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Impact of Switching Production to Bioenergy Crops:
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Abstract

This paper reports the results of a series of simulations that evaluate the general equilibrium effects of substituting crude oil by biomass, specifically switchgrass, in the production of petroleum in the USA. The simulations are inspired by debates over the implications for developing countries if agricultural policies in the USA are changed so that agricultural land is transferred from the production of cereals and other crops to biomass production. The results confirm expectations that such a policy shift would raise cereal and other agricultural prices, due to a general reduction in food production in the USA. However, the reduction in the demand for crude oil in the USA causes terms of trade effects that more than offset any potential benefits for developing countries due to the depreciation of their exchange rates, causing a general decline in economic welfare. Moreover, the declines in welfare are proportionately greater for developing countries due to their small levels of production of the commodities whose prices increase with the change in USA agricultural production.

Keywords: Biomass; Energy; Computable General Equilibrium; USA agricultural policy.

JEL numbers: Q42; Q43; D58; Q18.

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INTRODUCTION

The last 20 years has witnessed a growing level of concern about the role of carbon emissions from the use of fossil fuels and the consequent implications for global warming. While there remain doubts about the conclusiveness of the evidence linking fossil fuel use to global warming, a broadly based consensus has emerged that the level of global use of fossil fuels is dangerously high. The most visible manifestation of this consensus is the Kyoto agreement. The analysis reported in this paper evaluates the effects of substituting a biomass product, in this case switchgrass, for crude oil in the production of petroleum in the USA. Specifically the analyses focus upon the global general equilibrium implications; this is achieved by using a multi-region computable general equilibrium (CGE) model with detailed commodity markets.

If the USA adopts a policy of encouraging the substitution of crude oil by biomass products this may have substantial effects upon the agricultural industry since an expansion of switchgrass production will affect other agricultural sectors in the economy through factor market, particularly land, linkages. Programs that expand biomass production may allow the USA to adopt agricultural policies that provide support for farmers through avenues that introduce a lower level of distortion to global agricultural markets. Indeed, since the USA is a major exporter of agricultural commodities, an increase in biomass (e.g. switchgrass) production may also involve a reduction in the production of traded agricultural commodities that will affect global agricultural markets. Of particular interest are the implications for developing countries that have arguably been most adversely affected by the agricultural support policies of developed market economies.

A priori it might be expected that the withdrawal of land from conventional agricultural production for use in biomass production would have beneficial effects upon developing countries; provided it allows a reduction in agricultural support in the USA. Specifically a reduction in the land area in the USA used for conventional agricultural production might be expected to contribute to an increase in agricultural commodity prices, and thereby to welfare gains in developing countries. However, substituting biomass for crude oil will have direct effects on the market for crude oil, and may have indirect effects on the global markets for agricultural products. It is this interaction between the markets for agricultural commodities and crude oil upon which the analyses reported in this paper focus. The results indicate that the general equilibrium effects realised through the crude oil market are substantial and that they are typically sufficiently large as to overwhelm the initially positive price effects for agricultural producers. But the welfare measures of gains and losses are based on changes in household expenditures and therefore do not include the potential environmental gains from reduction in global use of crude oil; rather they are indicative of the economic costs of substitution crude oil with biomass.

The rest of the paper is organised as follows. The next section reviews the Global Trade Analysis Project (GTAP) database used for this study and provides a series of descriptive statistics that describe many of the key economic relationships. This is followed by a general description of the global CGE model used to carry out the analyses, and then by an analysis section that details the policy simulations carried out and summarises the main results. The main body of the paper ends with a series of concluding comments. The paper also contains an appendix that provides additional information about the data.

DATABASE

The database used for these analyses is a Social Accounting Matrix (SAM) representation of the Global Trade Analysis Project (GTAP) database version 5.4 (see McDonald and Thierfelder, 2004a, for a detailed description of the core database). The GTA project produces the most complete and widely available database for use in global computable general equilibrium (CGE) modeling; indeed the GTAP database has become generally accepted as the preferred database for global trade policy analysis and is used by nearly all the major international institutions and many national governments. Hertel (1997) provides an introduction to both the GTAP database and its companion CGE model[1].

The precise version of the database used as the starting point for this study is a reduced form global SAM representation of the GTAP data developed (McDonald and Thierfelder, 2004b, for a detailed description of the process and discussion of the advantages of using a reduced form). The structure of the global SAM is illustrated by a representative SAM for one region, which is given in Table 1; the structure of the SAM for each and every region is identical.[2] In general terms the SAM structure follows the conventions of the System of

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1 While Hertel (1997) remains the best single source for *general* descriptions of the GTAP database and model it is now quite dated; for up to date descriptions of the database and the GTAP model it is necessary study a number of technical documents available from the GTAP web site.

2 For a general description of a SAM see King, 1985; Sadoulet and de Janvry, 1995; Pyatt and Round, 1977; Pyatt, 1991; and Reinert and Roland-Holst, 1997.

National Accounts for 1993 (UN, 1993), with adjustments in light of the limited data on intra-institutional accounts.

SAM TRANSACTIONS

The SAM reports total demand for composite (see below) commodities (reading across the rows of the commodity accounts); as originating from five groups of agents: activities, private households, government, investment and other regions. These transactions are valued at purchasers prices, i.e., inclusive of all commodity specific taxes. The supplies of commodities are reported in the commodity columns; these are made up of domestic production, valued at sellers prices, plus imports, valued free on board (fob) in the source region, trade and transport margins on imports (see below for more detail) and all commodity specific taxes. Note how for imported commodities the sellers prices are the prices received by the exporting region plus the per unit transport costs plus the per unit tariff rates (reading down the columns of the commodity accounts), while for domestically produced commodities sellers prices are the (producer) prices received by domestic activities; note how export taxes are recorded. Domestic producer prices are derived from the production costs, which are made up of the costs of intermediate inputs valued at purchasers prices, plus the factor use and production taxes and payments to primary inputs.

Table 1 Transactions in the Social Accounting Matrix for a Representative Region

		1	2	3	4	5	6	7	8	9	
		Commodities	Activities	Factors	Private Household	Taxes	Government	Capital	Trade Margins	Rest of World	Total
1	Commodities		Intermediate inputs		Private demand		Government demand	Investment demand		Exports of Goods and Services	Total Demand
2	Activities	Supply matrix									Total Output
3	Factors		Payments to Factors								Factor Incomes
4	Private Household			Payments for factor use							Household Income
5	Taxes	Import taxes, Export duties, Purchase taxes	Production Taxes, Factor taxes	Factor Income Taxes	Income taxes						Tax Revenues
6	Government					Government income from taxes					Government Income
7	Capital			Depreciation	Savings		Savings			Trade balances	Total Savings

8	Trade Margins	Trade Margin Imports									
9	Rest of World	Imports							Trade Margin Payments		
	Total	Total Supply	Total Inputs	Factor Expenditures	Household Expenditures	Tax Expenditures	Government Expenditure	Total Investment	Expenditure on Margins		

All factor incomes, after the payment of factor income taxes and allowances for depreciation, accrue to the private household. The private household then spends its income on consumption, the payment of income taxes and savings. Government income is simply defined as the aggregate of all the tax incomes; and this income is used to fund government consumption and government savings[3] – these can be negative, i.e., government borrowings used to fund current consumption. Domestic savings are made up of depreciation allowances, private savings, government savings and balances on the current account of the trade accounts.

Trade transactions consist of two elements; expenditures on commodities and expenditures on transport margins. Exports are valued 'free on board' (fob) and after the payment of any export duties. Exports of transport services to the global transport pool are recorded as exports to a global pool of transport services, which is recorded as a separate 'region'. Imports of commodities are also valued fob, with transport services recorded separately. The sum of the two represents expenditure on imports inclusive of carriage, insurance and freight (cif). Consequently, there are two types of trade balances. The first represents the trade balances with each and every region on goods and services that are valued fob, while the second are the trade balances of each and every region with the global transport pool with respect to the transport services.

SAM DIMENSIONS

The dimensions of the SAM are determined by accounts identified in the GTAP database, which has 57 sectors (commodities and activities), 5 factors, 4 institutions and 78 regions (see Table 2). Hence the SAM has 57 commodity accounts and 57 activity accounts where production by each activity involves the use of up to 5 factors. Since each production activity can be charged factor specific taxes on factor use and an activity specific indirect/production tax, these require another 6 accounts. Factors can also be charged a tax on factor incomes, which requires a single direct tax account.

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[3] In the GTAP database the sources of savings by domestic agent are not identified. In this version of the database the implicit presumption is that all domestic savings come from households with the implied income tax rates on the private household being adjusted so that they are 'net' of government savings/borrowings. McDonald and Sonmez (2004) report a method for overcoming this limitation.

Table 2 SAM Dimensions

Description	Code	Base number	Multiples	Total
Commodities	*c*	57	1	57
Activities	*a*	57	1	57
Factors (incl factor specific taxes)	*f*	5	2	10
Regions (trade data)	*k*	78	6	474
Domestic Institutions and tax vectors	*i*	6	1	6
			Total	604

For trade relations, each region **can** import from and export to all other regions, hence there needs to be one account for each of 78 regions, and since all trade transactions can be taxed, import duties and export taxes, there needs to be 156 trade tax accounts. With three types of transport margins associated with each trade transaction there needs to be three accounts for each region that a region **can** trade with to capture trade and transport costs (234 accounts). Trade with the global trade and transport pool is captured by creating an additional region. Finally, there are three domestic institutional accounts: the private household, the government and the capital (savings and investment) account.

