FOOD PRODUCTION VS. BIOMASS EXPORT VS. LAND-USE CHANGE: A CGE ANALYSIS FOR ARGENTINA

Perry, Miles

Centre for Environmental Policy, Imperial College, London

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Miles PERRY

Centre for Environmental Policy
Imperial College
London, SW7 2AZ, UK

miles.perry@imperial.ac.uk

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EXECUTIVE SUMMARY: This study explores the potential for the economy of Argentina to respond to a global surge in demand for biofuels by increasing its exports of key biofuel feedstocks. The purpose of the study is to complement existing studies that explore the technoeconomic potential for global trade in bioenergy by using a Computable General Equilibrium (CGE) model to assess the quantities of biomass that the economy of Argentina would be able to export in response to a biofuel-related demand shock and to assess the consequences of this shock on the rest of the economy and population. The study finds that, in response to a shock, the economy could increase exports of vegetable oils and oilseeds (the commodities for which the assumed world price increase is greatest) by 35%-66%. However, much of this increased production would come at the expense of other crops, such as cereals, for which lower world price rises are predicted. When the economy's land use and capital are permitted to expand, exports of oils and oilseeds increase by over 100% with less output foregone in other sectors. However, this benefit is nullified when land use expansion is prohibited and only capital stock permitted to expand. In most cases, the effects of the shock on the purchasing power of wage-earners are small but unambiguously negative. The study concludes that, if expansion of the agricultural area must be limited for reasons of climate protection, the ability of Argentine exports to respond to biofuel-related demand shock is approximately halved, with further negative consequences for the rest of the economy. It appears, therefore, that technological improvement is needed to enable Argentina to exploit global biomass markets while avoiding negative consequences for domestic workers or the global environment. However, even in this case, domestic workers would only benefit indirectly since 1st generation biofuel crops are not labour-intensive. In addition, since additional land is crucial to Argentina's ability to benefit from increased biofuel demand, further research is required into the sustainability, availability and commercial viability of agricultural land expansion in the country.

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CONTENTS

1 INTRODUCTION

In recent years, the conversion of agricultural crops such as cereals, oilseeds and sugar crops into biofuels has provided a new market for agricultural commodities. This market is set to expand considerably between now and 2020 as a result of policies to replace fossil fuels with biofuels in the EU and US. Such policies could lead to a large expansion in world agricultural trade as major markets import biofuels, their feedstocks or other agricultural products to replace domestic production that has switched to biofuels.

From a technoeconomic point of view, several studies have established the possibility of exporting biomass from third countries to these markets without threatening agricultural self-sufficiency or using land required for nature conservation or carbon sequestration [1] [2]. At the same time, the prevalence of deforestation and its link to demand for land-intensive products has been documented in studies such as Morton *et al.* [3] and Nepstad [4]. Until recently, few studies have linked the potential for bioenergy trade and its potential consequences for other land uses to competition for resources in a market economy.

This paper examines these consequences for the case of Argentina, a significant exporter of both cereals and oilseeds to world markets. To do this, we use a purpose-built computable general equilibrium (CGE) model, BioTradeLand, to simulate the economy-wide effects of increased global demand for biofuel feedstocks on potential exporting country. Although CGE is not the most sophisticated tool for biophysical modelling and assessment of land use change, its comparative advantage lies in its ability to jointly consider the impacts of competing demands on an economy's natural resources without resorting to resource allocation mechanisms chosen subjectively. In this way, this study complements existing studies that analyse bioenergy potential from a technical or technoeconomic perspective. Section 2 provides background information in the form of a brief overview of existing studies into the economic and environmental impacts of biofuel demand and the agricultural sector in Argentina. Section 3 describes the features of the model used to analyse the effects of bioenergy demand while Section 4 describes the scenarios that are used as model inputs. The results are presented in Section 5 and analysed in Section 6 where areas for improvement of the analysis are also discussed. Conclusions are drawn in Section 7.

2 BACKGROUND INFORMATION

2.1 Existing Studies of Bioenergy Potential

Studies of global bioenergy potential estimate that 47-450 EJ [5] or even over 1000 EJ [2] [6] could be produced in the long-term. While studies of this kind typically take account of the need to ensure adequate food production and preserve land for biodiversity and carbon storage, trade-offs between these land uses are typically avoided by using some kind of hierarchical allocation mechanism, such as only allowing biomass to be cultivated on land not required for food.

More recently, several initiatives have been undertaken to incorporate bioenergy and land-use change into existing world economic models that have an agricultural focus. Searchinger *et al.* [7] use the CARD model to analyse the effect of doubling US production of corn ethanol by 2016 and estimate that 10.8 Mha of additional land would be cultivated worldwide, with associated GHG emissions requiring several decades of fossil fuel replacement to be repaid. The European Commission [8] estimates that a 10% EU biofuels target in 2020 (of which 30% is met by 2nd generation biofuels) will lead to a 3-6% increase in cereal prices and an 8-15% rise in oilseed prices compared to business as usual. Greater increases are estimated by IFPRI [9] in a scenario where all current planned biofuel investments are realized. Banse *et al.* [10] use a version of the GTAP world trade model, modified to allow land-use change and more detailed land characterisation, to estimate the effects of the EU Biofuels Directive 2003/30/EC[1] on world agricultural markets. They find that the Directive will lead to increased agricultural land use worldwide, compared to the reference scenario, with the most substantial increase occurring in South America.

In this paper, the trade-offs between bioenergy and other land uses are examined using a small, open-economy CGE model of a single country — Argentina. CGE is a modelling technique in which the whole economy is characterised as a closed system where economic agents simultaneously consume scarce resources to maximize their welfare (consumers maximize consumption utility, producers minimise cost and maximise profit) according to the laws of Walrasian general equilibrium[2]. Previous examples of equilibrium modelling involving bioenergy include CGE analysis of the potential for producing electricity from woody biomass in Poland [11] and a partial equilibrium analysis of the potential for energy crops to be planted (and compete with the planting of food crops) in the USA in response to a carbon price [12].

2.2 Background about Argentina.

In the year 2000, the base year for the BioTradeLand model, Argentina exported $4.1 billion of vegetable oils and co-products, $1.2 billion of wheat, $1 billion of maize and $776 million of soya beans: products that can be used as foodstuffs or bioenergy feedstocks. In 2007, Argentina was the 2nd largest exporter of maize to the EU, supplying 2.7 Mt. Argentina also exported 357,000 t of vegetable oils and animal fats, 313,000 t of soybeans and 8,521 t of wheat to the EU [13]. Between 2000 and 2006, the harvested area for soybeans in Argentina increased by 74% while the area harvested for wheat and maize fell by 15% and 21% respectively. The area harvested for the 3 crops combined increased by 27% to reach 23 Mha [14].

The country has a surface area of 281 Mha, of which 96 Mha is classified as pastureland, 78 Mha as grassland, 38 Mha as shrubland, 34 Mha as cropland and 19 Mha as forest [15]. This data is from the GTAP land-use database, which reports data from around the year 2000. In this year, the total harvested area was 30 Mha, implying that most agricultural land was under cultivation[3].

3 BIOTRADELAND MODEL AND DATA

3.1 Model Structure and Economic Data

The BioTradeLand model is a comparative static CGE model of the Argentine economy, calibrated to the year 2000. For analysis of bioenergy trade, this type of model has a number of strengths as well as limitations. Its most notable features are the following.

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[1] This Directive calls for a 5.75% biofuel blend in EU transport fuels by 2010.

[2] For an introduction to CGE in principle and practice, see Wing I S. *Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis.* MIT Joint Program on the Science and Policy of Global Change. 2004.

- *The model is independent of time:* When shocks are applied to the model, economic actors adjust their production and consumption choices to the new reality that represents the same conditions as the Baseline except for a number of specified changes. This has the advantage of allowing us to investigate *what if?* questions surrounding the effects of a bioenergy demand shock under *ceteris paribus* conditions. However, the use of such abstract conditions limits the model's predictive power since it does not capture the ways in which, in reality, the economy would adapt gradually to a sustained change.

- *Land, labour and capital are fundamentally scarce:* In a classic CGE model, these three resources are only available in fixed quantities. This means that if resources are to be diverted towards a particular sector, sacrifices must be made elsewhere. This condition also means that a bioenergy demand shock can affect real wages, land rental rates and the price of capital. However, the assumption that these quantities are fixed also ignores phenomena such as land-use change, population growth and capital investment over time. We therefore relax this assumption for some of the model runs undertaken in this study.

