Energy Policy 55 (2013) 636–647

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Economy-wide impacts of biofuels in Argentina

Govinda R. Timilsina [a,*], Omar O. Chisari [b], Carlos A. Romero [c]

[a] The World Bank, United States
[b] Universidad Argentina de la Empresa y CONICET, Argentina
[c] Universidad Argentina de la Empresa, Argentina

HIGHLIGHTS

- Argentina is one of the largest biodiesel producer and exporter using soybeans.
- Economy-wide impacts are assessed using a CGE model for Argentina.
- Policies simulated are feedstock and biodiesel price change, and domestic mandates.
- Increases in international prices of biofuels and feedstock benefit the country.
- Domestic mandates for biofuels cause small losses in economic output

ARTICLE INFO

Article history:
Received 23 August 2012
Accepted 19 December 2012
Available online 17 January 2013

Keywords:
Biofuels
Energy economics
General equilibrium modeling

ABSTRACT

Argentina is one of the world's largest biodiesel producers and the largest exporter, using soybeans as feedstock. Using a computable general equilibrium model that explicitly represents the biofuel industry, this study carries out several simulations on two sets of issues: (i) international markets for biofuel and feedstock, such as an increase in prices of soybean, soybean oil, and biodiesel, and (ii) domestic policies related to biofuels, such as an introduction of biofuel mandates. Both sets of issues can have important consequences to the Argentinean economy. The simulations indicate that increases in international prices of biofuels and feedstocks would increase Argentina's gross domestic product and social welfare. Increases in international prices of ethanol and corn also can benefit Argentina, but to a lesser extent. The domestic mandates for biofuels, however, would cause small losses in economic output and social welfare because they divert part of biodiesel and feedstock from exports to lower-return domestic consumption. An increase in the export tax on either feedstock or biodiesel also would lead to a reduction in gross domestic product and social welfare, although government revenue would rise.

1. Introduction

Argentina is a competitive producer of oilseeds and has developed a world-class vegetable oil industry. It is also an efficient producer of wheat and corn, its traditional grains. Since the 1980s, the country has emerged as one of the main exporters of oilseeds and vegetable oil to the international market, at the top of the exporters' ranking in soybean oil and sunflower oil. Also, it is the second largest exporter of maize to the world.

Due to this well-tested comparative advantage, the domestic producers and processors of oilseeds in Argentina perceived the increasing international demand for biofuels as a new business opportunity. Thus the private sector engaged in new investments that put in place an exporting industry in only 4 years. At the same time, the economy was facing declining natural gas reserves and pressures on environmental issues. The government responded by passing several laws promoting the use of renewable energy sources, specifically the blending of biofuels in transportation fuels. At present, there are several plants already producing biodiesel using soybean oil and ethanol from corn or sugar cane, and there is the expectation that their production will grow rapidly. The mandatory substitution has been complemented with a selective regime of subsidies to biofuel production. But the actual effect on the industry scale and dynamics depends on more subtle questions since other government actions are indirectly at work.

Will the industry be developed and become sustainable by itself in a country with clear advantages for the production of alternative agricultural products that compete for the use of land,

* Corresponding author. Tel.: +1 202 473 2767; fax: +1 202 522 2714.
E-mail addresses: gtimilsina@worldbank.org (G.R. Timilsina), ochisari@uade.edu.ar (O.O. Chisari), cromero@uade.edu.ar (C.A. Romero).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.12.060

and in which prices of agricultural goods have great influence on real wages, external trade balance and fiscal surplus? To answer this question, changes in relative prices are relevant since they have the potential to modify the value of projects and subsequently determine whether the technologies of production of biofuels become feasible. The evaluation of project viability under endogenous relative prices is one of the contributions of the general equilibrium perspective to the analysis.

At present, biofuels do not represent a significant portion of the economy. But when we consider their potential as substitutes of traditional fuels, and the interaction with the agricultural and oil industries via input/output relations. In order to address these issues, this paper presents the results of the analysis of the biofuel sector in Argentina using a Computable General Equilibrium (CGE) model. Up to now, most of the claimed positive results of the development of this industry in the country are conjectural or based in sectoral studies (Cámara Argentina de Energías Renovables, 2009; Chisari, 2009). Our objective is to evaluate the gains and losses of the production of biofuels for Argentina, taking into account opportunity costs of resources and overall impact on economic performance.

