, r)∗[pms (i, s, r) – pms (i, j, r)] where s ≠ j ≠ k are different *sources* of exports to *destination* 'r'. In case of intra-regional exports, r = s, say, then the above equation can be expressed as:
qxs (i, r, r)= qim (i, r)–ESUBM∗MSHRS (i, k, r) ∗ [pms (i, r, r) – pms (i, k, r)]
– ESUBM∗MSHRS (i, j, r) ∗ [pms (i, r, r) – pms (i, j, r)] where r ≠ j ≠ k.

global transportation sector) to ROW whereas for ROW the intra-regional export is 49%. In ROW, USA faces competition from composite region ROW itself (supplying 52% of total imports) and EU (supplying 26% of its imports). In the post-simulation scenario, ROW experiences a rise in the market price of Stuff by 0.12%. The rise in the price of imports of composite Stuff from its own constituent regions is 0.103%. USA as the source of innovation experiences the maximum fall in the relative price of its Stuff after the HNTP shock. Now, the price of imported Stuff from USA to ROW fell by 0.283 % whereas it fell by 0.183 % in case of imports from EU. This led to a relatively larger percentage increase in export sales from USA to ROW (1.6) as compared to that in export sales from EU to ROW (1.1). On the other hand, the rise in the price of intra-regional imports from constituent regions by 0.103% causes a decline in intra-regional exports in ROW by 0.33 per cent[26]. Table 9 displays all these figures for percentage changes in bi-lateral export sales.

Table 9 Simulated effects on bilateral export sales

To / From	USA	EU	ROW
USA	0.00	2.05	1.60
EU	2.20	0.00	1.09
ROW	0.75	0.10	–0.33

Sectoral performance is described below.

5.2 Sectoral Effect: Effects on Traded 'Stuff' Sector

Our foregoing discussion documents that for each region, marginal productivity of 'raw' primary composite factor inputs (in conventional units), real value-added in *effective units* and production of Stuff go up exactly by the same percentage as the TFP improvement. Demand for *real* value-added measured in *conventional units* does not change (see row 6, Table 2). Effective price of value-added (quality-adjusted) declines in USA and EU and rises in ROW. More pronounced TFP changes lead to a more productive primary factor composite and to *falling costs* in USA and EU.

[26] These calculations are: *for USA as the source*, 1.588=0.462–5 × 0.26 × [-0.283 – (–0.183)]–5 × 0.52 × [–0.283 – (+0.103)]; *for EU as the source*, 1.09 = 0.462–5×0.22×[-0.183–(–0.283)]–5 × 0.52 × [(–0.183–(+0.103)]; *for ROW as the source*, –0.33 = 0.462–5 × 0.26 × [0.103 – (–0.183)]– 5 × 0.22 × [0.103 – (– 0.283)].

Stuff is produced combining the value-added composite and composite material inputs of Stuff using the Leontief technology at the top nest of the production tree (where intermediate inputs and value-added are *not* substitutable). Due to the expansionary effect of an increased demand, increased production of Stuff entails an equivalent increase in *intermediate input demand* [*qf (stuff, stuff, r)*]going into its *own* production in each region—i.e., 2, 1.07 and 0.05% in USA, EU and ROW respectively.

The percentage falls in the price indexes for purchases of domestic 'Stuff' as intermediate input [*pfd (stuff, stuff, r)*]—0.3 % in USA and 0.19 % in EU—are relatively larger than percentage increments in price indexes of composite imports of foreign-sourced Stuff [*pfm (stuff, stuff, r)*]—0.05 in USA and 0.02 in EU. Given *qf (stuff, stuff, r)*, the decline in relative price of domestic vis-a-vis foreign sourced Stuff—0.35 % in USA and 0.21 % in EU—leads to substitution in favour of domestic intermediate stuff.[27] Thus, the Armington structure causes a larger percentage increase in intermediate input demand for *domestic* Stuff [*qfd (stuff, stuff, r)*] i.e., 2.07 and 1.13 % in USA and EU respectively. For demand for the composite import of Stuff [*qfm (stuff, stuff, r)*], these are 1.19 (USA) and 0.604 (EU).[28]

The decline in relative price of composite imports vis-a-vis domestic Stuff by 0.17 % in ROW results in a 0.41 % increase in intermediate input demand for imported Stuff whereas intermediate input demand for domestic Stuff falls by 0.01 %. In all regions domestically-sourced stuff has a much larger share than the foreign-sourced stuff in its production (row 3, Table 10). The supply price of Stuff depends on the *pva* components and price of intermediate Stuff. Now, the price of value-added in constant efficiency units falls in USA and EU and rises in ROW (see row 9, Table 2). Also, the price of intermediate input Stuff falls in USA and EU and rises in ROW. Consequently, the zero-pure-profits equation