- *Producers can substitute between factor inputs:* In the model, each unit of output per sector requires a fixed quantity of intermediate inputs. The sector also requires inputs of factors of production (land, labour, capital). However, some substitution between these inputs is permitted, allowing industries to become more land, labour or capital-intensive depending on the economic environment.

- *Technology does not change:* Aside from the substitutability of factors of production, production technology does not change. This is an important limitation of this study since reductions in production cost and improvements in agricultural yields are not considered.

- *The exchange rate is flexible:* Trade is characterised in the model as the sale of output for foreign exchange. Actors in the domestic economy demand foreign exchange as a way of paying for imports. The exchange rate (i.e. the price of foreign currency) is affected by the supply and demand for foreign currency. In reality, the exchange rate is affected by many other factors, or may be managed by monetary authorities. Nevertheless, the use of a flexible exchange rate, in which an increase in the price of an economy's main exports leads to an appreciation of the domestic currency, is considered a reasonable assumption.

The source data for the BioTradeLand model is the Social Accounting Matrix (SAM) of Argentina in the year 2000 developed by Petri *et al.* [16] and used as the source data for the Argentina section of the GTAP model. A SAM is a matrix representing all economic activity in a given year as a series of sales and purchases between sectors of the economy (an Input-Output table). As well as the traditional Input-Output elements, a SAM also includes all sales, purchases and financial flows between institutions such as households, government, and the outside world, thus representing the Walrasian economy and circular flow of income. The model is written in the GAMS/MPSGE programming language. This allows the trade-offs made by producers and consumers, when allocating scarce resources between final output and productive input respectively, to be characterised by a series of equations. The extent to which factors of production into a given output are substitutable is characterised by Constant Elasticity of Substitution (CES) functions in which the elasticity parameter can range from zero (they are not substitutable and must be used in fixed proportions) to ∞ (they are perfectly substitutable). A more detailed description of the BioTradeLand model is given in Annex A.

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[3] Harvested area is not directly compatible with land area since areas that are cultivated multiple times within a given year are recorded multiple times. The ability to perform multicropping depends on the suitability of the land and climate, and the level of investment in agricultural inputs and infrastructure. We are not aware of the extent to which multicropping occurs in Argentina.

Since we are primarily interested in agricultural and land-using sectors, the original SAM has been aggregated into 22 industrial sectors (plus financial flows and institutions). Industrial sectors not immediately related to bioenergy trade are aggregated to a greater degree than agricultural and land-using sectors of the economy. The elasticity parameters for the BioTradeland model are taken from the version 5 of the GTAP database [17] with the exception of consumer preferences for which a Cobb-Douglas function is used.

We made two disaggregations of the original SAM data in order to improve the BioTradeLand model's ability to analyse bioenergy trade and land-use. Firstly the original SAM contained two primary inputs into production, 'capital' and 'labour' where 'capital' is a residual category representing all value-added not accounted for by labour or intermediate inputs. Since this study is particularly interested in the relationship between biomass trade and land-use, we split the residual 'capital' sector into its component land and capital elements. To do this we take the shares of land in primary value added from the RunGTAP database [18]. The second disaggregation uses the SAM's source data [19] to separate the outputs of the vegetable oil sector into oil (a potential feedstock for 1st generation biodiesel) and meal (an animal feed with potential applications in heat and power). This process is discussed in greater detail in Section 4.2.

3.2 Agricultural land use in the base year

Detailed data concerning harvested land area, yields and crop production for the year 2000, split between a number of Agro-Ecological Zones, is available from the GTAP Land Use Database (GLUD) [15]. The total area harvested for crops in the base year was 30 Mha, compared to 34 Mha of designated cropland [14]. This implies that without improvements in agricultural productivity, substantial increases in crop cultivation will need to be achieved by conversion to agriculture of shrubland, grassland, forest or pasture (the current extent of pastureland may be larger than that actually required to support the grazing population).

4 SCENARIOS

In order to investigate the effect of foreign biofuel demand on the Argentine economy, 3 sets of *ceteris paribus* shocks are used. This means that the model replicating the baseline (year 2000) economic conditions is left unaltered, apart from the shocks and changes mentioned. The following 3 scenarios are used:

World Price Shocks: world prices for tradable products are altered in order to simulate increased global demand for biofuels and feedstocks.
Split Model: the vegetable oil (*aceites*) sector is disaggregated into its two main products.
Infinite Supply: in the Baseline, land and capital are available in fixed quantities with prices set endogenously. We also consider a situation where land and/or capital are assumed to be available in infinite quantities at a constant price.

The above scenarios are not mutually exclusive and can be run simultaneously. Theoretically, 36 distinct outcomes (3*4*3) can be obtained through combinations of the 3 scenarios described. However, outcomes are only obtained for scenario combinations believed to add value to the analysis.

4.1 World Price Shocks

The effect of policies promoting biofuels on world agricultural markets has been analysed by the European Commission [8] and IFPRI [9]. An important feature of a price shock based on the demand for biofuels is that the prices of agricultural outputs will be affected simultaneously but to different extents. For this reason, we impose the set of price changes shown in Table I on the Argentine economy. These are based on Schmidhuber's [20] analysis of the effect of adding an additional 10 million tonnes to the global demand for sugar, maize and soybeans. We also consider an alternative set of price shocks, based on IFPRI analysis of the price premium predicted as a result of currently planned biofuels policies [9].

Table I: Changes in world prices entered into BioTradeLand model

Commodity	Basic Shock (Schmidhuber)	Alternative Shock (IFPRI)
Wheat	+2%	+8.3%
Maize	+4.2%	+26%
Other Cereals	+2%	+8.3%
Soybeans	+7.8%	+18%
Sunflower Seeds	+7.8%	+18%
Other Oilseeds	+7.8%	+18%
Vegetable Oil	+7.8%	+18%
Rice	+1.4%	-
Beef	+0.4%	-
Poultry	-2%	-
Oil Meals*	-7.6%	-

* Price change for oil meals only applied to scenarios where oil and meal are separated

4.2 Split Model

Given Schmidhuber's analysis [20] that a purely biofuel-driven demand shock would have divergent effects on world prices for oilseeds and oil meals, we consider a variation of the model in which these two outputs of the *aceites* sector are split, allowing them to be sold to different markets for different prices. The split is obtained by making the following assumptions, based on the SAM source data [19]:

- Oil and meal are the only outputs from the *aceites* sector (in reality they account for 96% of the sector's production). They are produced in constant proportions.
- Other sectors consume oil and meal in constant relative proportions, shown in Table II. In addition, domestic final consumers are assumed not to consume meal (they do not in the base year). *Aceites* also forms a constant proportion of annual production to inventory, meal is assumed to account for a constant 33% of this.
- Meal accounts for 51% of the export revenue from the *aceites* sector in the base year and 2% of *aceites* imports. The model assumes all exports are perfectly substitutable as means of acquiring foreign exchange (which is used to purchase imports). Therefore, although the products must be produced in fixed proportions, the proportion of oil exports to meal exports can vary.

- The fraction of meal in domestic *aceites* production in the baseline is calculated as a residual quantity based on the information given above. i.e.:

Domestic Meal Production = Intermediate Sales
+ Sales to Inventory
+ Exports
- Imports

In summary, this means that the proportion of oil and meal consumed in the economy can vary by the following means:
- Consumers can substitute between oil and other goods in consumption
- As the composition of domestic output changes, the relative requirement for oil and meal as intermediate inputs will change
- There is no restriction on the relative quantities in which oil and meal can be imported or exported.

Table II: Purchases of Oil and Meal as Intermediates

Sector	Oil	Meal
Meat & processed foods	87%	13%
Livestock	0%	100%
Fish & Mineral	100%	0%
Beverages	91%	9%
Textiles	85%	15%
Petrochemical	100%	0%
Construction	100%	0%
Services	100%	0%

Source: Based on [19]

4.3 Infinite Supply

In the first simulations, the Basic Shock is applied to a comparative static model in which primary factors of production are available in fixed quantities. Although informative, this framework provides little insight into the issue of land-use change since expansion of the agricultural area is merely assumed not to occur. We therefore, include two further variants:

i) *Infinite Supply:* in which land and capital are available at a constant price with no restriction placed on the quantity employed and
ii) *Infinite Supply, Land Fixed*: in which capital is available at a constant price but expansion of the total agricultural land area is not permitted.