We focus in the assessment of costs and benefits in an economy which can be characterized by the following stylized facts. Firstly, biofuels are already being produced, but there are clear differences between biodiesel and bioethanol in terms of development of the industry and competitiveness (with respect to other countries, such as Brazil). Secondly, Argentina has comparative advantages for several agricultural products at the international level, a fact that creates opportunity costs for land use and for direct exports of crops. Also, the country has a developed oilseed industry, with potential complementarities with biofuel production. Additionally, there is a complex tax structure, that has a direct incidence on agricultural exports, and that is subject to changes that accommodate fiscal results and the need of sustaining a positive trade balance. Finally, the cost of capital has been structurally high – basically due to the country risk component – and has discouraged investments in general and biofuel projects in particular.

The plan of the paper is the following. In Section 2, we summarize the basic facts of the biofuels industry in Argentina. Then, the third section presents the database required for implementing the CGE model, organized in a Social Accounting Matrix. Most of the sectors in the value chain of bioethanol and biodiesel are disaggregated and introduced explicitly. After that, we discuss the main features of the CGE model (Section 4) and we conduct several counterfactual experiments, in Section 5, to study the response of the biofuel industry to policy shocks and to changes in international prices, as well as to appraise the reaction of the economy and of industries related to biofuels via substitution or complementarity relations. The final section concludes with main lessons obtained from the analysis.

2. The biofuel industry in Argentina

Oilseeds production has been growing in Argentina since the late 1980s. This trend corresponds to a long-term path that accelerated in the last 5 years. Production growth and area expansion were mainly due to the availability of new technologies in soybean production (GMO seeds plus the diffusion of zero tillage techniques)[1] that were so important as to increase the profitability of the agricultural sector on average. Biofuels played a minor role in this development, though gaining some importance in recent years.

Environmentalists and agricultural experts have raised concerns about the deforestation that accompanied the expansion of soybean area in the Northern provinces of Argentina. In their opinion, the expansion of soy production over the past several years has fueled deforestation, poor water resource management and increased land degradation (World Bank, 2009). In response, producers' organizations have pointed out that rotation practices have not been abandoned and that the spread of "zero tillage" practices compensates for the damages when combined with adequate fertilizer and agrochemicals adoption. However, the growth of soybean area in comparison to cereals or livestock created concerns on the possibility of persistent mono-cropping. These facts prompted interventions in the market through subsequent increases of export taxes on soybean grain, thus reducing price incentives to production of the crop. At the same time, due to the rally in international food prices, wheat and corn exports were banned transitorily. As a result, the effects on wheat and corn outweighed the diminished soybean profitability and soybean crop share kept its increasing trend in production.

Argentina started biodiesel production on a large scale in 2006. Bioethanol from sugarcane or corn did not start to develop until 2010. Previously, only anecdotal cases of biofuel production could be found. They consisted of a few producers that used own grains and oilseeds as fuels for self-consumption through simple transformation methods. In the case of ethanol from sugar cane, a previous failed experience of mandatory blending took place between 1984 and 1988.

The rapid development of biodiesel in comparison to ethanol shows a clear response of economic agents involved in the agro-industrial activity to market incentives. These incentives became apparent to investors in the early 2000s and were the following: (i) increasing international prices of biofuels attracting new investments to the value chain of an already highly competitive domestic industry of soybean oil, (ii) attractive (but not fully secure) demand from markets such as the EU, with traditional commercial ties with Argentine oilseeds exporters, (iii) excess domestic demand of diesel for transport uses covered through costly imports, (iv) increasing share of oilseed production in the agricultural activity, (v) scarce feed grains and sugar cane along with gasoline surplus that inhibited market incentives in the case of bioethanol and (vi) segmentation of the biofuels domestic market by Law in order to promote exclusive participation of small and medium enterprises (SMEs).

Brazil's competitiveness in the bioethanol international market has also opened a question on the role of Argentine potential supply, its costs and complementation/competition with the MERCOSUR main partner. Notwithstanding, some analysts[2] consider that bioethanol production will be organized in Argentina in view of the potential future constraints on gasoline. Currently this constraint is not binding, what may explain why oil distilleries are more interested in biodiesel relative to bioethanol mandatory blending. A new policy scenario that could re-launch investment in gas and oil could have retarding effects on the biofuels incipient domestic market. Biodiesel exports appear to be rather independent of this outcome but crucially dependent on EU regulations on biodiesel standards.[3]

[1] Zero tillage is a planting system to improve soil conservation where the new crop is planted stubble of the previous crop with even less soil disturbance than with minimum tillage. The importance of this agronomic practice in Argentina is

(*footnote continued*)
reflected by the existence of an influential NGO of producers promoting its adoption: www.aapresid.org.ar

[2] The Argentine Chamber of Renewable Energies (CADER), in its periodic review of the biodiesel sector.