---

[27] Intermediate input demand for domestic Stuff by firms producing Stuff can be written as:
qfd = qf−ESUBD∗ [1−FMSHR]∗[pfm−pfd] where FMSHR is share of composite import of Stuff going into its production. Analogously, firms' demand for imported Stuff is given by:
qfm = qf−ESUBD∗ [FMSHR]∗[pfd−pfm]. ESUBD (=2.5 in the database) is the Armington elasticity.

[28] These calculations are: for USA, 1.19=2−2.5 × 0.922 × (+0.35); for EU, 0.604=1.07−2.5 × 0.8866 × (+0.21).

determines that the industry price of composite tradable Stuff falls in USA and EU and rises in ROW.

TABLE 10 Simulated regional effects of technology shock on Stuff [(a)]

Percentage change in:	USA	EU	ROW
1.Output of Stuff	2.00	1.07	0.05
2.Supply Price of Stuff	-0.30	-0.19	+0.12
3.Share of domestically-sourced stuff	0.92	0.89	0.85
4.Share of foreign-sourced stuff	0.08	0.11	0.15
5.Demand for imported Stuff as an input	1.18	0.59	0.41
6. Demand for domestic Stuff as an input	2.07	1.13	-0.02

(a) Figures are rounded upto 2 decimal places.

6. Conclusion

In this paper, embodied technology spillovers through bilateral trade linkages have been analyzed within the GTAP framework. The analysis is embedded in a setup where each region produces a traded ‘Stuff’ along with a non-traded capital good. However, the Armington assumption of product differentiation by origin opens the scope for international trade in the source-specific ‘Stuff’. Embodied technology spillover occurs via bilateral trade in Stuff between source (viz., USA) and destination (viz., EU and ROW). Absorption capacity (AC) and structural congruence (SS) jointly determine a capture-parameter which, together with the trade volume, *endogenize* the spillover coefficient. We considered an exogenous 2% value-added augmenting TFP shock in the source country USA. Following the shock, the higher value of the capture parameter in EU allows this region to realise a high percentage of the potential productivity improvement, whereas ROW experiences a relatively less pronounced TFP improvement despite a larger proportional stimulus in imports from USA than that from EU.

The TFP shock leads to an increase in the marginal productivity (in conventional units) of the ‘raw’ primary factor composite in all three regions whilst the effective price of value-added (quality-adjusted) declines in USA and EU. Owing to the Armington structure and identical Armington elasticities across uses and regions, the relatively larger percentage falls in the price indexes for the purchases of domestically sourced Stuff as compared to the percentage rises in the price indexes of composite imports of foreign-sourced stuff, resulted in substitution in favour of domestic stuff in USA and EU. On the other hand, the decline in the relative price of foreign composite imports and an increase in the price of domestic stuff in ROW cause substitution in favour of imported Stuff. Given the expansionary effects due to increased general activity levels, changes in the price relativities between regions alter the trading conditions.

Divergences between the export supply price of Stuff in the regions and its average world price have led to changes in regional terms of trade. Thus, the rise in the price of Stuff in ROW erodes its competitive edge in the global market for Stuff. In particular, a decline in the price of exports in USA and EU translated into a larger percentage expansion of exports from USA and EU to ROW than that from ROW to both of these regions. ROW loses its export share in its own market. With no scope for inter-generic-commodity competition, the terms-of-trade effect predominantly reflects the export price effect.

Given the general–equilibrium relative price effects, a higher percentage increase in the value of exports than in the value of imports in both USA and EU has caused their initial trade deficits to decline. For ROW, the TFP shock causes the value of imports to rise by a larger proportion than that of its exports leading to a fall in its initial trade surplus. Thus, *trade creation* between the regions is manifest as an increase in bilateral and global trade volumes. However, in the case of the composite region ROW, the loss in competitiveness has caused *trade diversion* and a resultant loss in the export share in its own market.

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APPENDIX

In this appendix, we document the aggregation method, set definitions, parameter settings and associated files as used in the implementation of a one-sector, three-region macro model. The economic model is the one described in Hertel (ed.) [1997], with some additional equations, coefficients, and variables as described in the main text.