The two *Infinite Supply* variants are used to reflect the fact that, over the medium-term, it may be possible for domestic output to respond to a biofuel-driven shock by bringing additional land into production or increasing capital investment. This idea is comparable to the use of comparative steady state models, such as Rutherford & Tarr [21], in CGE analysis. However, the *Infinite Supply* variants should not be considered steady state. In comparative steady state analysis, the rental rate of capital is fixed as the difference between the current purchase price of a unit of capital and the present value of a depreciated unit of capital in the next period. In the *Infinite Supply* model, by contrast, the rental rate for capital (and land where applicable) is fixed at the same rate as in the base year.

5 RESULTS

5.1 World Price Shocks

In both the Basic and Alternative shocks, production of wheat falls by over 30% while production in the vegetable oil sector increases by over 50% and substantial production increases are recorded in all oilseed sectors. In the Alternative shock, where the largest price increase is for maize, production of maize increases by 20%. However, even in this scenario the proportional increase in oil and oilseed production is greater. Falls in production are registered in all other land-using sectors, while production falls in all other sectors, though generally by less than 5%.

Table III: Change in domestic production in comparative static model due to price shocks

Commodity % Change in Production	Basic Shock	Alternative Shock
Wheat	-32.9%	-44.2%
Maize	-13.0%	+20.9%
Soybeans	+36.8%	+51.6%
Sunflower Seeds	+46.3%	+68.3%
Other Oilseeds	+20.7%	+23.9%
Vegetable Oils (single commodity)	+55.4%	+82.5%
Other plant products	-3.8%	-7.1%
Meat & Processed Foods	-4.2%	-7.8%
Livestock	-4.4%	-8.1%

In the Basic shock, wheat exports fall by 50.7% while exports of vegetable oils, sunflower seeds and soybeans increase by 66%, 48% and 35% respectively. In the Alternative Shock, the effect on each crop is similar, though the response is greater. In this scenario, exports of vegetable oils increase by 100%.

Final consumption of all cereals and oilseeds falls by 6-7% in the Basic Shock while changes of between -1% and +1% are recorded for non-agricultural products such as manufactures, clothes, beverages and textiles. The overall effect on consumption is broadly neutral, increasing by less than 1% although this is mainly due to a small increase in consumption of services which account for 73% of domestic spending. Since the BioTradeLand model features a single representative agent as consumer and owner of land, labour and capital, this finding should not be interpreted as evidence that bioenergy expansion has a broadly neutral effect on consumers' welfare overall. A more insightful measure is the effect on the real wage (cost of labour / cost of the composite consumption good) and purchasing power for particular products. Here, the overall purchasing power of labour falls by less than 1%, although the purchasing power of labour in terms of fruits & vegetables, cereals and meat & processed foods falls by 5.6%, 7% and 2.8% respectively.

5.2 Split Model

When the Basic Shock is applied to the Split Model with no change in the price of oil meal, production in the *aceites* sector increases by 29% above the baseline (compared to 55% in the unsplit model). When the Basic Shock, including a 7.6% fall in the price of oil meal, is applied to the Split Model, the production of vegetable oil falls slightly (by under 1%) while increases in production of soybeans and sunflower seeds are reduced from over 30% to 6.0% and 1.5% respectively. The growth in production of other oilseeds (a lower proportion of which enter the *aceites* sector) remains at around 20%. Production of maize, which falls in the version of the model that has a homogenous vegetable oil sector, increases by 7.2%. The increase in exports from the *aceites* sector is also largely eliminated in the scenario where meal prices fall, as shown in Figure 1.

As in the non-split model, the overall effect of the shock on wage purchasing power is slightly negative. However, when the model is split, with only the oil element of *aceites* experiencing a sharp price rise, the negative effect on consumers' purchasing power is considerably lessened. Compared to the Basic Shock the fall in workers' ability to purchase foodstuffs is less pronounced in the Split Model due to a combination of higher real wages and lower rises in domestic prices. This is shown in Table IV.

Table IV: Purchasing Power of Wages in Different Split Model Variations

	% Change from Baseline		
	Basic Shock	Split Model	Split Model: Meal Price Drop
Real Wage[1]	-0.5	-0.3	-0.2
Wage Purchasing Power: Crops (various)	-5.5 - -9.2	-3.5 - -5.9	-1.7 - -2.9
Wage Purchasing Power: Meat & Processed Foods	-2.8	-1.7	-0.7

Notes:

1 – Real Wage is the price of labour relative to *cons* the composite basket of goods and services consumed by households.

5.3 Infinite Supply Model

As an alternative to the comparative static model, in which all factor endowments are fixed, we consider several scenarios in which additional land and/or capital can be brought into production at a constant price – the Infinite Supply Models. The ability to procure additional land and capital amplifies the effect of the Basic Shock considerably, compared to the scenario where supply of these factors is fixed. In all model runs where availability of land and capital is unrestricted, production and export of oils and oilseeds increases by 100% while production in most (but not all) other sectors is sacrificed to a lesser extent. In Infinite Supply Split Model outcomes, the availability of additional land and capital appears to lessen the negative effect of the unchanged (or reduced) meal price on production and exports from the *aceites* sector. Changes in exports in different Infinite Supply outcomes are shown in Figure 2. In the Split Model with Infinite Supply, production from the sector increases by 102% compared to the Baseline. This falls only slightly, to 100%, when a fall in the meal price is included.

In contrast to simulations in the comparative static model, a slight increase in workers' purchasing power is noted for all commodities in the Infinite Supply Model. This includes mass export products such as sunflower seed and soybeans. The extra resources required to produce this output in the Infinite Supply Model with Full Split and a fall in the price of oil meal are a 23.5% increase in the productive land resource and 2.3% increase in the capital stock. The increase in land use refers to a 23.5% increase in the land units measured in the SAM. This consists of value-added measured in USD2000. An increase of 23.5% does not therefore correspond to an increase of this magnitude in land area under cultivation. In order to equate this quantity to a physical area of land more detailed information about suitability and yields of surplus agricultural land is required. Assuming that yields exhibit diminishing marginal returns as cultivated area expands, it is reasonable to assume that an increase in area of over 23.5% would be needed in order to increase value-added by this amount.

We also consider a no land-use change scenario in which the endowment of both land and labour is fixed but the price of capital is held constant. This may be considered the most desirable scenario of all the combinations described in Section 4 since it represents a situation where biomass export cannot lead to agricultural land expansion but limitless capital investment is permitted.

Allowing the quantity of capital employed under the Basic Shock to vary produces very little response in terms of increased domestic production, as Figure 3 and Table V show.

Table V: % change in production following Basic Shock: with & without variability in quantities of land and capital employed

	Basic Shock	**Fixed Price: Land & Capital**	**Fixed Price Capital Only**
Wheat	-32.92%	-23.39%	-33.01%
Maize	-12.96%	+19.79%	-13.04%
Soybeans	+36.80%	+133.00%	+37.02%
Sunflower	+46.32%	+155.00%	+46.58%
Vegetable Oils	+55.36%	+182.32%	+55.70%

When land and capital are permitted to expand, the real wage increases by 2% and improvements in worker purchasing power are registered even for cereals, oilseeds and vegetable oil. However, when land is fixed, worker purchasing power falls by 0.6% with greater falls for crops and food products. This is shown in Figure 4.

When land supply is fixed, the amount of capital stock employed actually falls by 0.3% compared to the baseline while the price of productive land increases by 23.1%.

6 DISCUSSION

6.1 Quantities of Bioenergy Crops Exported

The quantity of cereals, oilseeds and vegetable oils that Argentina would release onto world markets in the scenarios discussed in Section 5 are shown in Table VI below. These are obtained by multiplying the model results (which are given in real monetary terms) by the physical quantities exported from Argentina in 2000. It should be noted that when the *aceites* sector is not split, relative shares of oil and meal cannot be calculated by the model. Apart from in the Split Model, the quantities for these products shown in Table VI are merely illustrative.