[3] This assessment was confirmed in an interview with managers at one of the major biodiesel exporting companies.

Table 1
Argentina, 2006. Production and value added structure as percentage of totals.
Source: Own elaboration based on INDEC.

Sectors	Value added	Domestic intermediate consumption	Imported intermediate consumption	Labor	Capital	Gross output
Soy	3.00	1.66	0.20	1.25	4.73	2.27
Maize	0.52	0.31	0.04	0.19	0.73	0.41
Sugar cane	0.14	0.04	0.00	0.06	0.24	0.09
Rest of agriculture	4.64	2.38	0.28	1.65	6.21	3.43
Petroleum and mining	5.61	2.47	0.91	1.82	7.98	4.01
Soy oil	0.45	1.19	0.30	0.17	0.21	0.75
Other vegetable oils	0.13	0.35	0.09	0.07	0.09	0.22
Sugar	0.12	0.30	0.08	0.09	0.11	0.19
Rest of food, beverages and tobacco	5.89	15.02	3.75	4.11	5.13	9.67
Textiles, leather, wood, paper **and** printing	3.28	8.25	9.68	2.61	2.89	5.76
Gasoline	0.35	0.59	0.28	0.06	0.39	0.45
Diesel	0.68	1.20	0.69	0.14	0.87	0.91
Biodiesel	0.0037	0.0095	0.0022	0.0009	0.0056	0.0059
Bioethanol	0.0001	0.0001	0.00004	0.00002	0.0001	0.0001
Refineries: other products	0.90	1.96	0.16	0.21	1.29	1.31
Other manufacturing industries	12.13	16.41	59.22	9.02	9.66	16.60
Transport	6.19	6.29	11.54	6.38	5.77	6.53
Trade, construction **and** services	55.97	41.57	12.77	72.15	53.68	47.40
Totals	100.00	100.00	100.00	100.00	100.00	100.00

As regards the domestic market, diesel and gasoline prices are among the lowest in the Western Hemisphere. Noticeably, in spite of low diesel retail prices in Argentina, biodiesel costs are not much apart. In fact, the relation between these two fuels highly depends on the price of soybean vegetable oil, which entails the majority of biodiesel cost. Subsidized transport and fuels have sustained an increasing demand for all sorts of fuels. Fuels consumption has also been affected by the increase in demand derived from Argentine rapid growth since 2003 and the fast growth of the agricultural activity. Finally, mandatory blending requirements have also played an important role in the surge of domestic demand for biofuels.

Biofuel technology in Argentina is related to the quality standard. In general, the quality standard has followed the European requirements, considering that most of the industry exports were oriented towards the EU market.

Regarding environmental concerns, the scheme launched by the law promoting the sector of biofuels suggests that the government is more interested in the promotion of small scale investments and job creation at the regional level than in the reduction of CO_2 emissions. Though the law promoting alternative energy sources might have some background in the environmental concerns, it also reflects the interest in the broadening of alternative energy sources in a context of future energy supply constraint.

3. The social accounting matrix including biofuel sectors

The basic data for the model are obtained from a social accounting matrix (SAM) that in this case also isolates sectors related with biodiesel and bioethanol production from the other accounts.

Here we summarize the most critical aspects of data collection and treatment. The initial matrix of intermediate purchases is based on the 1997 data (INDEC, 2001); it was updated in Chisari et al. (2009). For this study, we used sectoral information to update it as of 2006. The distribution of the factor income across income groups is based on the distribution observed in Argentina in 2006 according to household income surveys. The distribution of the consumption basket per type of goods and services is based on aggregates from a new household consumption survey for 2005.

In both the input and output matrix and the household consumption, consistent data on consumption and production were obtained through the cross-entropy method (Robinson et al., 2001). As for the government expenses, distribution between goods and services data are available for 2006 for the national and provincial governments. Municipal expenditures are assumed to be distributed in the same proportion as the average for the two other government levels. Aggregate demand and supply in the SAM are consistent with national accounts.