The most immediately obvious points about the SAM are the large number of accounts and the relative scarcity of entries in the SAM. The large size of the SAM is a consequence of the detailed treatment of trade relations in the database. Overall the dimensions of the SAM indicate several very important features of the GTAP database.

- Information is concentrated in the trade accounts.
- The within regional information emphasises inter-industry and final demand transactions.
- The tax information relates overwhelmingly to trade taxes.
- The only detailed inter-regional transactions are those associated with commodity transactions, inclusive of trade and transport margins.
- There is very little information about domestic institutions other than for consumption.

AGGREGATION OF THE GLOBAL GTAP SAM

Global CGE models typically use aggregations of the GTAP database that reduce the number of sectors and/or regions and/or factors. There are two key reasons for using aggregations; first, they allow the modeller to focus upon the sectors and regions that are of particular concern to the study in hand, and second, they ensure that the model has dimensions that are amenable to the derivation of practical solution[4]. In this case the objective of the study dictated the approach to aggregation: it was necessary to retain enough detail on agriculture and food production to capture the effects upon food and agriculture while keeping enough detail elsewhere to identify other effects – in particular it is necessary to have both crude oil and petroleum sectors to capture the substitution effects of increasing the use of switchgrass as a crude oil substitute. Furthermore so as to provide some insights into the potential range of effects upon other sectors and regions it was necessary to keep enough sectoral detail elsewhere in the model. The sectors in the model are identified in the first two columns of Table 3, while the mappings from the GTAP database are reported in Appendix 1.

A similar rationale was applied to the choice of regional aggregation. The concern in the study with the impact of a internal policy shift in the USA upon, particularly, developing countries required the separate identification of the USA and several key developing country regions – southern Africa, northern Africa, south Asia, east Asia – while maintaining a balanced coverage of the world's major economies. The regions in the model are identified in the last two columns of Table 3, while the mappings from the GTAP database are reported in Appendix 1.

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[4] In practice as the degree of aggregation decreases so the model size increases at an approximately exponential rate.

Table 3 **Model Sectors (Commodities and Activities) and Regions**

Commodities/Activities		Regions	
Cereals	Petroleum etc	USA	Japan and Korea
Other crops	Chemicals etc	European Union	East Asia
Switchgrass	Heavy manufacturing	Rest of Europe	Australia and NZ
Livestock	Electricity	Southern Africa	South America
Crude oil	Gas and Water	Northern Africa	Rest of Americas
Other minerals	Construction	South Asia	Rest of the World
Food Processing	Trade and Transport	China HK Taiwan	
Textiles	Services		
Light manufacturing			

ADDITIONS TO THE DATABASE

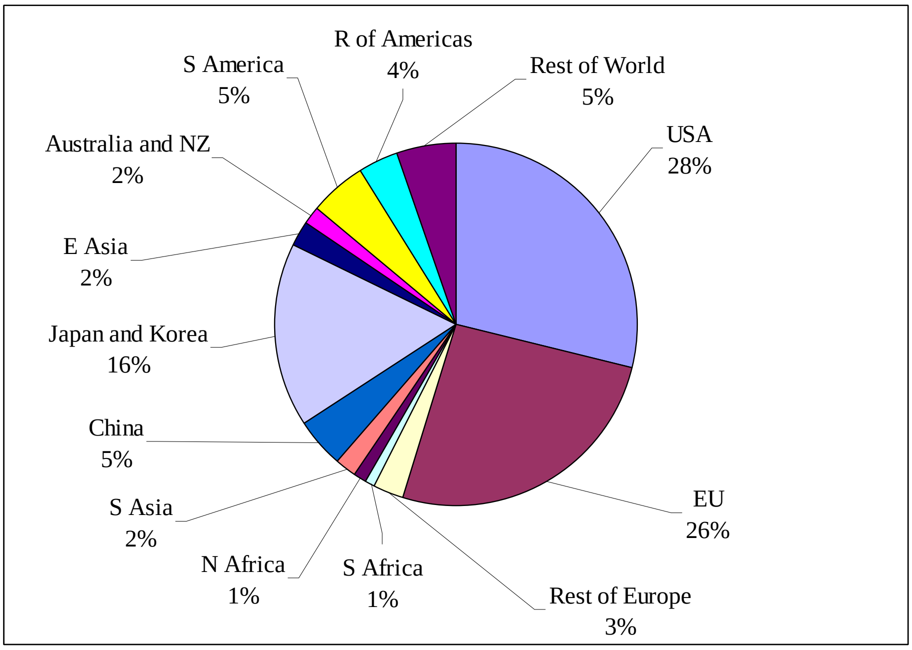
The GTAP database does not record switchgrass as a separate commodity/activity account, rather switchgrass is part of a larger aggregate that includes cereals and other similar field crops. Since switchgrass is not traded and it is not envisaged that switchgrass production and use will change elsewhere, there are no direct linkages with respect to switchgrass between the regions in the model. All the inter-regional effects will be indirect—as switchgrass production in the USA expands, it draws land from other agricultural sectors which contract. These production changes affect trade and therefore other regions. Therefore, for purposes of these analyses it is only necessary to add switchgrass commodity and activity accounts to the SAM for the USA.

Since switchgrass is a member of the graminae family and is harvested only once per year its input mix is similar to that of other cereal crops. However it is a perennial and therefore only requires periodic planting and reduced usage of intermediate inputs. Based on information in microeconomic studies, and in the absence of better information, it was assumed that the primary input coefficients were the same as those for other US cereals and that the intermediate input coefficients were 70 percent of those for cereals in the USA. All output was assumed to be purchased as an intermediate input by the petroleum activity.

DESCRIPTIVE STATISTICS

An overview of the database used in the study can be obtained by a brief review of some descriptive statistics. Gross Domestic Product (GDP), from the values added side, indicates the relative size of the regions in the global economy (see Figure 1). The USA, the EU and Japan and Korea are by far the largest regions, both in terms of total GDP and GDP per capita, moreover these three regions dominate global trade accounting for 60 percent and 61.5 percent of global imports and exports respectively (see Figure 2). Similar dominances by these three regions are found for trade in cereals (58 and 53 percent of global exports and imports, Figure 3), other crops (41 and 65 percent of global exports and imports, Figure 4) and livestock (47 and 67 percent of global exports and imports, Figure 5). For crude oil however the situation is very different, while these regions dominate import demand, 71 percent of global demand, they are responsible for only a small share of exports, 6 percent (see Figure 6). When the other developed economies, Australia and New Zealand, Rest of Europe and Rest of America are taken into account the extent of the dominance of world GDP and trade is still more pronounced.

Figure 1 **Gross Domestic Product (GDP) by Region** (Percent shares)

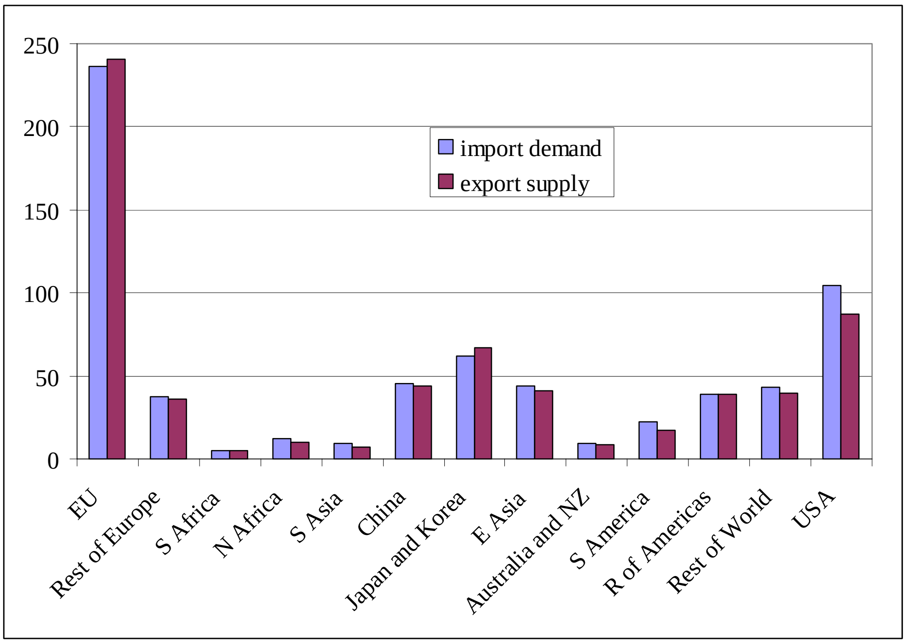


Source: GTAP/Model database

Combined the middle income regions, China, east Asia, south America and the rest of the world, account for about 17 percent of global GDP, but are relatively slightly more open to trade than the developed regions since they account for 23 percent of global import demand