Table VI: Quantities of Agricultural Exports in Different Model Scenarios

	Quantity Exported (Mt)				
	Year 2000	Basic Shock	Infinite Supply	Infinite Supply: Fixed Land Supply	Split Model: Meal Price Drop
Aceites	19.7	32.8	62.0	32.9	19.7
Vegetable Oil**	4.8	8.0	15.1	8.0	4.9
Meal**	14.9	24.8	46.9	24.9	14.8
Soybeans	4.1	5.6	10.9	5.6	5.3
Sunflower Seed	0.3	0.4	0.8	0.4	0.3
Maize	10.8	8.2	11.1	8.2	12.1
Wheat	11.0	5.4	6.9	5.4	10.2

Notes:

Year 2000 exports from FAOSTAT [14]

** Apart from in the Split Model, the share of oil and meal in *aceites* exports is purely illustrative. Each product is assumed to have the same share of *aceites* exports as in 2000.

6.2 Land Expansion and Workers' Purchasing Power

When expansion of land and capital is permitted, the Basic Shock results in an improvement of workers' purchasing power for all products. This is not surprising since the real wage is increased due to increased global demand leading to greater demand for factor inputs and increased returns to the only scarce factor – labour. At the same time, the availability of additional factors of production lessens the extent to which domestic prices increase as a result of the demand shock.

However, when the productive land area is held fixed and only the capital stock is permitted to expand, the effect of the Basic Shock on workers' purchasing power is strongly negative, as Figure 4 shows. In this case, wage purchasing power of crops falls by 5.7%-9.3%. The food categories of greatest relevance are those consumed directly by households. These are "meat" (a general processed food category including prepared foods, dairy and milled products) and "plant" (a category that includes the crops most commonly purchased by consumers such as rice, potatoes, fruits and vegetables). The fall in consumer's purchasing power for "plant" is 5.6% while the fall in purchasing power for "meat" is less pronounced. Purchasing power for this sector's output falls by only 2.9%, reflecting the fact that land is used indirectly in this sector with crops and livestock accounting for 6.9% and 18.2%

of the sector's inputs respectively.

The contrast in purchasing power between these 2 model variants appears to be mainly due to technological structure of the sectors most affected by the Basic Shock, soybeans, sunflower seeds and vegetable oils.

As Table VII shows, soybeans and sunflower seeds use land and capital most intensively as factor inputs.

Table VII: Share of land, labour and capital per unit of output in the base year

	Soybeans	**Sunflower Seeds**	**Vegetable Oils**
Land	0.27	0.25	0.00
Labour	0.05	0.05	0.03
Capital	0.26	0.24	0.05

When the economy moves from the baseline equilibrium to the Basic Shock, production of oilseeds and vegetable oils for export becomes relatively more attractive. To increase production of these products, it is necessary to divert land, labour, capital and intermediate inputs into these sectors. Since the elasticity of substitution between land, labour and capital is less than 1, it is only possible to change the proportions in which these inputs are used, to a limited extent[4]. When additional capital and land can be purchased for a constant price, substitutability between factor inputs is not a significant barrier to expansion of production since, as Table VII shows, relatively small quantities of extra labour need to be diverted from other sectors in order to expand output.

As a result of the relatively small labour requirement, the sunflower and soybean sectors are able to expand production while maintaining the same input structure as before the shock, as demonstrated by the 3rd column of Table VIII. Although these sectors' labour requirement increases almost 3 times, the labour required by the sector after the shock represents only 0.55% of the economy's labour resource.

[4] $\sigma < 1$ means that, *ceteris paribus*, each additional unit of a given input yields a less than proportional increase in output.

Table VIII: Change in factor inputs[5] to the sunflower and oilseed sectors when land and capital prices are held constant (labour supply is fixed)

	Baseline (USD2000, billion)	**Basic Shock, Infinite Supply (USD2000, billion)**	**Change**
Labour Input: Soybeans	0.19	0.45	**131.85%**
Labour Input: Sunflower	0.05	0.13	**153.75%**
Capital Input: Soybeans	0.95	2.22	**133.01%**
Capital Input: Sunflower	0.24	0.62	**155.01%**
Land Input: Soybeans	1.07	2.48	**133.01%**
Land Input: Sunflower	0.27	0.69	**155.01%**

When the total land resource is not permitted to expand, the oilseed sectors respond to the shock by becoming more labour and capital-intensive, Table IX shows. Although vegetable oils are not a land-intensive sector, their response to the Basic Shock echoes that of oilseeds since soybeans and sunflower seeds account for 57% of vegetable oil inputs.

[5] The units in of the SAM these tables are year 2000 USD. Therefore they do not by themselves directly correspond to a certain number of labour-hours or quantity of produce. However, the units are real (i.e. non-nominal) and are therefore directly comparable before and after the shock.

Table IX: Change in factor inputs to the sunflower and soybean sectors when only capital prices are held constant (land and labour supply are fixed)

	Baseline (USD2000, billion)	Basic Shock, Infinite Supply, Land Fixed (USD2000, billion)	Change
Labour Input: Soybeans	0.19	0.27	**40.59%**
Labour Input: Sunflower	0.05	0.07	**50.40%**
Capital Input: Soybeans	0.95	1.34	**40.39%**
Capital Input: Sunflower	0.24	0.36	**50.19%**
Land Input: Soybeans	1.07	1.42	**33.54%**
Land Input: Sunflower	0.27	0.39	**42.87%**

The large fall in workers' purchasing power in the fixed-land-supply variant has two main causes. Firstly, the domestic prices for agricultural products increase by 5.5-9.6%, whereas in the scenario where land expansion is permitted, prices increase by less than 1%. Secondly, the real wage falls (by 0.6%) in the Infinite Supply, fixed-land outcome compared to an increase of 2% when additional land is permitted.

The fall in the real wage in the Infinite Supply, fixed-land outcome is also greater than the fall observed from the Basic Shock (when land, labour and capital are available in fixed quantities) despite the possibility of obtaining additional capital. This is because the fixing of the capital price actually leads to a net decrease in the quantity of capital used and hence a fall in the productivity of labour. There is an increase of 9%, 12% and 38% in the amount of capital used by the *aceites*, sunflower seed and soybean sectors respectively but this is outweighed by the decrease in capital used by other sectors.

6.3 Land Expansion and Geography of Argentina

According to the GTAP Land-use Database [17], the area of cropland harvested in the base year was 30Mha (excluding forestry and pasture). In the Infinite Supply simulation where expansion of land and capital stock is permitted, the land input to crops increases by 54% while the land input into livestock production falls but by only 0.06%, leading to a 38% increase overall. It should be pointed out that this scale of cultivation should not be considered a conservative estimate since we consider neither an increase in rental rates, nor a deterioration in attainable yield as land becomes more scarce.

An expansion of cropland on this scale would require an additional 16.2 Mha of cropland, exceeding the 4 Mha of apparently surplus cropland available in 2000 and requiring conversion of other land types to agriculture. In 2006, cropland harvested in Argentina reached 32.45 Mha, 8% or 2.45 Mha greater than in the base year. Over the same period, the deflated FAO Food Price Index (which includes cereals and vegetable oils) rose by 22.4% from 2000-2006[6] [22]. In nominal terms, the index rose by 37% while its component cereals and oils & fats elements rose by 43.5% and 62.5% respectively.

One possible symptom of a bioenergy-driven demand shock as opposed to a general increase in demand for agricultural products (such as that caused by a global trend towards meat-based diets) is the extent to which the price of meals has grown more slowly than that of vegetable oils and other agricultural products. By March 2008, the FAO oilcakes index had increased by 170% compared to its level in 2000 while the FAO oilseeds index had risen by 238%. This offers some evidence of a greater relative increase in demand for vegetable oils compared to oil meals. However, the real price of oilcakes still recorded a 72.2% price increase in real terms over this period.

The conversion of an additional 16.2 Mha of land to agriculture would be roughly equivalent to conversion of half of Argentina's shrubland to agriculture, as Table X shows.

Table X: Extent of Land Cover by type in Argentina, 2000.