The model includes 29 production sectors, four for agriculture, one for petroleum and mining, 16 for goods and eight for services. In addition to the usual activities, the SAM identifies sectors related to the production of biofuels as separate sectors: soy, corn, sugar cane, soy oil, industrial sugar, refined gasoline, diesel, biodiesel and bioethanol. Table 1 presents participation of each sector in terms of value added, expenses in inputs and gross output. The sectors ‘‘Textiles and others’’, ‘‘Other manufacturing industries’’ and ‘‘Services’’ are disaggregated in our complete SAM and account for 13 sub-sectors.

Four factors of productions are accounted for: labor, land, physical capital and financial capital. Both labor and financial capital are mobile across sectors while physical capital is sector specific. Land is mobile within various agricultural sub-sectors.

Biodiesel is a small sector according to 2006 data, but is growing steadily. Though there were many investment projects ongoing, there was no production of bioethanol yet for that year.[4] Hence, to perform simulations considering future production of this product, we have included a ‘‘latent’’ industry of bioethanol (see Table 1) in which the proportions of value added, labor and capital costs, and intermediate costs are coincident with those of the current available bioethanol technology. This ‘‘virtual’’ or latent sector is ready to grow if the simulations give the proper incentives.

Table 2 shows the intermediate transactions as percentage of total intermediate costs for the sector included for the specific

[4] As of 2006; there were some bioethanol plants already in operation and several announced investments.

Table 2
Argentina, 2006. Intermediate cost structure (%).
Source: Own elaboration.

Sectors	Soy	Maize	Sugar cane	Soy oil	Other vegetable oils	Sugar	Gasoli-ne and diesel	Bio-diesel	Bio-ethanol
Soy				69.47					
Maize					2.78				30.77
Sugar cane						35.89			26.67
Rest of agricultura	25.14	30.13	50.02	0.69	73.41	12.17			
Petroleum and mining				0.01	0.02	0.28	76.85		
Soy oil								82.02	
Other vegetable oils				0.05	0.05				
Sugar						1.89			
Rest of food, beverages and tobacco				0.07	0.08	0.56	0.13		
Textiles, leather, wood, paper **and** edit				0.51	0.78	3.28	0.31		
Gasoline	0.55	0.49		0.01	0.01	0.10	0.43		
Diesel	10.48	9.35		0.11	0.12	1.84	2.80		
Biodiesel	0.04						0.01		
Bioethanol							0.00		
Refineries: other products							1.76		
Other manufacturing industries	59.05	50.64	27.74	0.47	0.54	3.92	1.59	17.54	11.94
Transport	3.84	8.36	22.25	2.17	10.20	20.81	7.39		11.16
Trade, construction **and** services	0.90	1.03		26.45	12.01	19.27	8.74	0.44	19.47
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

purposes of this analysis. The biodiesel and bioethanol cost structures are based on own estimates.

Regarding the demand side, domestic consumer groups are divided by income decile, the government, one foreign consumer and one foreign producer. The small open economy assumption is adopted, implying that Argentina is a price taker in the international markets.

Information on the government accounts was obtained from the Ministry of the Economy (Oficina Nacional de Presupuesto).[5] Income and expenditures of the public sector are consolidated results for the federal administration, the provinces and the municipalities. Considering expenditures, government consumption represents around 14% of GDP followed by household transfers (10% of GDP). The information on national and local taxes was provided by the "Administración Federal de Ingresos Públicos" and Provincial ministries, respectively.

The SAM also accounts for the positive result of the trade balance and the current account observed in 2006. The information on the balance of payments was obtained from the "Banco Central de la República Argentina".

A summary of the SAM of the Argentine economy of 2006 is shown in Table 3. This simplified SAM has three activity sectors, two factors (with capital representing an aggregate of land and physical and financial capital), taxes, public and private investment and the rest of the world (ROW). Columns show the decomposition of sales of the budget of every agent, while rows represent markets.

Total amounts of intermediate sales and purchases were required to estimate the new input-output transaction matrix, using cross entropy. Besides, total purchases of consumers and their respective disposable income were necessary to estimate the new consumption expenditure matrix, also using cross-entropy.

The input–output matrix is the sub-matrix of the SAM that represents transactions between activity sectors (activities, activities). Below this, the matrix of factor demands is presented (factors, activities), followed by the matrix of taxes paid by activity (taxes, activities). The SAM separates taxes paid by exports, intermediate uses, final consumption and investments. Finally, the matrix of imported purchases is included (ROW, activities). Totals of rows and columns of each sector are the respective gross output value.