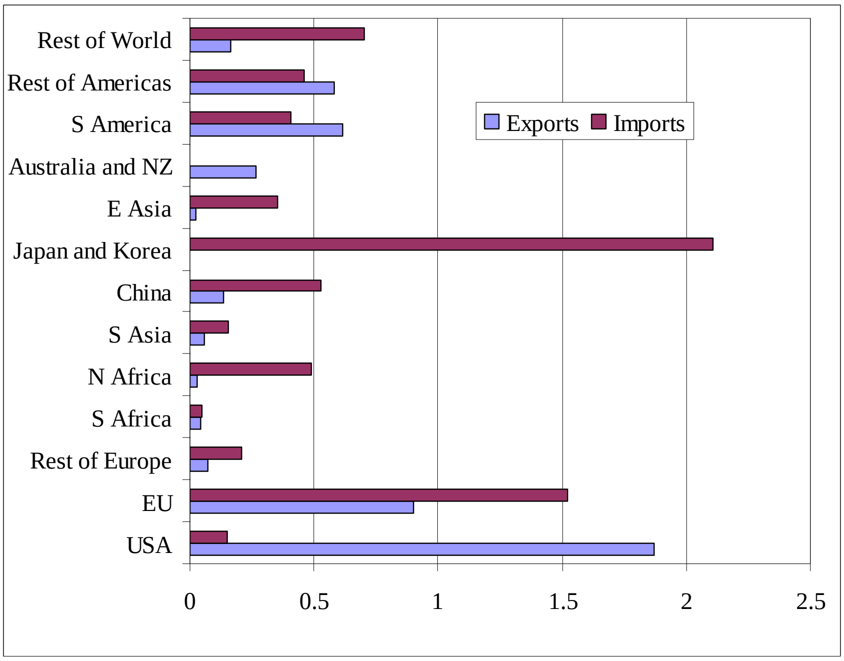
and 22 percent of global export supply. The situation for agricultural commodity trade is slightly more pronounced with trade in cereals (20 and 28 percent of global exports and imports, Figure 3), other crops (31 and 19 percent of global exports and imports, Figure 4) and livestock (21 and 22 percent of global exports and imports, Figure 5) demonstrating, on average, a slightly greater degree of openness than found for the three economically largest regions. For crude oil however the situation is very different, while these regions dominate export supply, 62 percent of global supply, while only accounting for 17 percent of global import demand (see Figure 6).

Figure 2 **Total Import Demand and Export Supply by Region**



Source: GTAP/Model database

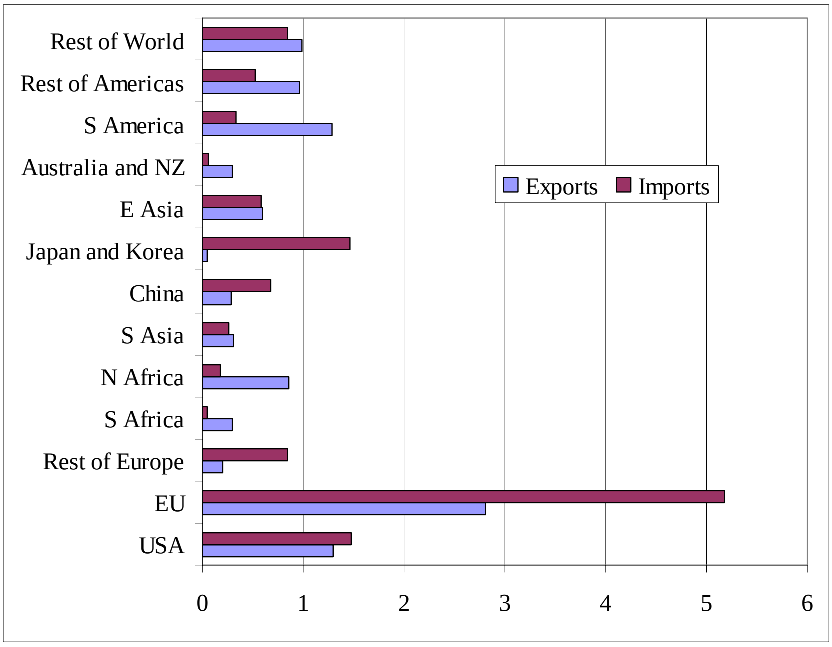
Figure 3 **Cereals Trade** ($(US) 10 billion)



Source: GTAP/Model database

Consequently the developing country regions, southern Africa, northern Africa and south Asia, are responsible for small proportions of global GDP, 3.7 percent, and global import demand, 4 percent, and export supply, 3.4 percent. Their involvement in agricultural commodity trade is equally small, with trade in cereals (2.7 and 9.7 percent of global exports and imports, Figure 3), other crops (14.3 and 4 percent of global exports and imports, Figure 4) and livestock (3.3 and 2.2 percent of global exports and imports, Figure 5) demonstrating a relatively high degrees of dependence on cereals imports and other crop exports. They are also relatively substantial exporters of crude oil, 14.4 percent of global exports, but are less prominent as importers, 4.2 percent of global imports (see Figure 6).

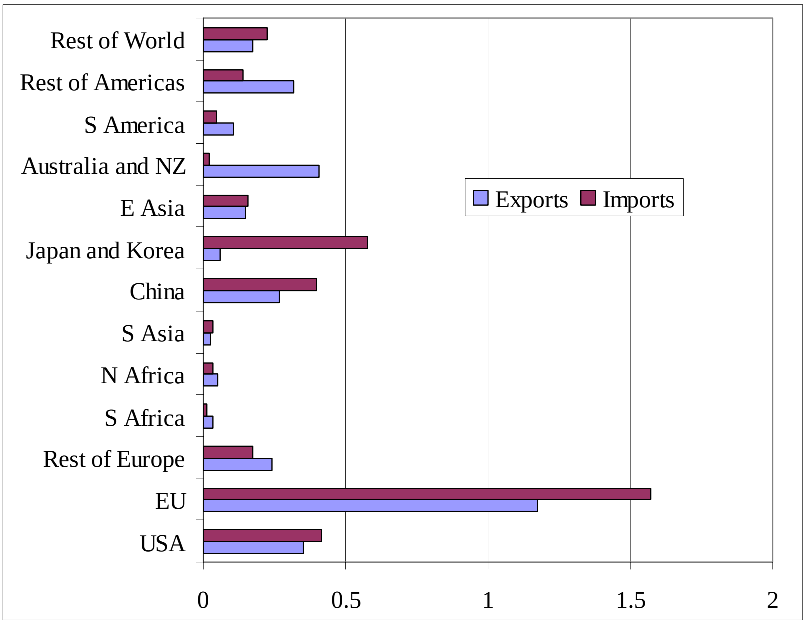
Figure 4 **Other Crops Trade** ($(US) 10 billion)



Source: GTAP/Model database

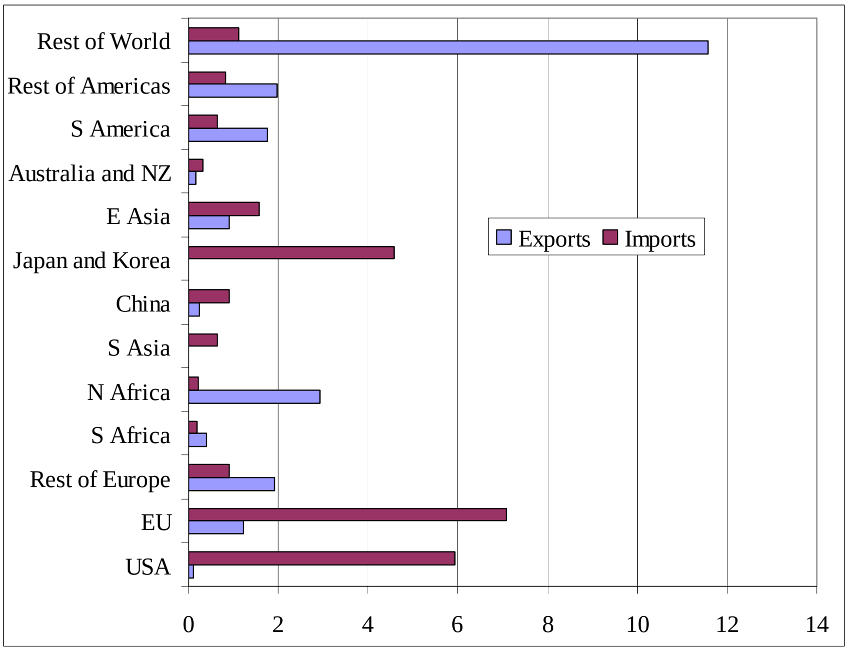
The differentials in the stage of development of the developed, middle income and developing regions is also well illustrated by the relative importance of agricultural and food commodities to these groups of regions (see Figure 6). In general terms there is an inverse relationship between the state of development of regions and the production shares accounted for by agricultural and food commodities. What is most noticeable however are the large production shares for agricultural commodities in south Asia and the substantially lower shares for the two African regions; indeed in southern Africa cereals production accounts for a smaller share of total commodity production than found in most middle income regions. Most importantly it emerges that developing regions are net importers of cereals and net exporters of other crops.