Land Cover Type	Land Area (Ha)
Forest	19,915,922
Savanna Grassland	77,716,558
Shrubland	38,219,651
Cropland	34,010,533
Pastureland	96,452,178
Builtupland	1,064,915
Otherland	13,828,819

Source: [15]

6.4 Limitations of the model and areas for improvement

The BioTradeLand model presented in this paper has demonstrated some of the economic and environmental effects of imposing foreign biofuel demand on a business-as-usual agricultural economy. Due to its all-encompassing nature, several of the model's assumptions are simplistic and could be refined in order to improve the analysis. Most notable among these are:

- introducing an expandable land frontier that is more sophisticated than merely allowing additional homogenous land to be purchased for a constant price.
- analysis of the feasibility of transferring land, labour and capital between economic uses. Currently the model has no barriers to factor mobility.

[6] The Food Price and Oilcake indices are deflated using the index of unit value of global exports of manufactured goods (MUV), as recommended in FAO, *Soaring Food Prices: Facts, Perspectives, Impacts and Actions Required*. Report for High-level Conference on World Food Security: the Challenges of Climate and Bioenergy, Rome 3-5 June, 2008.

7 CONCLUSIONS

This study has used CGE analysis to explore the response of the Argentine economy to an expansion in global demand for biofuels and their feedstocks. Due to the limitations of comparative static CGE modelling and the simplifying assumptions made, these responses should not be seen as authoritative forecasts. However, by comparing the response of the economy under a series of different circumstances, the following conclusions can be drawn:

- An increase in global biomass demand such as that suggested by Schmidhuber [20] appears to lead to an expansion in the production and export of vegetable oils and oilseeds from Argentina. This expansion occurs primarily at the expense of other agricultural products (notably cereals) that experience a smaller boost in world prices.

- When the oil crushing (*aceites*) sector is disaggregated and meal assumed not to experience the same demand shift as the oil itself, the boost in production and export of vegetable oils following the same demand shock is reduced. This situation also leads to less output in other sectors of the economy being sacrificed.

- Availability of additional land and capital has a significant effect on the economy's ability to respond to the same demand shock. When use of both resources can be increased, the production and export of oils and oilseeds increases by more than 100%. At the same time, other sectors of the economy, notably maize and other crops, are able to increase their production.

- Availability of additional capital without the ability to expand land use severely hampers the ability of the economy to respond to the demand shock. This leads to a boost in biomass exports that is not substantially different from that produced when the available quantities of land, labour and capital are fixed (see Table VI).

- In most circumstances, the imposition of the demand shock leads to a slight fall in the real wage of 0.15% - 0.45%. However, the real wage is mainly affected by services. Purchasing power of wages for the most relevant foodstuffs falls by 2.8% (meats and processed foods) and 5.6% (fruits, vegetables and other consumer crops). These falls are smaller than those observed in consumers' ability to purchase the most common biofuel feedstocks such as maize and wheat.

- When additional land and capital are both available, the purchasing power of the real wage increases for all consumer products. However, when the supply of land is fixed, the purchasing power of wages falls. This is because the economy's production structures are unable to absorb the additional quantities of capital that are hypothetically available and could increase the economy's output and the productivity of workers.

Given that the model presented here does not analyse different types of consumer in detail, the observed effect on consumers' welfare should be treated with caution. Since the impact of the shock on workers' overall purchasing power is low, it may be that many people experience adverse effects that are extremely small. If such welfare losses were accompanied by substantial improvements in employment and wages, for example amongst the rural poor, one might even conclude that a bioenergy shock would have a positive welfare effect overall. However, given that the biofuel feedstocks identified are not labour-intensive, it appears unlikely that this would be the case.

The overall conclusion from this analysis is that, in the event of a biofuels-based demand shock, a restriction on the expansion of agricultural land in Argentina would reduce the quantities of oilseeds and vegetable oils made available to world markets by around 50% compared to the amounts hypothetically available in the absence of such a restriction. At the same time, the output from other sectors and purchasing power of workers would deteriorate.

If expansion of the area under conventional agriculture is ruled out for reasons of climate protection then mere availability of additional capital to invest in current agricultural technologies would be insufficient to enable countries such as Argentina to export substantial quantities of biomass without adverse effects for the rest of the economy and working population. To achieve this end, new technologies and particularly the use of feedstocks that are both competitive and labour-intensive would be required. Technological improvements in the existing capital-intensive agricultural sectors would not benefit workers directly but could benefit the economy overall by requiring fewer other outputs to be sacrificed in order to produce biomass exports.