[5] www.mecon.gov.ar/onp

The factors account shows the income distribution matrix (households, factors) that distributes the remuneration of factors to households. Part of the capital is owned by the rest of the world.

For the demand side, we summarize the matrix of household expenditures (activities, households), government consumption (activities, government), private and public investments (activities, investments) and the vector of exports (activities, ROW). The matrices (household, household) and (household, government) correspond to transfers between agents.

Private savings, public savings and foreign savings are added up to finance investments. The row BNI closes the model and it represents the superavit/deficit of every agent; it corresponds to financial transactions as of 2006.

4. Basic characteristics of the general equilibrium model

Our model is organized in 10 representative households, 29 production sectors, one consolidated public sector and the rest of the world, and a thorough decomposition of the tax structure and regulatory regimes. It takes into account different degrees of factor mobility and several technologies that compete to produce the same good or service. The information has been updated as of 2006 and it includes a dynamic recursive component to take into account economic growth. Also discussed here are specific characteristics of the economy of Argentina, like unemployment and significant export taxes for crops and oil.[6] It allows simulating the economy-wide impacts of large scale production of biofuels in the country. The model is numerically solved using GAMS/MPSGE.[7] A more detailed description of the model is presented in Appendix A.

[6] The model is flexible to address different elasticities and parameters, as well as different degrees of factor mobility. Also, different mobility of factors can be taken into account in the model; this is relevant for capital in agriculture which is taken as mobile only among agricultural sectors.

[7] The solution of the model is obtained using the representation of General Equilibrium and using the Mixed Complementarity Approach –see Ferris and Pang (1997) for a survey of the mathematical method and Böhringer and Rutherford (2008) for a recent description on the usefulness to model energy sectors in CGE. The model is developed in the environment of GAMS/MPSGE (see Rutherford (1999)). At present it can be used in interface with GAMS (see Brooke et al.,1992).

Table 3
Argentina, 2006. Aggregated SAM (Millions of $).

		Activity sectors			Factors		Taxes	Households		Govern-ment	Investment		ROW
		***S*01**	***S*02**	***S*03**	***L***	***K***		***H*1**	***H*2**		**Priv**	**Pub**	
Activity sectors	***S*01**	7819	61,545	18,785				3627	2257	0	1838	266	30,767
	***S*02**	15,207	115,971	70,928				70,000	52,175	0	10,127	1466	110,497
	***S*03**	13,410	63,004	164,495				101,381	124,315	81,248	89,509	12,959	20,771
Factors	***L***	9796	32,461	154,518									
	K	59,213	61,477	176,976									
Taxes	**IM**	55	2549	105				320	350		1640		
	IVA	2775	17,316	18,284									
	Indi	6332	14,261	22,649									
	IX	3182	11,529	0									
	IL	1768	6865	20,251									
	IK	6347	7563	7126									
	IH							4098	25,111		3125		
House-holds	***H*1**				61,053	43,861			53,443	31,325			
	***H*2**				135,723	245,815				30,649			
Government							183,603						
Invest-ments	**Priv**								136,819				1328
	Pub									14,691			
ROW	***S*1**	1000	51,830	16,974		7990		10,253	13,898		31,907	0	
BNI									3820	25,691			−29,511
Totals		126,904	446,372	671,090	196,775	297,666	183,603	189,681	412,187	183,603	138,147	14,691	133,853

Activities: *S*01: Agriculture and Mining, *S*02: Manufacturing industry, *S*03: Trade, Construction and Services. Factors: *L*: Labor, *K*: Capital and Land. Households: *H*01: first 5 income deciles (poorest), second 5 income deciles (richest). Investments: Priv: Private, Pub: Public. Taxes: IM: import tariffs, IVA: value added tax, Indi: rest of indirect taxes, IX: tax on exports, IL: Labor taxes and contributions, IK: taxes on capital, IH: taxes paid by households, ROW: Rest of the World.

Since it is necessary to take into account the opportunity costs of land and alternative allocation of crops (producing vegetable oil or exporting grain directly), the model is structured to have a more detailed and realistic representation of the biofuel industry and the potential trade-offs and opportunity costs, focusing specially on alternative uses of land. A detailed representation of alternative technologies for biofuel production and uses is also included (actual or latent technologies to be selected for operation by the economy depending on relative prices).