Figure 5 **Livestock Trade** ($(US) 10 billion)



Source: GTAP/Model database

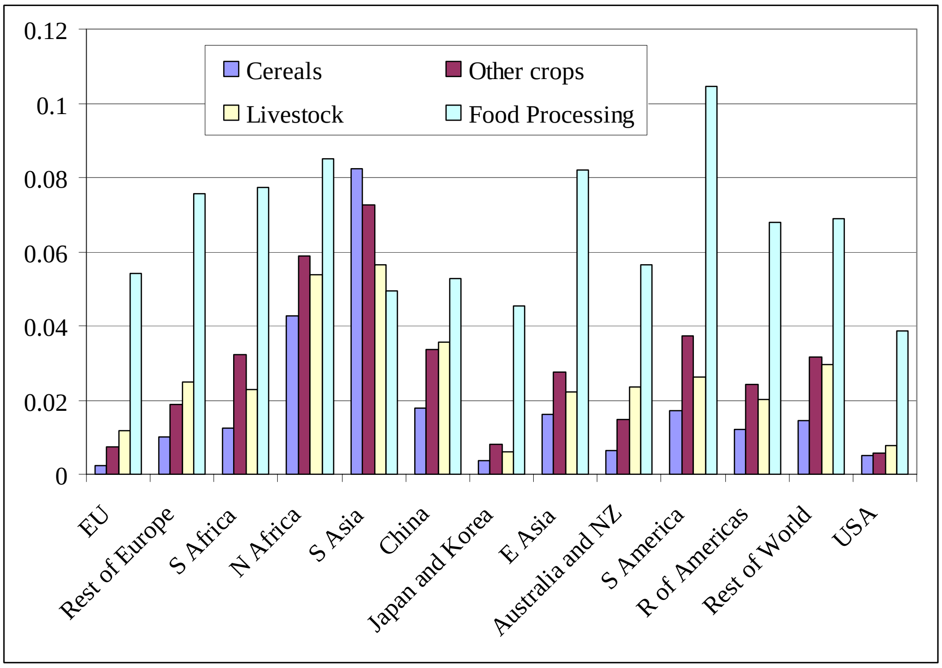
Figure 6 **Crude Oil Trade** ($(US) 10 billion)



Source: GTAP/Model database

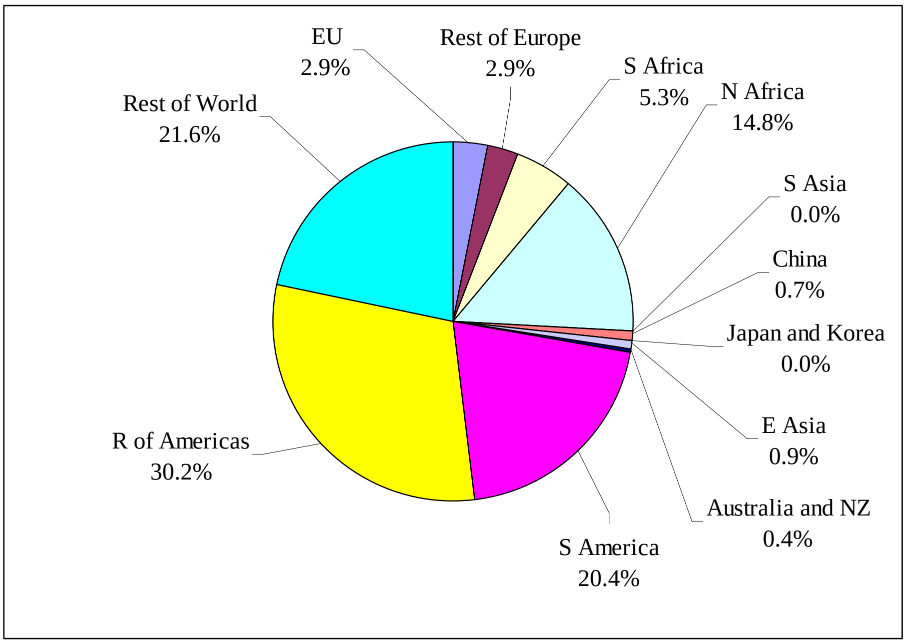
The USA, the EU, and Japan and Korea are the three largest oil importing regions (see Figure 7). More importantly from this perspective of this study is the extent to which the USA imports crude oil from all regions in the model, with 30 percent coming from the Rest of Americas (primarily from Mexico), 21 percent from the Rest of the World, and 20 percent from South America (primarily from Venezuela), see Figure 8. This contrast with the other large oil importing regions whose sources of supply are less diversified.

Figure 7 **Production Shares of Agricultural Commodities by Region**



Source: GTAP/Model database

Figure 8 **USA Crude Imports by Source Region** (Percent shares)



Source: GTAP/Model database

THE MRT-GLOBE MODEL[5]

This model is a member of the class of computable general equilibrium (CGE) models that are descendants of the approach to CGE modeling described by Dervis *et al*., (1982). The implementation of this model, using the GAMS (General Algebraic Modeling System) software, is a direct descendant and development of the single country models devised in the late 1980s and early 1990s, particularly those models reported by Robinson *et al*., (1990), Kilkenny (1991) and Devarajan *et al*., (1990), and the multi-country model developed by Robinson and co-workers to analyse NAFTA in the early 1990s (see Lewis *et al*., 1995, for a later application).

The model is a SAM based CGE model, wherein the SAM serves to identify the agents in the economy and provides the database with which the model is calibrated. Since the model is SAM based it contains the important assumption of the law of one price, i.e., prices are common across the rows of the SAM. The SAM also serves an important organisational role since the groups of agents identified by the SAM structure are also used to define sub-matrices of the SAM for which behavioural relationships need to be defined. As such the modeling approach has been influenced by Pyatt's 'SAM Approach to Modeling' (Pyatt, 1987).

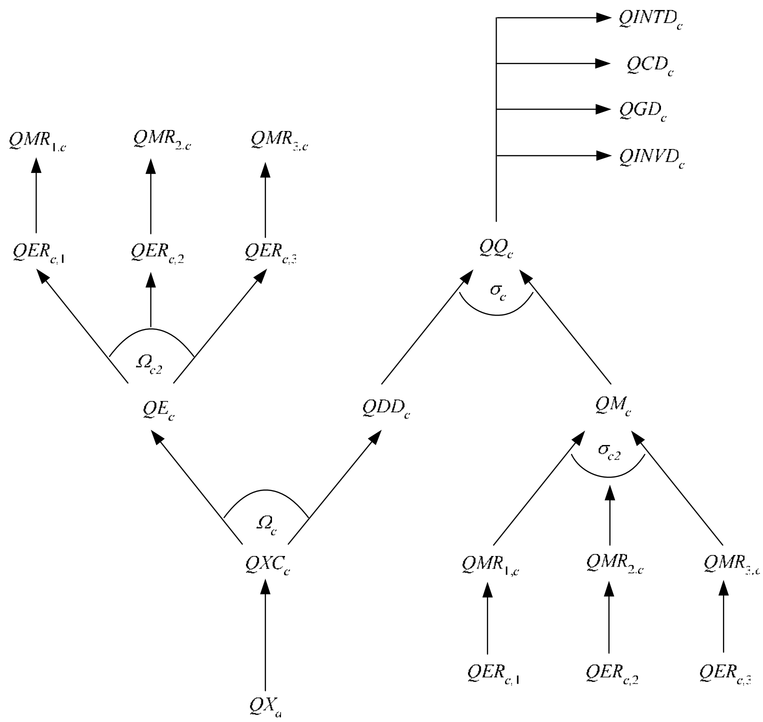
TRADE

Trade is modeled using a treatment derived from the Armington 'insight'; namely domestically produced and consumed commodities are assumed to be imperfect substitutes for both imports and exports. Import demand is modeled via series of nested constant elasticity of substitution (CES) functions; imported commodities, c, from different source regions, w, to a destination region, r, ($QMR_{c,w,r}$) are assumed to be imperfect substitutes for each other and are aggregated to form composite import commodities ($QM_{c,r}$) that are assumed to be imperfect substitutes for their counterpart domestic commodities ($QD_{c,r}$) (see Figure 9 for an illustration for a typical region with three trading partners where the region subscripts, r, have been removed for simplicity). The composite imported commodities and their counterpart domestic commodities are then combined to produce composite consumption commodities ($QQ_{c,r}$). These are the commodities demanded by domestic agents

[5] The description of the model provided here short and intended only to provide brief overview of the model's structure and operation. A detailed description is available in McDonald *et al*., (2005).

as intermediate inputs ($QINTD_{c,r}$), and for final demand as private ($QCD_{c,r}$), government ($QGD_{c,r}$) and investment ($QINVD_{c,r}$) consumption.

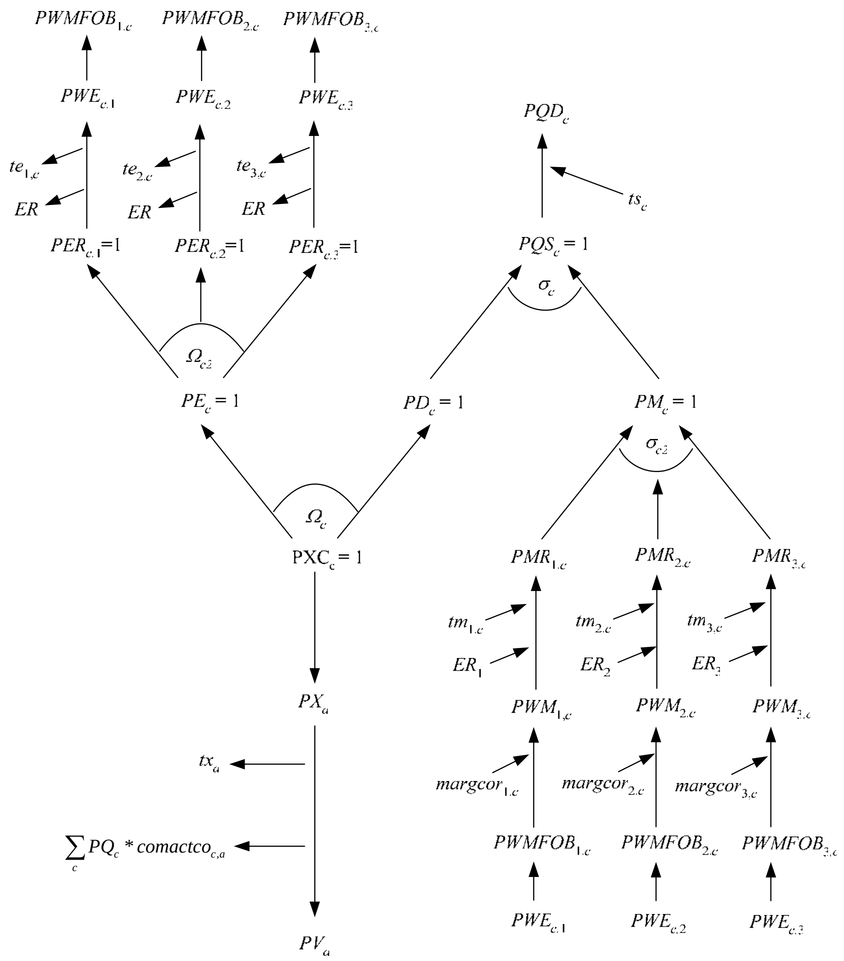
Figure 9 Quantity System for a Typical Region