8 FIGURES

Figure 1: Change in Exports, relative to baseline, in Split Mode

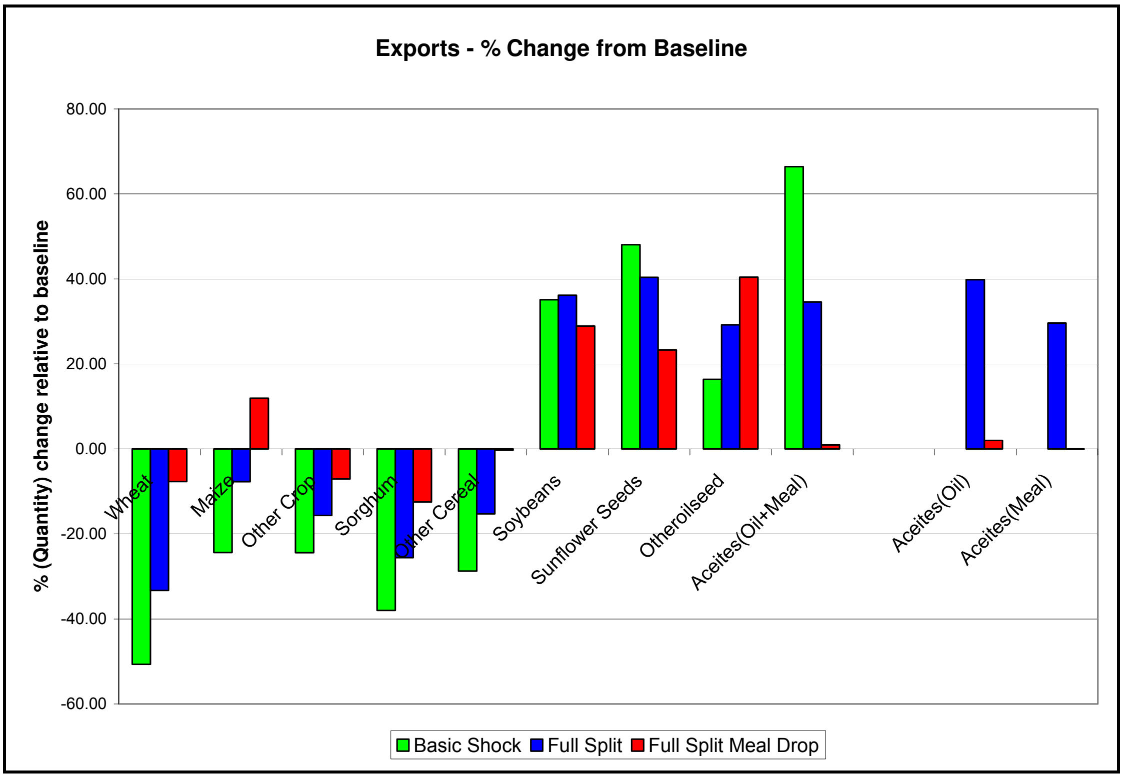


Figure 2: Change in Exports, relative to baseline, in Infinite Supply Model

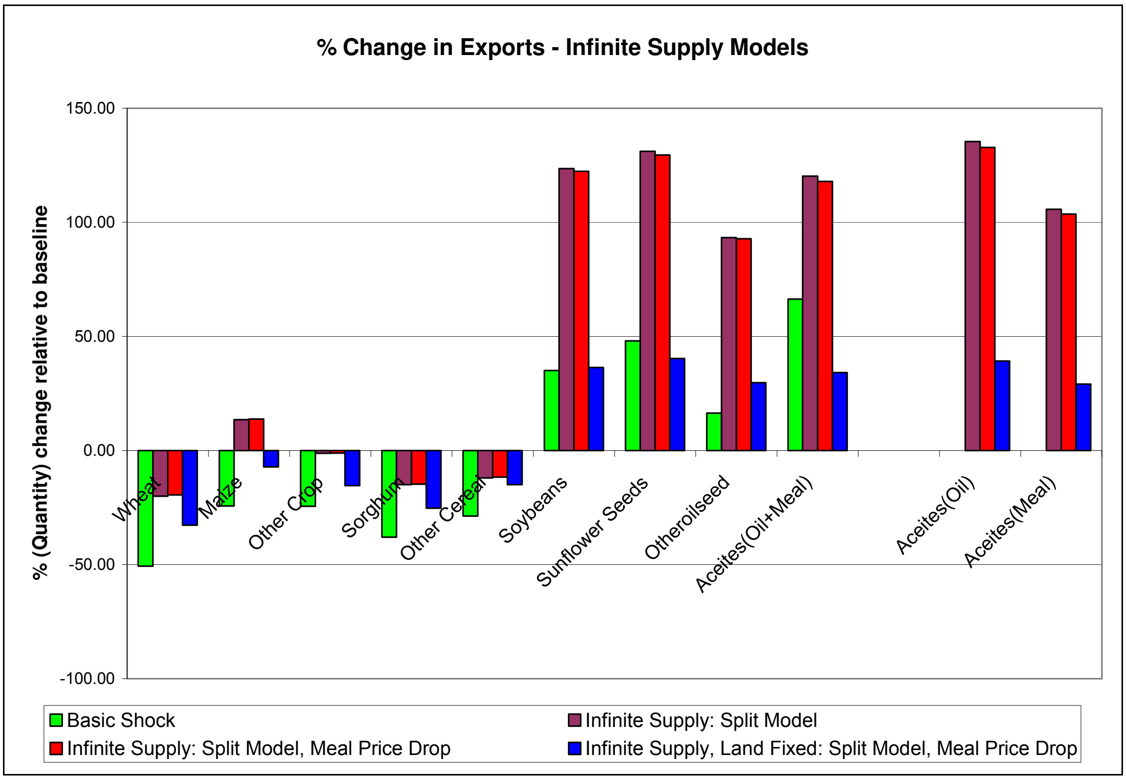


Figure 3: Change in Production, relative to baseline, in Infinite Supply Model with and without Fixed Land Supply

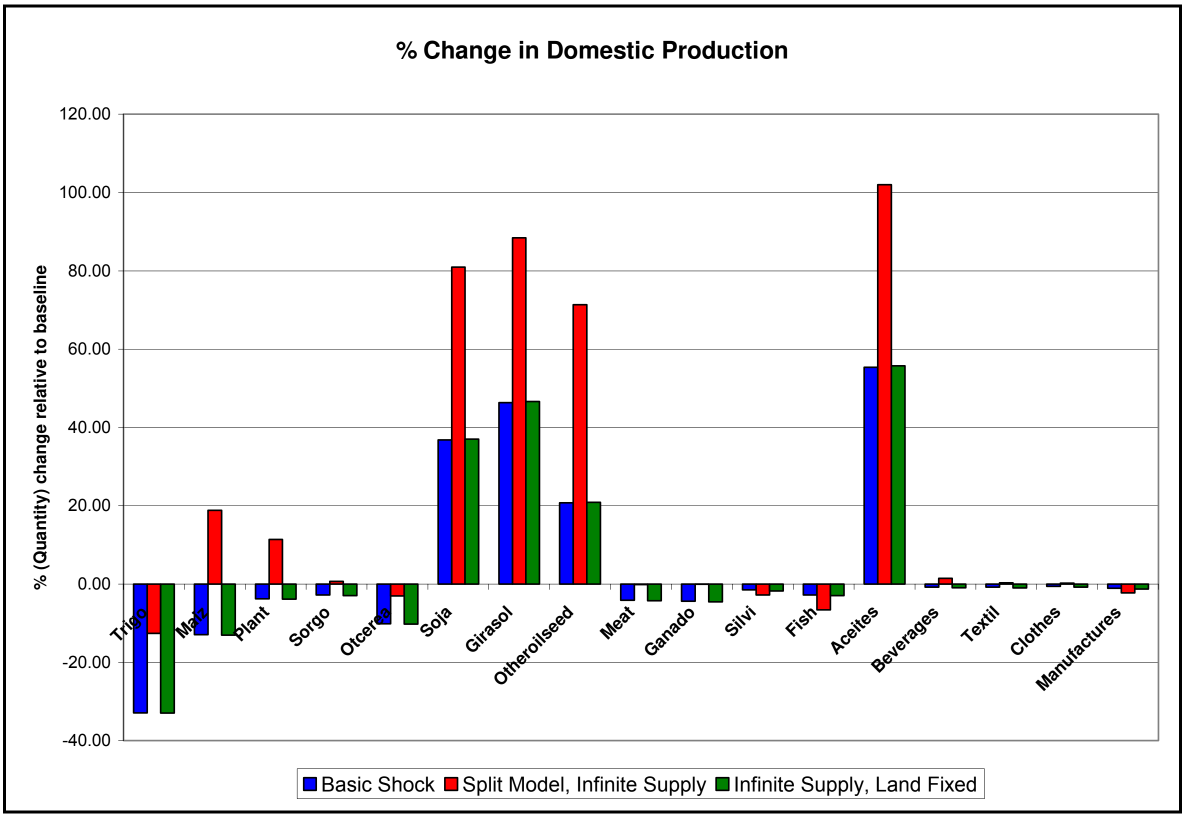
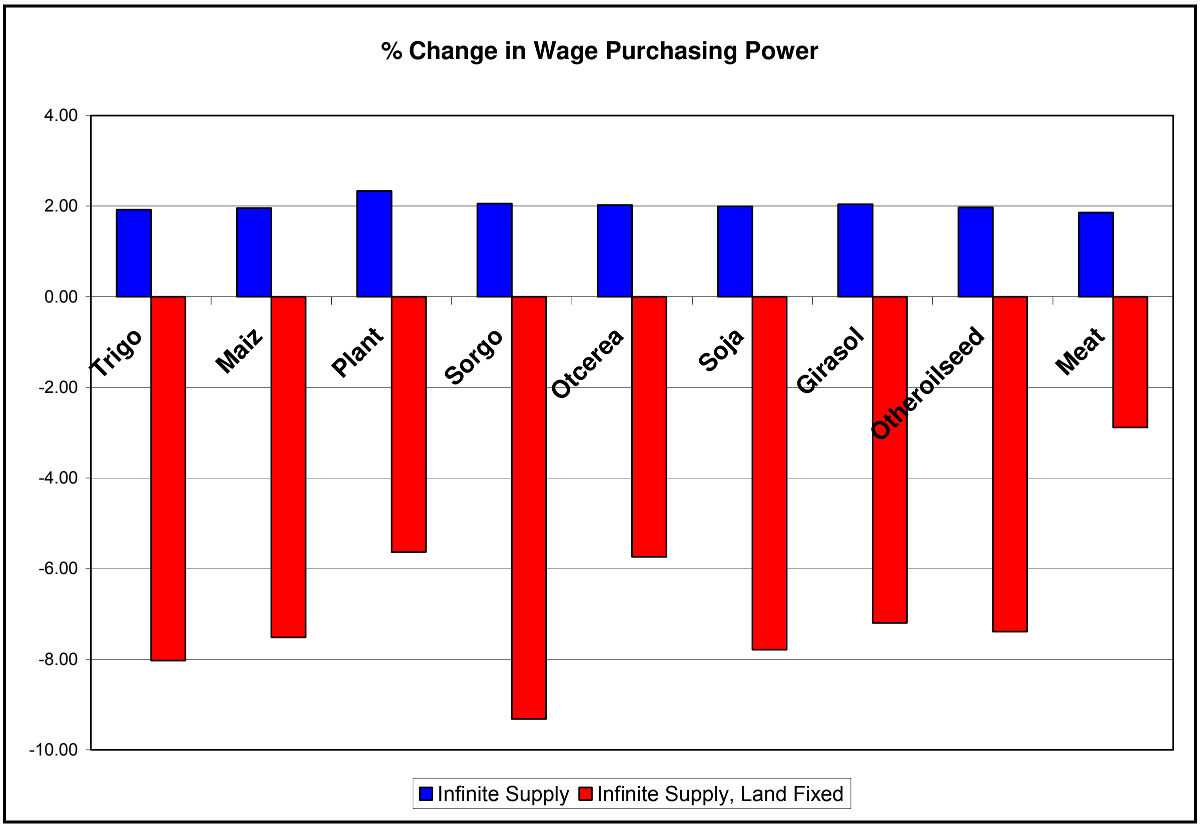


Figure 4: Change in Worker Purchasing Power for Consumer Products



ANNEX A: BIOTRADELAND MODEL DESCRIPTION

BioTradeLand is a single country, small open-economy, comparative static general equilibrium model written in GAMS/MPSGE [23] and based around the Argentina SAM for the year 2000 developed by Petri *et al.* [16]. The purpose of the model is to analyse the effects of plausible world price scenarios on the ability of the domestic economy to export bioenergy feedstocks and to analyse the implications of these scenarios on the domestic economy and land-use.