It is also possible to estimate how biofuel production and its associated sectors (agriculture, fuel and food) could influence the performance of the economy in terms of exports and trade balance, fiscal implications, welfare and growth. Relative prices and mobility of resources can explain why certain industries and technologies expand or contract. Therefore in the model, production is neither mandatory nor inevitable; it is determined by market forces and relative prices.

For every period, prices are computed to simultaneously clear all markets. The model used is a recursive dynamic model that simulates growth for the economy, based partially in the Computable General Equilibrium for Argentina presented in Chisari et al. (2009). It is not a model of optimal growth; instead, agents make savings decisions in period t using only information for that same period; then, savings are used in the following period $t+1$ as additional capital. This new capital is not specific by sector but malleable, and it is fully mobile between sectors of production. Therefore it is allocated at the same time that prices are being determined by the model; the final allocation of "brand-new" capital responds endogenously to the relative profit opportunities and it is reallocated until the reward to new capital is the same in all industries. Henceforth, the final industrial scale depends on market incentives determined by the model itself.[8]

From the supply side, the production function in each sector is a Leontief function between value-added and intermediate inputs: one output unit requires an x percent of an aggregate of productive factors (labor, physical capital, financial capital and land) and $(1-x)$ percent of intermediate inputs. The intermediate inputs function is a Leontief function of all goods, which are strict complement in production. The Leontief formulation focuses the model on higher-level substitution issues.

Value-added is a Cobb–Douglas function of productive factors. Regarding factor endowment, both types of capital are fully employed, while there exists labor unemployment. Wages are assumed to be fixed in real terms. The modeling of unemployment is quite important for the case of Argentina. The assumption of full-employment could modify the evaluation of benefits of trade liberalization (see Diao et al., 2005); in full-employment models, increased demand for labor (from increased activity and exports) leads to higher real wages, such that the origin of comparative advantage is progressively eroded; but in models with unemployment, real wages are constant and the increase in exports is larger.

Financial capital and labor are perfectly mobile while physical capital is sector specific, involving the same cost between sectors for the first two factors and sector specific cost for the last factor. Land is included as a separate factor in this version of the model because of its relevance in the analysis of biofuels (see details in Appendix A).

The demand side is modeled through 10 representative households, a government and an external sector. Households buy or sell bonds, invest and consume in constant proportions (Cobb–Douglas) given the remuneration for the factors they own (and the transfers from the government). The choice of the optimal proportion of the consumption good is obtained from a nested production function into the utility function, through a process of cost minimization. Government is represented as an agent that participates in markets for investments, consumes and makes transfers to households and has a Cobb–Douglas utility function; its main source of income is tax collection (though it also makes financial transactions through the bonds account). The external sector buys domestic exports and sells imports, and also makes transactions of bonds and collects dividends from investments.

[8] The dynamic model was calibrated for total GDP of the economy growing at 4% for 2006, leaving aside exogenous shocks identified for the economy in 2006. The simulations assume that labor force is not growing, this is a neutral assumption taking into account that what matters are the comparative dynamics of the basic scenario of growth with respect to the simulated cases.