Export supply is modeled via series of nested constant elasticity of transformation (CET) functions; the composite export commodities ($QE_{c,r}$) are assumed to be imperfect 'substitutes' for domestically consumed commodities ($QD_{c,r}$), while the exported commodities from a source region to different destination regions ($QER_{c,w,r}$) are assumed to be imperfect 'substitutes' for each other. The composite exported commodities and their counterpart domestic commodities are then combined to produce composite production commodities ($QXC_{c,r}$). The properties of models using the Armington 'insight' are well known (see de Melo and Robinson, 1989; Deverajan *et al*., 1990), but it is worth noting here that this model differs from the GTAP model through the use of CET functions for export supply; this ensures that domestic producers will adjust their export supply decision in response to changes the relative prices of exports and domestic commodities, which help to moderate the magnitude of the terms of trade effects in this class of model.[6]

6 The terms of trade effects will prove to be important determinants of the results produced by the simulations reported below.

Figure 10 Price System for a Typical Region



The agents are assumed to determine their optimal quantities of commodities in accordance with the relative prices of the commodities; hence underlying the model's quantity system is a price system – see Figure 10. Each source region (r) exports commodities (c) to destination regions (w) at specific prices ($PWE_{c,r,w}$) that are valued free on board (fob), such that each destination region imports commodities from source regions at specific fob prices ($PWMFOB_{c,r,w}$). These import prices need adjusting to capture the cost incurred with trade – trade margins – to yield carriage insurance and freight (cif) paid prices ($PWM_{c,r,w}$); the underlying assumption is that fixed quantities of trade services ($margcor_{c,r,w}$) are incurred for each unit of a commodity traded between each and every source and destination[7]. The cif prices are the 'landed' prices expressed in global currency units; to these must be added any import duties ($tm_{c,r,w}$) and the resultant price converted into domestic currency units ($PMR_{c,r,w}$) using the exchange rate (ER_r) to get the source region specific import price ($PMR_{c,r,w}$). The

[7] Bilateral data on trade margins are not available in the GTAP database. Instead, trade margin services are assumed to be a homogeneous good; they are not differentiated by country of origin.

price of the composite import commodity ($PM_{c,r}$) is then a weighted aggregate of the region specific import prices and the domestic supply price ($PQS_{c,r}$) is a weighted aggregate of the import commodity price and the domestically produced commodity price ($PD_{c,r}$).

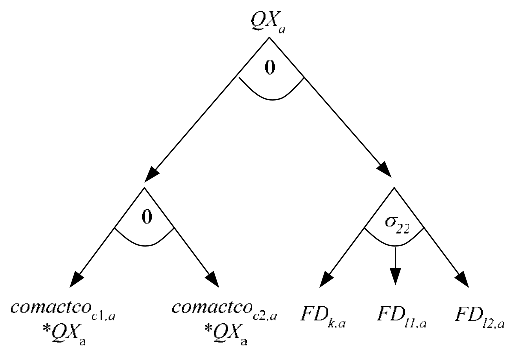
The prices received by domestic producers for their output ($PXC_{c\ r}$) are weighted aggregates of the domestic price and the aggregate export price ($PE_{c\ r}$) which is itself a weighted aggregate of the prices received for exports to each region ($PER_{c\ r\ w}$) in domestic currency units. The fob export prices are then the determined by the subtraction of any export taxes ($te_{c\ r\ w}$) and converted into global currency units.

There are two important features of the price system in this model that deserve special mention. First, each region has its own numéraire such that all prices within a region are defined relative to the region's numéraire; the model code allows two standard options for these numéraire – the consumer of the producer price indices. And second there is a global numéraire such that all exchange rates are expressed relative to this numéraire; the model code allows the selection of any region's exchange rate as the numéraire.

PRODUCTION

The production structure is a two stage nest, see Figure 11. Intermediate inputs are used in fixed proportions ($comactco_{c,a,r}$) per unit of output ($QX_{a,r}$) – Leontief technology. Primary inputs are combined as imperfect substitutes, according to a CES function, to produce value added.

Figure 11 Production System for a Typical Region



In the current context it is useful to examine how changes in the use of switchgrass are introduced to the production system. If the use of switchgrass as an input to the petroleum producing industry increases at the 'expense' of crude oil the technology change can be represented as an increase in the intermediate input coefficient for switchgrass and reduction in the intermediate input coefficient for crude oil. Since the coefficients represent the quantities of intermediate inputs used, on average, to produce a unit quantity of output it is also necessary to determine the ratio by which switchgrass use must increase to achieve a unit reduction in crude oil use. This is done in the simulations.

FINAL CONSUMPTION

Final demand by the government and for investment is modeled under the assumption that the relative quantities of each commodity demand by these two institutions is fixed – this reflects the absence of a clear theory that defines an appropriate behavioural response by these agents to changes in relative prices. For the household there is however a well developed behavioural theory; hence the model contains the assumption that households are utility maximisers who respond to changes in relative prices and their incomes. In this version of the model the utility functions for the private households are assumed to be Cobb-Douglas; this has the advantage that with a standard, neoclassical, set of closure rules that changes in household consumption expenditure can be interpreted as equivalent variations in welfare, and hence provides a useful summary measure of the welfare effects of the policy simulations.[8]

ANALYSES

MODEL CLOSURE RULES

The closure rules adopted for these simulations are relatively straightforward. The foreign exchange markets are cleared under the assumption that balances on the current accounts are constant and the exchange rates adjust. The model is investment driven with household savings rates flexible so as to maintain a constant level of investment; this ensure that adjustments to a new equilibrium do not take place through changes in the volumes of investment. All the tax rates are fixed with constant government spending and flexible government savings. The factor market closure is long run; all factors are assumed to be fully employed and fully mobile across all sectors but are immobile across regions. In the sensitivity analyses, the case of an endogenous supply of land at a constant price is evaluated.

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[8] The closure rules are: consumer price index numéraire, fixed current account, flexible exchange rate, fixed household savings rates and fixed tax rates.

POLICY SIMULATIONS

The policy change simulated in the model is the substitution of crude oil by switchgrass in the technology of the petroleum activity. Clearly a wide range of degrees of input substitution may be technologically feasible, although the realistic range of alternatives is likely to be much more limited. The changes in the area of land used for switchgrass production and the use of crude oil by the petroleum activity considered in this study are those implied by the partial equilibrium studies into the use of switchgrass as a crude oil substitute (see De La Torre Ugarte and Hellwinckel, 2004a and b); these studies indicate that if some 6 percent of USA agricultural land were changed to switchgrass production there would be a reduction of some 4 percent in the use of crude oil by the petroleum activity.[9] The model is 'calibrated' to achieve these targets by the derivation of a conversion factor this ensures that the increase in land used for switchgrass and the reduction in the direct use of crude oil are consistent with the changes derived from partial equilibrium studies.

The policy simulations are carried out in four stages so that the different effects of the proposed policy change can be separated out:

1. Direct substitution of Crude Oil by Switchgrass – this involves a reduction in the input-output coefficients for crude oil use by the petroleum activity and an equal increase in the coefficient for switchgrass; this one-to-one substitution amounts to an assumption that one unit of switchgrass substitutes for one unit of crude oil. This simulation is called 'One-to-One' in the subsequent text.
2. Derivation of Switchgrass Conversion Factor – the first simulation produces results where the land area in switchgrass is substantially less than indicated by the partial equilibrium studies; this simulation produces an estimate of the units of switchgrass required to replace a unit of crude oil in petroleum production so that some 6 percent of land is devoted to switchgrass production. This simulation is called 'Calibrated' in the subsequent text, and is the main simulation.
3. Efficiency Gains in Petroleum Production – the conversion factor in simulation 2 implies that there is a decline in the 'efficiency' of the petroleum activity; this simulation estimates the extent to which efficiency in the petroleum activity

9 Since a partial equilibrium model will not capture the multiplier effects the simulations in this study assume that 4 percent is the target reduction in the use of crude oil per unit output of the petroleum activity.

must increase to compensate for the change to switchgrass. This simulation is called 'With TFP' in the subsequent text.

4. Endogenous Land Supply – the USA has implemented various set aside policies for agricultural land, which means that one possibility is that land restored to agricultural production is used to produce switchgrass; this simulation explores this possibility. This simulation is called 'With Land' in the subsequent text.

The first two reported simulations are concerned with achieving a replication of the estimates from partial equilibrium studies while the last three simulations study the sensitivity of the results to the calibration process. [10] The results of these simulations are discussed sequentially below.