The following document describes the basic version of the BioTradeLand model. In this version, factors of production (land, labour and capital) are available in fixed quantities (although additional land can be made available in response to increased rent levels), land is a homogenous resource and the soybean sector produces a single output.

Core Model Data - the SAM

The core of the BioTradeLand social accounting matrix (SAM) is a square matrix describing transactions in the entire economy, although focused particularly on agricultural sectors. The SAM contains 22 product sectors, derived through aggregation of the sectors used in the original SAM. The aggregation scheme is chosen in order to concentrate mainly on agricultural sectors of the economy. Sectors that could supply biomass for export are therefore the least aggregated. The sectors from Petri *et al.* [16] are mapped to the BioTradeLand aggregation scheme in Annex B.

In order to model the land-use dimension of a bioenergy-related trade shock, it is necessary to characterise the share of land in each sector's production. However, in the original SAM, value-added is created from only two primary factors of production, labour and capital. 'Capital' in this case is a residual category consisting of all value-added other than that supplied by labour. Therefore, to account for the share of land in production, we therefore split the composite capital category into its land and capital components using the value-added shares from the GTAP database [18]. This results in classifying as land 52% of the original composite capital in the sectors trigo, maiz, plant, sorgo, otcerea, soja, girasol, otheroilseed and Ganado. For forestry (silvi) the composite capital input is maintained since we are primarily interested in agricultural land.

Model Structure

The BioTradeLand model is a standard computable general equilibrium (CGE) model of a small open economy. This means that the data in the SAM is used to calibrate the baseline scenario for the model. The baseline therefore consists of an economic equilibrium in which all markets are perfectly competitive and resources are allocated so as to maximise the welfare of the consumer (the representative agent), given the resource endowments (land, labour and capital) and production technologies available.

In a CGE model, general equilibrium is achieved when the following conditions are met in all relevant markets:

- **Zero-profit for all producers:** in a competitive market, where prices are unconstrained, positive sectoral profits cannot be achieved.

- **Market clearing in all goods and factor markets:** at a given price, the quantity supplied of any product or factor of production must equal, or exceed, the quantity demanded by consumers.
- **Income balance:** the value of each agent's income, which agents sell to fund their consumption of goods and services, must equal the value of the agent's factor endowments.

These conditions are explained in greater detail in papers such as Wing [24], Rutherford & Böhringer [25] or Markusen [26].

The BioTradeLand model is written in the MPSGE programming language. This language allows production technologies and consumer preferences which follow the constant elasticity of demand (CES) structure, to be completely characterised by each sector's combination of inputs, outputs and elasticities of substitution in the base year. In this document, sectoral technologies are presented as a visual representation of each sector's zero-profit condition, as shown in Figure A1 below.

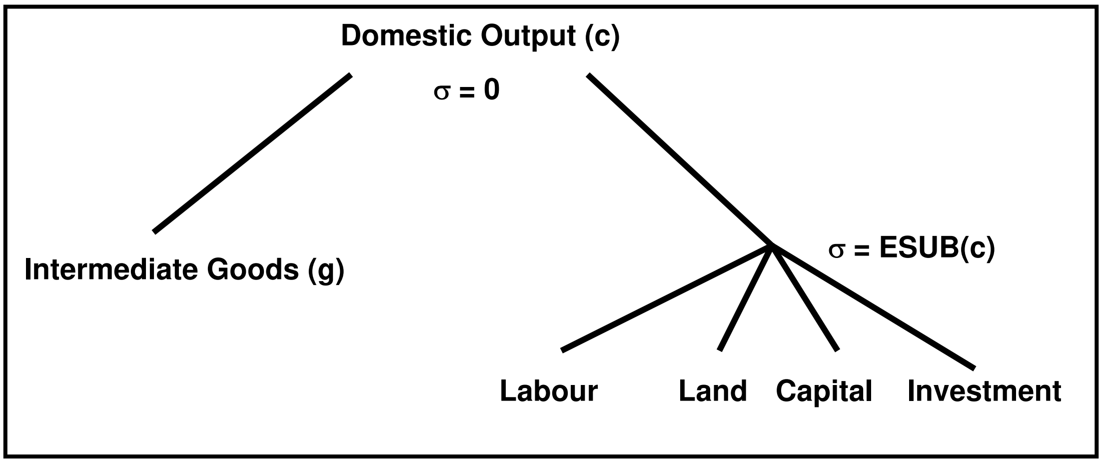


Figure A1: Nesting specification for production technologies in BioTradeLand model

This shows that domestic output in sector c is produced in a nested fashion where the upper nest consists of inputs of each other good (g) and the lower nest consists of factors of production labour, land, capital and investment. The elasticity of substitution, σ, denotes the extent to which the relative proportion of each input to a specific good can be substituted. When $\sigma=0$, inputs must be used in fixed proportions, while $\sigma=\infty$denotes perfect substitutability between inputs. Hence in the production of domestic good c, each intermediate input g and the total input of factors of production must be used in fixed proportions. However, the mixture of factors of production can consist of different combinations.

The sector-specific factor substitution elasticity, ESUB(c), is taken from the GTAP database. The BioTradeLand model's sectoral classification scheme is deliberately chosen to provide a high level of aggregation for non-agricultural products while maintaining separate classifications for products that are given different sectoral elasticities of substitution in the GTAP database. Algebraically, the upper nest of the production technology in Figure A1 is expressed by the following CES function.

$$Yd(c) = \left[\sum_{g=1}^{n} (\alpha_g Yh_g{}^{\rho}) + \alpha_{LLK} LLK^{\rho} \right]^{\frac{1}{\rho}}$$

given that $$\rho = \frac{(\sigma - 1)}{\sigma}$$

Yd denotes domestic production, □ denotes the share parameter of each input g and LLK denotes the second layer nest, itself the product of a CES function that allocates land, labour and capital to the sector. Each parameter α is determined by the relative share of each input in the base year while each parameter σ is obtained from literature.

Composite Domestic-Imported Output (the Armington good)

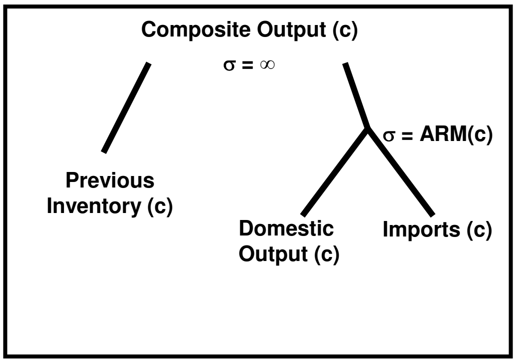


Figure A2: Composite domestic-imported output

Following the so-called Armington convention [27] domestic and imported goods are treated as imperfect substitutes to enable the model to deal with the phenomenon of cross-hauling (where an economy both imports and exports a particular good). For some sectors, the SAM includes a contribution of inventory from the previous period. In this case, the inventory is treated as a fixed endowment that can be used interchangeably with output from the current period to satisfy demand for each good (c).

The only exception to the production scheme shown in figures X and X is the aceites sector. In the case of the *split* model, the sector is assumed to produce two separate outputs, vegetable oils and meals, in fixed proportions. The procedure used to separate oil and meal in the SAM is elaborated in section 4.2.

Final Output Allocation

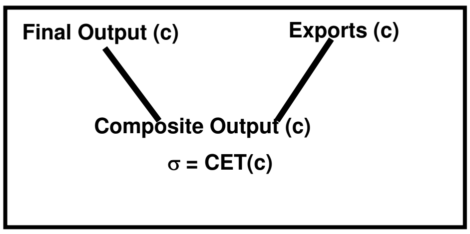


Figure A3: Allocation of composite output between exports and domestic markets

Following the same logic as the Armington convention, domestic and export markets are treated as imperfect substitutes.