A.1 Set Modifications

Text file SET1BY3.TXT written in the WINGEM text editor is used in running the MODHAR program interactively to create SET1BY3.HAR file.

SET 1BY3.TXT

```
!New Set File for 1 Traded &1 Non-traded goods CGDS in a macro-model GTAP !
3 Strings Length 12 Header "H1" Longname
"Name of The Regions";
USA
EU
ROW
1 String Length 8 Header "H2" Longname
"Name of The One Commodity";
Stuff
5 Strings Length 8 Header "H3" Longname
"Set of NSAV_COMM";
Land
Labor
Capital
Stuff
Cgds
4 Strings Length 8 Header "H4" Longname
"Set of Demanded Commodities";
Land
Labor
Capital
Stuff
2 Strings Length 8 Header "H5" Longname
"Set of PRODUCED COMMODITIES";
Stuff
Cgds
3 Strings Length 8 Header "H6" Longname
"Set of ENDOWMENT COMMODITIES";
Land
Labor
Capital
1 String Length 8 Header "H7" Longname
"Set of ENDWS_COMM";
Land
2 Strings Length 8 Header "H8" Longname
"Set of ENDWM_COMM";
Labor
Capital
1 String Length 8 Header "H9" Longname
"Set of ENDWC_COMM";
Cgds
```

Table A.1.1 displays a list of the SETS of Regions (REG) and tradable commodity (Stuff alone), TRAD_COMM, as well as endowment commodities, ENDW_COMM, and non-tradable capital goods, CGDS_COMM. TRAD_COMM and CGDS_COMM constitute the set of produced commodities, PROD_COMM. TRAD_COMM belongs to the set of Demanded Commodities, DEMD_COMM which comprises land, labor, capital endowment commodity and Stuff. CGDS_COMM is subset of PROD_COMM and 'capital goods' does not belong to the Set DEMD_COMM. "Stuff" belongs to a super set containing *non-savings* commodities, NSAV_COMM. NSAV_COMM comprises the Sets viz., TRAD_COMM, PROD_COMM, ENDW_COMM, DEMD_COMM and the Set CGDS_COMM. ENDWS_COMM is the set of sluggish factor i.e., land and ENDWM_COMM comprises the mobile factors labor and capital.

TABLE A.1.1 Definition of Regions and of Commodities in 1x3GTAP

Set REG	Set NSAV_COMM
USA European Union (EU) Rest of the World (ROW)	Land, Labor, Capital [ENDW_COMM] Stuff [TRAD_COMM] Capital Goods [CGDS_COMM] Stuff, Capital Goods [PROD_COMM] Land, Labor, Capital, Stuff [DEMD_COMM]

For our purpose, three different header array (.HAR) files are created for each of the three regions as sources of invention. These files corresponding to three individual sources viz., USA, EU and ROW are SRCUSA.HAR, SRCEU.HAR, and SRCROW.HAR respectively. This is useful for implementing these regions as different sources of invention. By choosing the name of the header array file (.HAR) relevant for our simulation corresponding to the logical name SETINFO in the Command file (.CMF), one can implement the simulation for a specific source of invention. In the current treatment, set SRC contains USA (as the only source of innovation) and the set REG_NOT_SRC (generated directly by TABLO–see below) contains the destinations EU and ROW and therefore, we select SRCUSA.HAR as the SETINFO file in the CMF file. Modification in the SET specifications in the TABLO file is given in Table A.1.2.

TABLE A.1.2 Modification for set definitions in TABLO File

SET SRC # Sources of Invention- Countries # SUBSET SRC is subset of REG SET REG_NOT_SRC=REG-SRC

A.2 Appended Variables and Equations[Ψ]

The equation that has been appended and implemented in our analysis is described in the text (vide Sections 2.2b and 4.1 in the text). Apart from these, we defined the following variable and equation for sake of explaining the result:

```
VARIABLE(All,r,REG)                    Tec_Chg(r);
 !Value-added-share weighted Value-added Augmenting   Technical change!
EQUATION E_Tec_Chg
(All,r,REG)    Tec_Chg(r)=sum(j,PROD_COMM,(VA_Share(j,r)*ava(j,r)));

(All,r,REG)   Sum(i,ENDW_COMM, VOA(i,r)) * NA_gdpfc(r)
                    = Sum(i,ENDW_COMM,(VOA(i,r)*[qo(i,r)+ps(i,r)]));
```

[Ψ] A complete list of variables including those additional ones appended are not provided here for want of space; those are available from the author on request.