RESULTS

Direct substitution Switchgrass for Crude Oil (One-to-One)

This simulation considers a change in production technology, under the maintained assumption that switchgrass is a perfect substitute for crude oil in the production of petroleum in the USA.[11] The input-output coefficient for crude oil use in petroleum production is reduced by 4 percent, thereby achieving a 4 percent reduction in the use of crude oil in the production of a unit of petroleum, and coefficient for switchgrass is increased by the same amount. Once all the adjustments to a new equilibrium have been realised the welfare implications, measured in terms of the equivalent variations in household welfare, are relatively small. The USA would experience a small increase in welfare, $(US)1.10 bn (0.02 percent), with only one other region experiencing a non-negative change in welfare, i.e., South Asia, and that is less than $(US)0.02 bn; overall the welfare impact is negative with a global welfare loss of $(US)1.85 bn (-0.01 percent). Although the majority of the welfare loss is concentrated in the developed and middle income regions[12], -$(US)1.59 bn, the proportionate welfare loss in developing regions is far greater, - 0.035 percent. This suggests

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10 In one simulation, the results for which are not reported here, a situation of government revenue neutrality was simulated where government revenues are held constant and the household (income) tax rates are flexible. This produced results that were virtually identical to those for the second – calibrated – simulation and therefore provided no additional insights.

11 Only a selection of the results generated by the simulations is reported in the text. A binary data file (8MB) with results from 15 simulations is available from the authors upon request.

12 The developed regions are defined as Australia and NZ, European Union, Rest of Europe, Japan and Korea, Rest of Americas and United States of America; the middle income regions as China HK Taiwan, East Asia, South America and Rest of the World; and the developing regions as Northern Africa, Southern Africa and South Asia.

that not only might the substitution of crude oil by switchgrass slightly reduce global welfare it is likely, overall, to have income distribution implications that are marginally regressive. Welfare is however only a summary statistic and it is important to understand how, why and from where these overall effects originate.

Table 4 **Household Welfare ($US billions)**

	Base	**Simulations** (Changes in welfare)			
		One-to-one	**Calibrated**	**With TFP**	**With Land**
USA	5,495.10	1.11	-2.02	0.70	0.19
EU	4,824.83	-0.79	-1.05	-0.82	-0.86
Rest of Europe	523.79	-0.07	-0.09	-0.07	-0.07
S Africa	108.38	-0.11	-0.14	-0.12	-0.14
N Africa	266.66	-0.16	-0.19	-0.17	-0.17
S Asia	357.46	0.02	0.01	0.01	0.02
China	689.73	-0.06	-0.11	-0.08	-0.04
Japan and Korea	2,769.95	-0.33	-0.53	-0.43	-0.21
E Asia	375.88	-0.03	-0.05	-0.02	-0.04
Australia and NZ	281.78	-0.02	-0.03	-0.02	-0.03
S America	1,022.46	-0.30	-0.33	-0.30	-0.32
Rest of Americas	712.41	-0.81	-1.06	-0.80	-0.97
Rest of World	949.12	-0.29	-0.36	-0.30	-0.30
Total	18,377.55	-1.85	-5.95	-2.43	-2.94

Source: Model simulation results.

Given the changes in intermediate input technology, switchgrass production increases (from a very low base) and crude oil production decreases by 4.83 percent. As switchgrass expands, it draws land from other agricultural products, and those sectors contract (see Table 5). Thus the substitution of crude oil by switchgrass has the anticipated effect of reducing the production of other agricultural commodities in the USA, by between 0.22 and 0.40 percent, and, as would be expected, this feeds through into a reduction in food commodity production while having minor adverse consequences for production elsewhere. These production declines increase the decline in crude oil production because they marginally reduce the overall level of production.

Table 5 **Proportions of Land in Different Agricultural Activities, USA**

	Base	One-to-one	Calibrated
Cereals	0.63	0.61	0.60
Other crops	0.24	0.23	0.22
Switchgrass	0.00	0.03	0.06
Livestock	0.13	0.12	0.12

Source: Model simulation results.

A large part of the welfare gains for the USA are due to second best effects as production changes. There is a high production tax on crude oil in the U.S. (23.5 percent) and a high subsidy on cereals production (30 percent); as crude oil production declines so the distortion effect of the production tax declines while as cereals production declines so the distortions for the subsidies decline, these positive effects are slightly enhanced by the decline in livestock production, on which there is also a (small) subsidy. The overall effect contributes to the marginal welfare gain in the USA. The decline in welfare in other regions can be explained by terms of trade changes. The USA decreases demand for imported crude oil, its total imports decline by 2.93 percent, which, since the USA is a large country, affects the world market price for crude oil; consequently the crude oil cif import prices for the USA from all regions decline while the export prices of crude oil by all regions decline, i.e., export revenues decline. Since the USA imports crude oil from all regions in the model, changes in USA demand affect all regions.

A key consequence of the changes in the demand for crude oil, especially imports of crude oil, is the effect on exchange rates (see Table 7). All regions experience a depreciation of their currency relative to the USA as the exchange rate (which measures domestic currency/world currency) increases; since the current account balances are held constant in each region and oil imports by the USA decline due the exogenous change in input use, then other regions must increase exports.[13] These changes affect the structure of production in each region, causing shifts in factor inputs to sectors with a high share of exports in production.

Table 6 **Production Taxes, Value Added Shares, and Changes, USA**

	Base data		Simulations	
	Indirect tax rate	Value added share of gross output	Production (percent change)	
			One-to-one	Calibrated
Cereals	-0.30	0.79	-0.28	-0.48
Other crops	0.01	0.55	-0.40	-0.69
Switchgrass	0.00	0.69	53,395.44	95,266.82
Livestock	-0.01	0.18	-0.22	-0.40
Crude Oil	0.24	0.33	-4.83	-5.90
Other minerals	0.17	0.43	-0.06	-0.08
Food	0.00	0.32	-0.16	-0.30
Textiles	0.00	0.34	-0.07	-0.12
Light manufacturing	0.00	0.42	-0.10	-0.14
Petroleum	0.00	0.08	0.24	-0.64
Chemicals	0.00	0.39	-0.01	-0.05
Heavy manufacturing	0.00	0.40	-0.09	-0.11
Electricity	0.00	0.47	0.00	-0.02
Gas and water	0.00	0.56	0.10	0.17
Construction	0.00	0.46	-0.01	-0.01
Trade and transport	0.00	0.58	-0.01	-0.05
Services	0.00	0.69	-0.01	-0.03

Source: Model simulation results.

The impact of these changes for food and agriculture in the developing regions (southern Africa, northern Africa and south Asia) are illustrated by Figures 12, 13 and 14. For southern and northern Africa food and agricultural imports decline (Figure 12) while exports increase (Figure 13) and the total quantities supplied to the domestic market decline (Figure 14). In all cases the proportionate changes are smaller, substantially less than 1 percent, and

[13] Since the USA's exchange rate is a numéraire in the model then this could symmetrically be described as being a consequence of an appreciation of the USA's exchange rate relative to all other regions.

the declines in total supplies are very small, less than 0.1 percent. The situation for south Asia is slightly different; although total supplies of cereals decline very marginally the supplies of other food and agricultural commodities marginally increase. Overall the implications for the African region are overwhelmingly negative, although very small, while for south Asia the effects are marginally positive, although extremely small.

However it is noticeable that the production of petroleum increases slightly, which although it seems to be a perverse result is a natural consequence of an increase in the relative price of petroleum following from the decrease in price of crude oil and other relative price changes. Moreover the share of land used in switchgrass only increases to 0.03 (see Table 5), which is substantially less than the share predicted by the partial equilibrium models. It is these results that the subsequent simulations particularly focus on examining.

Table 7 **Exchange Rate Effects** (percent change)

	One-to-one	**Calibrated**	**With TFP**	**With Land**
EU	0.20	0.25	0.19	0.22
Rest of Europe	0.21	0.26	0.21	0.24
S Africa	0.43	0.53	0.43	0.51
N Africa	0.42	0.50	0.41	0.49
S Asia	0.16	0.21	0.15	0.20
China	0.16	0.20	0.15	0.19
Japan and Korea	0.17	0.22	0.17	0.20
E Asia	0.16	0.21	0.16	0.20
Australia and NZ	0.18	0.23	0.17	0.22
S America	0.35	0.40	0.34	0.40
R of Americas	0.26	0.31	0.24	0.32
Rest of World	0.27	0.32	0.26	0.31

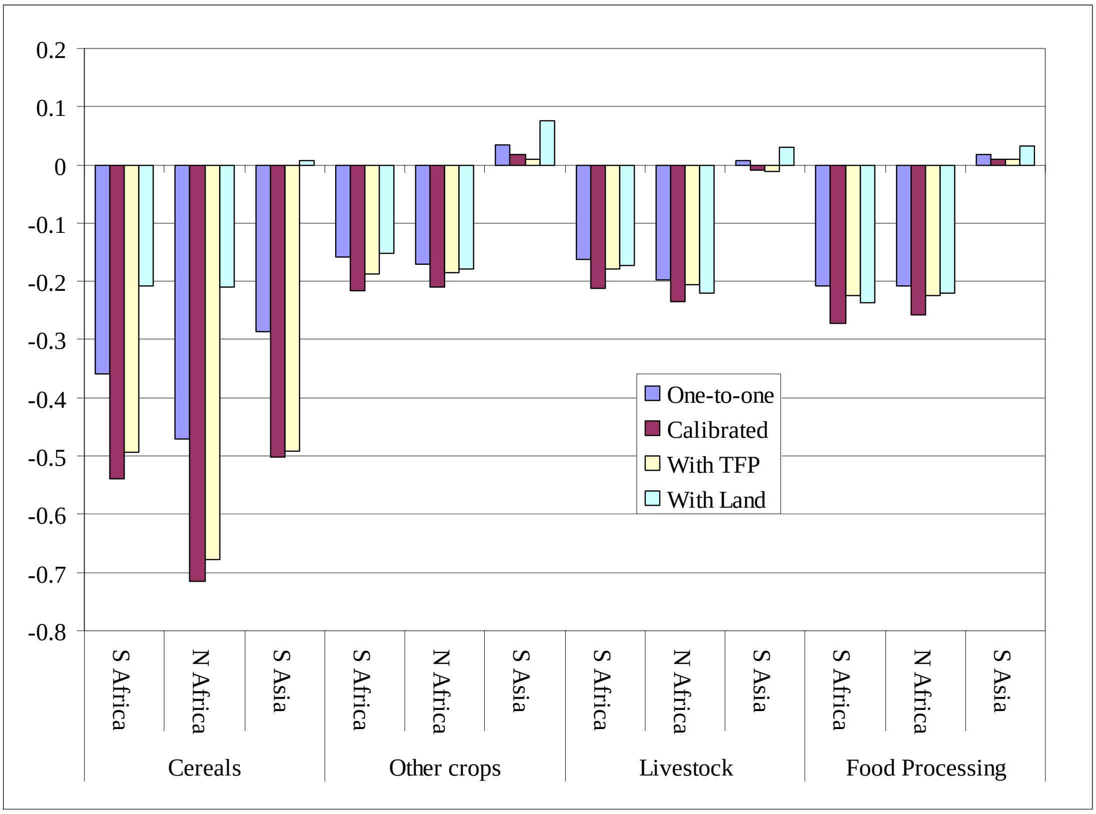
Source: Model simulation results.