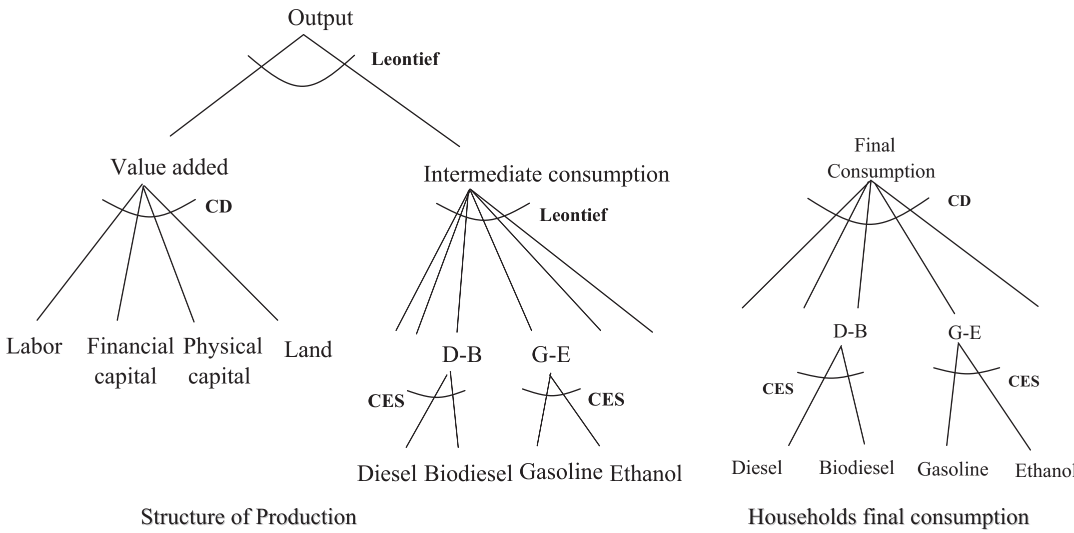

Fig. 1. Biofuels: structure of production and household consumption.

The model incorporates key sectors for the analysis of biofuels. Biofuels, such as biodiesel and ethanol and biofuel feedstock, such as sugarcane, maize, soybean, soybean oil, refined sugar, other oilseeds oils, are explicitly modeled (see Table 2).

Biodiesel production uses soybean oil as primary input, while bioethanol uses maize and sugarcane. These are combined with other inputs (mainly chemicals and energy) and value added for production. See Appendix A for a detailed presentation.

Intermediate consumption is represented as a nested Leontief production function. It is assumed the elasticity of substitution between fuels and biofuels (gasoline–ethanol and diesel–biodiesel) is equal to 2. The rest of the goods are complementary and the elasticity of substitution between them is zero. Fig. 1 shows the structure of intermediate consumption.

Fig. 1 also shows the incorporation of land as a factor in the value added. This agricultural production factor is assumed mobile between agricultural sectors. Households decision on the composition of their basket of fuels is represented similarly to intermediate consumption. We adopted a nested utility function with an elasticity of substitution equal to 2 between biofuels and their fossil fuel counterparts and an elasticity of one between the biofuels–fossil fuels composite and the rest of the goods.

As mentioned before, the version of the model presented here is recursive dynamic. Investments of year t are added to mobile capital at time $t+1$, and it is allocated between sectors until its reward is equalized – see also Al-Riffai et al. (2010) for an example of a General Equilibrium model which operates in a sequential dynamic recursive set-up.

5. Counterfactual exercises

The simulations are organized in two main categories: (1) international markets changes, and (2) policy shocks. Special attention is paid to the results of the following scenarios:

- Changes of prices of soy, soybean oil and biodiesel in international markets.
- Modifications in levels of export taxes on crops and subsidies to biofuel production.
- Introduction of market based incentives for biofuel projects.
- Modifications in non market based incentives (quotas of biofuels in total fuels used).

Key results, particularly indicators showing impacts on macroeconomic, distributional, international trade and industrial outputs, due to the above mentioned simulations are presented below. Tables in this section have to be read in the following way. Each simulation includes two columns: y1 stands for results of the first year simulated and y5 stands for the last year simulated. Since the SAM corresponds to 2006, the first year of the simulation is a counterfactual representation of macroeconomic results for 2007, and the last year of the simulations corresponds to 2012.Values shown in the tables are the difference between the percentage change in the simulations and in the baseline, i.e. the 1.2 of the GDP in the first year in the soybean simulation means that GDP increased 5.2% in the simulation while it increased 4% in the baseline. Percentage changes for the indicators in each year (the five periods simulated) and for all the simulations are presented in Appendix A. The only indicator that is not expressed as percentage change is the unemployment rate which is shown as percentage of people unemployed in each scenario.

The baseline is calibrated with respect to the total GDP of the economy growing at 4% for the first year, out of exogenous and policy shocks for the economy. Every year agents make saving decisions which are used in the following year as additional mobile capital. Policies in the baseline scenario are those that were in place in 2006. With regard to biofuels, as mentioned, their production, consumption and trade evolves endogenously determined by market forces and relative prices; this means that mandatory consumptions were not included for the baseline scenario.

5.1. International markets

Table 4 presents the results of scenarios in which prices of soy, soybean oil and biodiesel are changing more or less in the same percentage. The columns indicate the differences with respect to the baseline results for the initial and final years. In the initial year, 2006, the biofuels industry was still in its initial steps for that year; therefore, the initial year includes a modification of the SAM to include the incipient industry.

It can be seen that when export prices of soy, soybean oil and biodiesel are increased 20%, the result is an abrupt growth of production (and exports, not shown) of all of them. Producers react by reallocating resources until marginal benefits of selling soy, soybean oil and biodiesel are equalized. Since production of those goods attracts capital, there is a reduction of the activity level for manufactures, as well as for other agricultural products.