A.3 Additional Parameters:

The additional parameters in the original TABLO file are

COEFFICIENT (all, s, REG_NOT_SRC) HK (s) !The Destination-specific Human Capital Index parameter!
COEFFICIENT (all, r, SRC) (all, s, REG_NOT_SRC) SS (r,s) !The Binary Structural similarity Index parameter in the Spillover function !

The values of these parameters are chosen arbitrarily in the parameter file viz., AGPAR1X3.DAT for this aggregation.

A.4 Additional Coefficients:

The following Boxes show the additional coefficients encoded in TABLO language.

Box 1

```
COEFFICIENT  (all,i,TRAD_COMM) (all,r,SRC) (all,s,REG_NOT_SRC)
EMBINDEX(i,r,s)
!The Embodiment Index of Bilateral Technology Flows via Trade!;
FORMULA
(all,i, TRAD_COMM) (all,r,SRC) (all,s,REG_NOT_SRC)
EMBINDEX(i,r,s)=VXWD(i,r,s)/VOW(i,s);

COEFFICIENT  (all,i,TRAD_COMM) (all, r, SRC) (all,s,REG_NOT_SRC)
SPLCOEFFT(i,r,s)
!The Value of Spillover Coefficient of Source vis-a-vis Destinations !;
FORMULA
(all,i,TRAD_COMM) (all,r, SRC) (all,s,REG_NOT_SRC)
SPLCOEFFT(i,r,s)= (EMBINDEX(i,r,s))^(1-HK(s)*SS(r,s));

COEFFICIENT (All,j,PROD_COMM) (All,r,REG)                VA_Share(j,r);
  ! Share of Value-Added by Sector 'j' in Region 'r' in Total Value-Added in 'r'!
FORMULA(All,j,PROD_COMM)(All,r,REG)
VA_Share(j,r)=
(sum(i,ENDW_COMM,EVFA(i,j,r)))/(sum(i,ENDW_COMM,VOA(i,r)));
```

The first one in Box 1 corresponds to Equation (2.4) and the second one to Equation (2.7a) as documented in section 2 in the text. They have three subscripts corresponding to $i \in$TRAD_COMM, $r \in$SRC, $s \in$REG_NOT_SRC. VXWD(i,r,s) is the value of exports of traded commodity 'i' from 'r' to 's' evaluated at world prices. VOW(i,s) is the value of output in 's' evaluated at world prices, too. Ratio of these two gives the index for embodied technology spillovers from 'r' to 's' via trade (E_{rs}). 'SPLCOEFFT' measures the value of actual spillovers to recipients 's' [$\gamma_s(E_{rs}, \theta_s)$] depending on the values of HK(s) and SS(r,s). The third one defines the share of each value-adding sector (in our case, it is Stuff) in the region wise aggregate value-added. This has been added to capture the effect of value-added augmenting technical change in a particular sector on its share in value-added. In other words, the product of this share and the magnitude of value-added augmenting technical progress yields the region-wide technical change variable [Tec_Chg(r)].

Other coefficients are appended in the existing national accounts reporting module for sake of facilitating the computations of some macroeconomic variables. All these coefficients are not reported.

A.5 Encoded Computer Model and Software

The economic theory underlying the GTAP model is encoded in TABLO language based on FORTRAN programme. The model that we have used for the experiment is in TABLO input file named GTAP94.TAB. The model is solved using the TABLO facility of the GEMPACK software developed in MONASH [see Harrison and Pearson (1996)]. The system of linearised equation was solved using the Windows version of GEMPACK software [WINGEM]. Harwell sparse matrix code (Duff, 1997) is essential in any TABLO implementation. GTAP solutions are obtained using the 2-4-6 GRAGG method, mid-point solution procedure with extrapolation accuracy.

A.6 Generating Aggregated Data Base

The **INPUT files** created for running the data aggregation programme DAGG, in conformity with the three steps described in the text are as follows:

A.6.1 MAP1X3.TXT: the Text file containing the Mapping Vector (written in either ROW, or COLUMN order) for three Commodities to one Stuff. This has been used to create the SUPPLEMENTARY file "**SUP1X3.HAR**" by MODHAR (running interactively). This HAR file describing the integer-mapping vector is used along with the Original DAT2-01.HAR file for 3x3 GTAP to create in the first stage of DAGG run a file named **1x3GDAT.HAR**. This **'.HAR'** file contained partial aggregation. The file **DAGG.INP** contains all the input commands for this first run. The text file is produced below

```
! This Text File is used to create the SUP file "MAP1x3.HAR" used by DAGG in the Aggregation of
GTAP3x3 to 1 sector called "STUFF" ( MACRO MODEL)!
!Following Mapping Vector is size 3 in column order to the header array "smap"(longname, stuff
mapping) of MAP1x3.HAR.!

3 1 integer  col_order
HEADER "smap" LONGNAME "TRAD_COMM MAPPING";
1 1 1
! Next is "PROD_COMM" Mapping And Includes "CGDS" as  Non-Traded good!
4 1 integer  col_order
HEADER "cmap" LONGNAME "PROD_COMM MAPPING";
1 1 1 2
```

A.6.2 DAGG.INP Files: this is used in the initial run of DAGG using the command **—** *DAGG<DAGG.INP> DAGG.LOG***.**

This produces a LOG file containing the information on whether the implementation is 'correct'. 'SMAP' and 'CMAP' in the file DAGG.INP refers to the HEADERS corresponding to 'STUFF' (Trad_Comm) and PROD_COMM mappings. In the second run, another DAGG2.INP file is written for performing the task of complete aggregation for our purpose. This takes as input the HAR file created in the first run (1x3GDAT.HAR) to create the aggregated database in AGGRN1X3.HAR corresponding to the mapping vector in SUP1X3.HAR file.

The command used for the second run is the same as the earlier one.

Such files are given below:

DAGG.INP

```
DAT2-01.HAR   !EXISTING HAR FILE FOR 3X3 GTAP
1X3GDAT.HAR !NEW FILE for Aggregated 1x3 IMPLEMENTATION
SUP1X3.HAR    !SUPPLEMENTARY FILE FOR INTEGER MAPPING VECTOR

 REMAP      EVFA      3X4X3        2 cmap 2
 REMAP      VDFA      3X4X3        2 cmap 2
 REMAP      VDFM      3X4X3        2 cmap 2
 REMAP      VDGA      3X3          1 smap 1
 REMAP      VDGM      3X3          1 smap 1
 REMAP      VDPA      3X3          1 smap 1
 REMAP      VDPM      3X3          1 smap 1
 REMAP      VFM       3X4X3        2 cmap 2
 REMAP      VFM2      3X4X3        2 cmap 2
 REMAP      VFM3      3X4          2 cmap 2
 REMAP      VIFA      3X4X3        2 cmap 2
 REMAP      VIFM      3X4X3        2 cmap 2
 REMAP      VIGA      3X3          1 smap 1
 REMAP      VIGM      3X3          1 smap 1
 REMAP      VIMS      3X3X3        1 smap 1
 COLLAPSE    VIPA      3X3          1
 COLLAPSE    VIPM      3X3          1
 COLLAPSE    VIWS      3X3X3        1
 COLLAPSE    VST       3X3          1
 COLLAPSE    VST2      3X3          1
 COLLAPSE    VST3      1X3          2
 COLLAPSE    VXMD      3X3X3        1
 COLLAPSE    VXWD      3X3X3        1
 COLLAPSE    XMD1      3X3X3        1
 COLLAPSE    XMD2      3X1X3        1
 COLLAPSE    XMD3      3X3          1
 COPY
! For Headers 'SAVE', 'VDEP', 'VKB' which need not be aggregated for our purpose (Aggregation to one Commodity), the "COPY" COMMAND transfers all unmodified data items from the OLD to the NEW file!
```

DAGG2.INP

```
1X3GDAT.HAR !HAR file for 1st round aggregation using DAGG.INP and input in 2nd
                  round
AGGRN1X3.HAR  !output file with complete aggregation of GTAP33 to GTAP1x3
SUP1X3.HAR    !supplement. file-unused in this round, but used in 1st round

COLLAPSE   VDFA  3X2X3  1
COLLAPSE   VDFM  3X2X3  1
COLLAPSE   VIFA  3X2X3  1
COLLAPSE   VIFM  3X2X3  1
COPY
! For Other 'HEADERS' Which Need Not Be Aggregated/Changed in the Second Round, 'Copy' command will transfer them UNMODIFIED in the 'new' Complete Aggregated file AGGRN1X3.HAR !
```

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Helpful comments and suggestions from Matthew Peter and Philip Adams of the Centre of Policy Studies, Monash University, at various stages of this particular work, are appreciated. The research benefited from the financial help of Monash Graduate Scholarship and Overseas Post-Graduate Research Scholarships. The usual caveat applies.

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