Calibrated Change in Switchgrass Production

The partial equilibrium estimates indicate that approximately 6 percent of land area should be converted to switchgrass production; this implies that a one-to-one substitution of crude oil by switchgrass is inappropriate and that the amount of switchgrass substituted for crude oil in the production of petroleum should increase. Simulations indicate that the appropriate conversion factor is approximately 1.8, i.e., for each 0.01 reduction in the intermediate input coefficient for crude oil the coefficient for switchgrass should increase by 0.018.[14] In effect, this amounts to a decline in the economic efficiency with which the petroleum activity converts fuel stock into petroleum when it substitutes switchgrass for crude oil.

As a result of the loss of productivity, household welfare declines by $(US) 2.02 bn (-0.04 percent) in the USA and declines in all other regions except south Asia where it just remains positive (see Table 4). The global welfare impact is a loss of $(US) 5.95 bn (-0.03 percent), which is overwhelmingly concentrated in the USA due to the decline in the USA's economic efficiency; this is manifested in the greater proportionate reductions in production by most activities, especially crude oil that declines by a further percentage point, and by increased production Gas (and Water) attributable to the changes in the relative prices of competing energy products. Welfare declines for the other countries for the same reasons described above.

Figure 12 **Food and Agricultural Imports by Developing Regions** (percent change)



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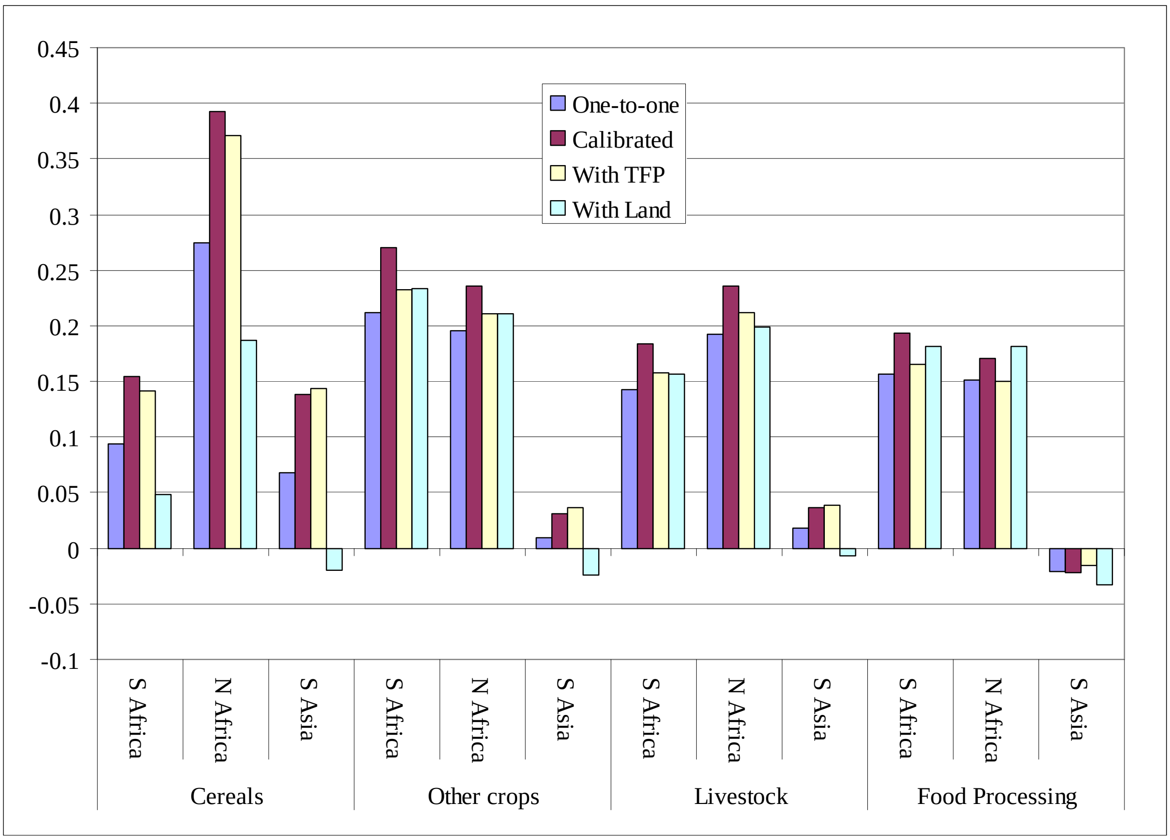
14 Note that because the conversion factor is derived from a general equilibrium solution it will differ from the partial equilibrium estimate because it will take into account the second and lower order effects of substituting crude oil by switchgrass.

Source: Model simulation results.

Because there is an increased shift in land into switchgrass in the USA, the increases in producer prices for food and agricultural commodities in the USA are substantially greater – nearly twice as large. Even so the impacts upon producer prices in the developing regions remain marginally negative, and are accompanied by further increases in exports and decreases in imports of these commodities by the two Africa regions and further reductions in supply while the smaller benefits to south Asia are further muted. Again the fundamental driving forces are the exchange rate effects, which result in a further depreciation of the exchange rates, and the role of the USA as major exporter of agricultural and food commodities and the limited abilities of the developing regions to compensate for these exchange rate movements. The biggest gainers, in terms of global market share, are two of the developed regions, the EU and Japan-Korea, and the rest of America (a middle income region).

Figure 13 **Food and Agricultural Exports from Developing Regions** (percent change)



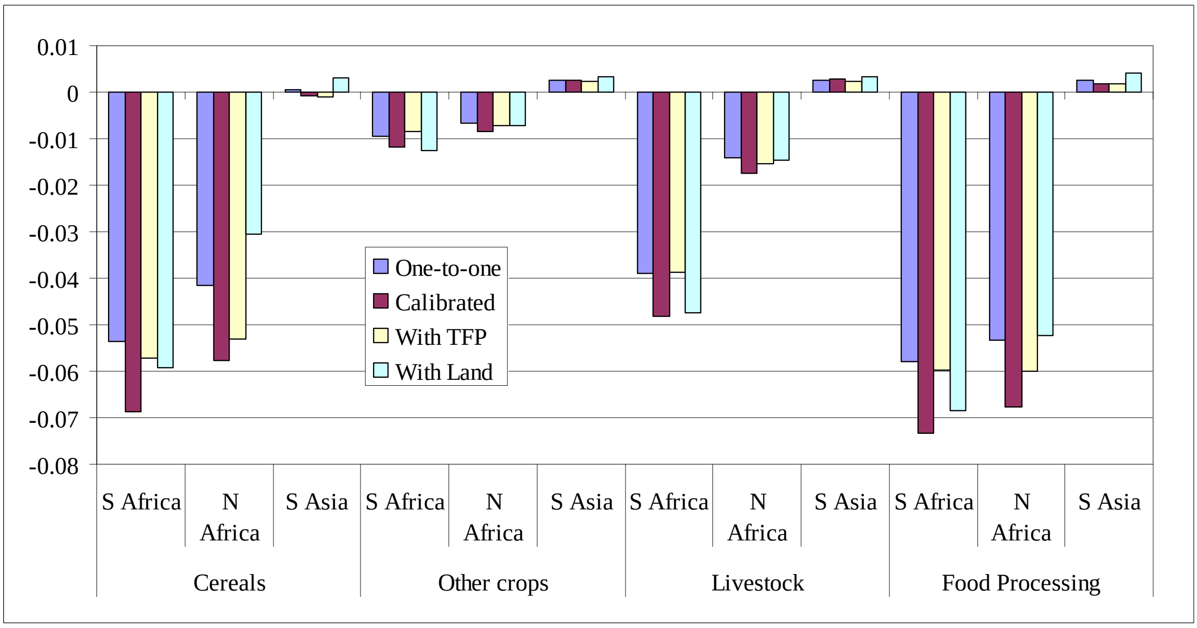
Source: Model simulation results.

Total Factor Productivity (TFP) Growth in Petroleum

The additional adverse implications for welfare of a decline in the efficiency of the USA's petroleum industry could be offset if there were a compensating increase the total factor productivity (TFP) in petroleum production. A 30 percent increase in the efficiency with which the petroleum industry uses its primary inputs – labour and capital - is sufficient to generate a small positive welfare effect in the USA while retaining the 1.8 conversion factor of switchgrass for crude oil and achieving the share of (USA) land devoted to switchgrass at 6 percent.[15] While this may seem like a large TFP shock, it is important to note that petroleum industry has a low share of value added in production (8 percent, see Table 6).