Foreign Trade

In the BioTradeLand model, exports and imports are characterised by the exchange of goods for foreign currency. Exports of goods and the injection of foreign investment are perfectly substitutable means of obtaining foreign currency which in turn can be used to purchase imports and service government debt owed to foreigners. Foreign debt is portrayed in the model as a fixed negative endowment of foreign currency.

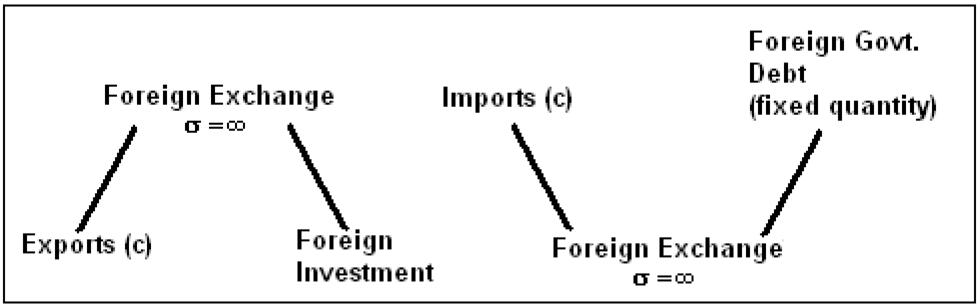


Figure A4: Sources and sinks of foreign exchange

Final Output Distribution

The share of final output not exported is distributed between three demand sources (consumers, government consumption and the investment sector) in fixed proportions. For consumers, it is assumed that a Cobb-Douglas production function (σ = 1) creates a composite consumption good from each individual good produced. Similarly, a composite government good is produced from various product inputs. A Leontief production function (σ = 0) is assumed for this good, meaning that a unit of government spending consists of constant proportions of each input product. The investment sector takes final output as its input and produces private and government investment and inventory in fixed proportions.

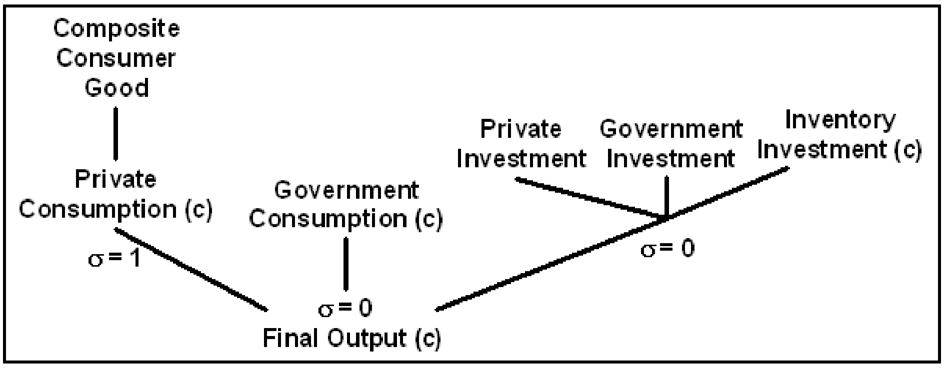


Figure A5: Ultimate destination for final output

Consumers' Income and Expenditure

Factors of production (land, labour, capital) in the model are owned by a single representative agent who receives income from renting them for productive use. Although spending of this income is distributed between the consumption of consumer goods, government goods, inventories and investment, the consumer in this model is characterised merely as a represenƭive agent covering the expenditure of various agent types (household, government, firms). Nevertheless, the distinction between different types of expenditure is maintained since this effects the structure of demand and supply in the economy.

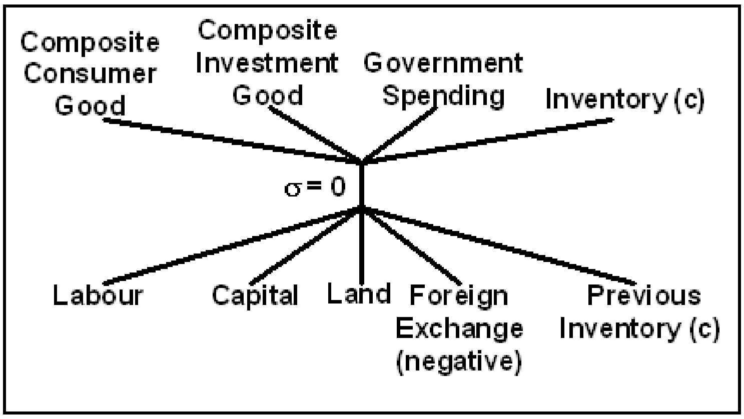


Figure A6: Sources of factor incomes and categories of expenditure

Since the model is static in nature, the dynamic, forward-looking nature of savings and reinvestment is not fully captured. For this reason, negative inventory sales (drawing down of stocks) in the base year is included as a fixed endowment used by consumers to contribute to domestic output. Similarly, annual repayment of the government's foreign debt is included as a negative endowment of foreign exchange, meaning that in any simulation, the combined value of exports and capital inflows from abroad will exceed the value of the goods the economy can import.

Taxation

The Argentina SAM contains four types of taxes, those levied on sectoral output, those levied on institutions and tariffs levied on imported goods. In the BioTradeLand model these are characterised respectively as VAT, household tax (a tax on the production of the composite consumer good), activity tax and import tariffs. VAT is levied on each unit of sectoral output, household tax is charged per unit of composite consumption by households, activity tax is charged per unit of domestically-produced output and tariffs are charged to imports. All tax rates are derived from the SAM, keeping the share of tax in gross income and output unchanged. The only function of taxation in the BioTradeLand model is to recycle income from various sectors of the economy back to the representative agent. Nevertheless, taxation is included in the model because of its distortion of the composition of production and consumption relative to an untaxed market economy.

ANNEX B: MAPPING FROM SECTORAL AGGREGATION IN PETRI *ET AL.* TO BIOTRADELAND AGGREGATION

BioTradeLand Sectors	**Sectors from Petri *et al.***
Trigo	Trigo (wheat)
Maiz	Maiz (maize)
Plant nec	Arroz (rice)
	Papa (potatoes)
	Cebolla (onion)
	Ajo (garlic)
	Tomate (tomatoes)
	Otveglug (other vegetables and pulses)
	Tvhoja (other leaf vegetables)
	Limon (lemon)
	Naranja (oranges)
	Mandarina (mandarines)
	Manzana (apples)
	Pera (pears)
	Uvamesa (grapes)
	Otfrutynu (other fruit and nuts)
	Otcultiv (other crops)
	Servagro (agricultural services)
	Semillas (seeds)
	Poroto (kidney beans)
Sorgo	Sorgo (sorghum)
Otcerea	Otcerea (other cereals)
	Cebada (barley)
Soja	Soja (soy beans)
Girasol	Girasol (sunflower seeds)
Other oilseed	Mani (peanut)
	Otoleag (other oleagenous crops)
Meat etc.	Carne (meat)
	Elabfish (prepared fish)
	Elabvegfr (prepared vegetables)
	Lacteos (dairy products)
	Molineria (cereals, flours)
	Mantrigo (processed wheat products)
	Otalimen (other foodstuffs)
	Granja (poultry, honey, eggs)
	Manazucar (sugar, candies, chocolate)
Ganado	Ganado (livestock)
Silvi	Silvi (forestry)
Fish & mineral	Langostino (king prawn fisheries)
	Otfish (other fisheries)
	Oil (oil and mining)
	Merluza (hake fisheries)
	Calamar (squid fisheries)
Aceites	Aceites (vegetable oils and animal fats)
Beverages & tobacco	Alcohol (alcoholic beverages)
	Noalcohol (non-alcoholic beverages)
	Tabaco (cigarettes & tobacco products)
Textil	Textil (textile fibres)
Clothes & Leather	Vestir (clothing)
	Cueros (leather products)
Manufactures & Utilities	Madera (wood products)
	Metal (metals, smelting)
	Prodmetal (metal products)
	Maquina (machinery)
	Otmanuf (other manufactures)

	Electri (electricity)
Papel	Papel (paper and printing products)
Petrochem	Refoil (petrol and oils)
	Caucho (rubber and plastic products)
	Quimica (Chemistry)
Autos	Autos (automobiles and other vehicles)
Constr	Constr (construction)
Services and Dwellings	Gobierno (government)
	Servicios (services)

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