This change certainly ameliorates the adverse welfare implications for other regions and returns them to the order of magnitude found in the first simulation. However, as reported in Table 7 it makes no substantive difference to the relative depreciations in the exchange rates or the changes in producer prices, see Figure 15, and consequently the welfare and structural implications for the other regions are virtually unchanged.

Figure 14 Food and Agricultural Commodity Supply for Developing Regions
(percent change)



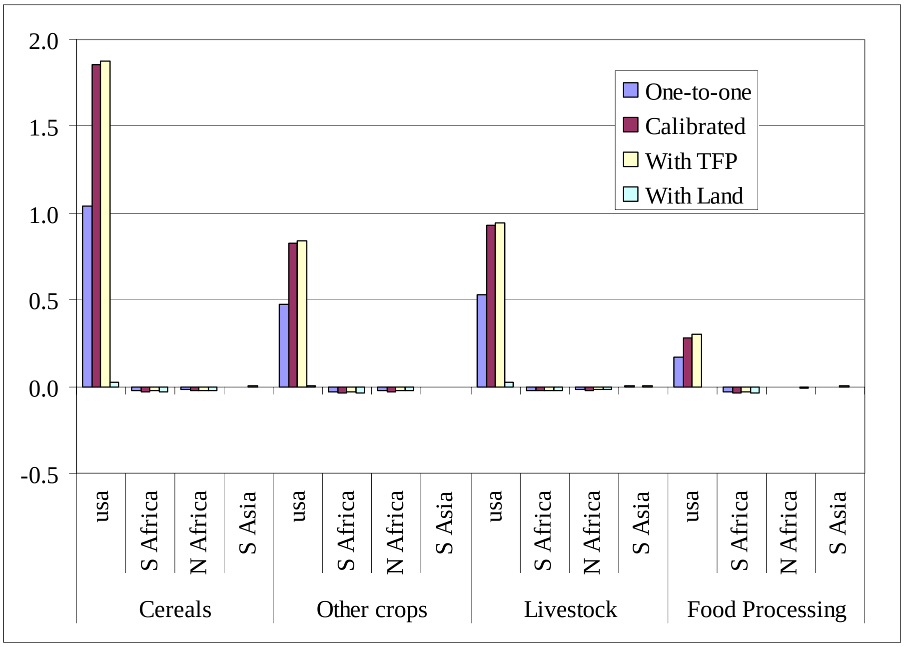
Source: Model simulation results.

[15] Since the intention with this simulation is indicative rather than predictive the model was not used to find the precise magnitude of the TFP shock associated with no change in USA welfare. Such an exercise could be easily implemented but would risk implying an inappropriate degree of precision.

Endogenous Land Supply

Agricultural policies in the USA have for some time made use of set-aside policies to restrain production and thereby reduce the costs of domestic agricultural policy interventions. Consequently one possible response would be for the USA to reduce the amount of land set-aside by restoring it to use in the production of switchgrass. When that is the case, the welfare change in the USA is marginally positive and although the changes in welfare are still negative for all other regions except south Asia, they are marginally less negative than in the calibrated case. Drawing land for switchgrass production from a ‘reserve’ of set-aside land has substantial impacts upon food and agricultural commodity prices in the USA; indeed it nullifies nearly all the increases in producer prices found with the earlier experiments. Nevertheless the impacts upon food and agricultural prices in developing regions are virtually identical to those for the calibrated simulation although the effects are still sufficient to produce small declines in food and agricultural production in southern Africa.

Figure 15 **Producers Prices for Food and Agricultural Commodities – USA and Developing Regions** (percent change)



Source: Model simulation results.

As before the dominant effect is through the effect of the substitution of crude oil by switchgrass upon demand for crude oil in the USA and the resulting appreciation of the USA’s exchange rate. The provision of excess land for use in the production of switchgrass marginally ameliorates the exchange rate effect, which confirms that a small part of the adverse exchange rate effects originates from changes in agricultural land use, but further strengthens the evidence that the effects within food and agriculture are dominated by those taking place in the crude oil and petroleum sectors, i.e., that they are genuine general equilibrium effects.

CONCLUDING COMMENTS

The paper reports results from a general equilibrium analysis of the effects of substituting switch grass for crude oil in the production of petroleum in the USA. The modeling framework accounts for the direct effect of an increase in demand for switchgrass and a decrease in demand for crude oil. There are linkages to the domestic economy in the USA as land is drawn out of other agricultural products, particularly cereals, and into switchgrass production. Since the USA is a major exporter of agricultural products, there are changes in production and trade in other regions as US exports decline. Changes in the global market for food and agricultural trade reduce production and imports in North Africa and South Africa. Developed regions, particularly the EU and Japan-Korea, benefit from an increased in export market share as the USA's market share declines. An important qualification of the results is the welfare measures do not account for the utility consumers derive from a cleaner environment; that measure may offset the welfare cost associated with a productivity loss as switchgrass replaces crude oil inputs.

The results for agricultural sectors are consistent with complementary partial equilibrium analysis (see for example De La Torre Ugarte, D, and Hellwinckel, C., 2004b). However, dominant changes to the global economy arise through the changes in the market for crude oil. As the USA, a major consumer of crude oil, imports less, its exchange rate appreciates relative to the currency in all other regions; it demands less foreign exchange because it consumes fewer imports. Also as a large country in the global market for crude oil, the terms of trade improve for the USA and deteriorate for crude oil exporters. Since the USA imports some crude oil from all regions in the model, the negative terms of trade effects influence welfare in all regions. Consequently, welfare declines for all other regions when the USA substitutes switchgrass for crude oil in production; in the one-to-one simulation the USA experiences a slight welfare gain through second best effects of changes in oil prices and taxes as production changes. But welfare declines for the USA when allowance is made for the quantity of switchgrass require to replace a unit of crude oil in the production of petroleum since this involves a productivity loss in the petroleum sector.

In addition alternative scenarios are analysed by way of sensitivity analyses. That seek to answer the question, “what changes in the economy would offset the welfare loss observed when switchgrass is substituted fore oil?” The results indicate that a 30 percent increase in factor productivity in the petroleum sector would offset the productivity loss associated with the substitution of switchgrass for crude oil. Likewise, an increase in switchgrass production based upon land that was previously set aside would offset the welfare losses in the USA increases.

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APPENDIX 1 ACCOUNT MAPPINGS

Model Sectors		
Code	**Description**	**GTAP Sectors**
cer	Cereals	Paddy rice, Wheat, Cereal grains nec, Oil seeds
swgr	Switchgrass	
ocrp	Other crops	Vegetables fruit nuts, Sugar cane sugar beet, Plant based fibres, Crops nec, Forestry
lstoc	Livestock	Bovine cattle sheep and goats horses, Animal products nec, Raw milk, Wool silk worm cocoons, Fishing
mins	Minerals	Coal, Oil, Gas, Minerals nec
fod	Food Processing	Bovine cattle sheep and goat horse meat prods, Meat products nec, Vegetable oils and fats, Dairy products, Processed rice, Sugar, Food products nec, Beverages and tobacco products
text	Textiles	Textiles, Wearing apparel, Leather products
olman	Other light manufacturing	Wood products, Paper products publishing, Electronic equipment, Manufactures nec
pet	Petroleum etc	Petroleum coal products
chem	Chemicals etc	Chemical rubber plastic products
hmanu	Heavy manufacturing	Mineral products nec Ferrous metals, Metals nec, Metal products, Motor vehicles and parts, Transport equipment nec, Machinery and equipment nec
cons	Construction	Construction
elec	Electricity	Electricity
gasw	Gas and Water	Gas manufacture distribution, Water
trad	Trade and Transport	Trade, Transport nec, sea transport, Air transport, Communication
serv	Services	Financial services nec, Insurance, Business services nec, Recreation and other services, PubAdmin Defence Health Educat, Dwellings

Model Regions		
Code	**Description**	**GTAP Regions**
anz	Australia and NZ	Australia , New Zealand
chin	China HK Taiwan	China, Hong Kong , Taiwan

easia	East Asia	Indonesia , Malaysia, Philippines, Singapore , Thailand, Viet Nam
eur	European Union	Austria, Denmark, France , Germany, United Kingdom, Greece , Ireland, Italy, Netherlands, Portugal, Spain, Sweden , Belgium, Luxembourg
jkor	Japan and Korea	Japan, Korea
nafr	Northern Africa	Morocco, Rest of North Africa, Uganda , Rest of sub-Saharan Africa
rame	Rest of Americas	Canada , Mexico , Central America and the Caribbean
reur	Rest of Europe	Finland, Switzerland, Rest of EFTA , Cyprus , Malta, Hungary, Poland , Bulgaria, Czech Republic, Romania, Slovakia, Slovenia, Croatia, Albania, Estonia, Latvia , Lithuania
row	Rest of the World	Russian Federation , Rest of Former Soviet Union , Turkey , Rest of Middle East, Rest of World
same	South America	Colombia, Peru, Venezuela , Rest of Andean Pact, Argentina , Brazil , Chile, Uruguay, Rest of South America
sasia	South Asia	Bangladesh, India, Sri Lanka , Rest of South Asia
safr	Southern Africa	Botswana, South African Customs Union ex Botswana , Malawi , Mozambique, Tanzania, Zambia , Zimbabwe, Rest of southern Africa
usa	United States of America	United States of America