Table 4
Impacts of 20% changes in international prices.

Indicators	Soy, soybean oil and biodiesel (20%)		Maize and bioethanol (20%)		Soy, soybean oil and other agricultural products (−20%)	
	y1	*y5*	*y1*	*y5*	*y1*	*y5*
Macroeconomic indicators						
GDP	1.9	2.2	0.3	0.4	0.5	−0.8
Trade balance	2.4	2.8	0.3	0.4	0.8	−0.9
Fiscal result	1.6	1.6	0.1	0.1	0.0	−0.9
Rate of unemployment	−0.1	0.0	0.0	0.0	−1.2	0.0
Welfare indicators						
Poorest household	2.1	2.3	0.3	0.4	0.9	−0.4
Richest Household	1.5	1.8	0.4	0.5	−0.1	−1.2
Aggregate sectors activity level						
Agriculture	5.8	6.8	1.1	1.4	−12.2	−14.7
Manufactures	−2.4	−2.7	−0.4	−0.5	3.4	2.4
Services	0.1	0.0	0.1	0.1	1.4	0.1
Specific sectors activity level						
Soy	53.3	61.4	−5.2	−5.9	−17.5	−19.5
Maize	−22.8	−26.0	93.6	107.5	46.1	51.4
Sugar cane	−10.9	−12.7	−1.8	−1.5	15.1	15.7
Rest of agriculture	−25.3	−29.0	−5.5	−6.2	−16.3	−20.1
Soybean oil	83.8	97.1	−0.5	−0.6	−87.7	−96.3
Diesel	−1.4	−1.4	−0.6	−0.5	0.1	−0.8
Gasoline	−1.6	−1.6	−0.6	−0.5	0.1	−0.8
Biodiesel	33.7	1222.2	−0.2	2.7	44.5	1722.2
Bioethanol	−2.7	−34.3	48.8	4323.3	2.6	−0.3
Gas emission index	2.9	3.3	0.6	0.7	−5.3	−7.0

N.B.: *y*1: 2007, *y*5: 2012. Figures are deviations from percentage change in the baseline of the corresponding year.

The fiscal situation is improved due to the taxes on exports, and that also has impact on the welfare of the poor (for it is assumed that transfers to the poor are a fixed proportion of total revenue of the government). The trade balance also shows a better result as a consequence of higher prices. The industry of biodiesel reacts strongly increasing production. But one thing to take into account is that the response of the biofuels industries is more noticeable in the fifth year because by year four unemployment is negligible and wages begin to grow (simulations assume a minimum real wage under unemployment); since biofuels industries are not intensive in labor, the rest of the economy experiences additional costs from the rise in real wages, and biofuels can grow relatively more.

Similar results are seen when the price of maize and bioethanol are increased 20%. Macroeconomic indicators show clear improvements though the industrial composition of the economy changes, and manufactures reduce the activity level (though at a smaller extent than in the case of soy and biodiesel). It is interesting to see that sugar cane production is reduced, even though it is possible to produce bioethanol with it; so the costs of capital (attracted to the production of maize) and the cost of opportunity of land (to produce maize again) seem to prevail over the potential use for production of bioethanol as an input.

The last column of Table 4 shows instead a reduction of prices of soy, soybean oil and other agricultural products (not maize, sugar cane); it can be seen that the opportunity cost of biodiesel production is reduced, and therefore the production of biodiesel is increased. The result for bioethanol is the consequence of the reduction of the activity level of the economy (as it is reduced the demand for gasoline) rather than the effect of relative prices.[9]

[9] We have performed a sensitivity analysis to different degrees of capital mobility. The model was calibrated to a 10% of mobile capital, consistent with the observed economic variables in the baseline growth scenario. Considering an economy with 40% mobile capital, we have observed that macroeconomic aggregates do not present important changes but at sectoral level, more flexibility in the capital has a more significant effect in terms of the sectoral activity level. For instance, in the simulations of changes in international prices the capital moves to the more profitable sectors. Hence, biofuels would have a lower growth rate when the capital is more mobile because they are relatively more intensive in use of capital.

5.2. Policy and fiscal interventions

This group of simulations evaluates the effects of mandatory substitution of biofuels for fuels, and increases of export taxes levied on soybean and soybean oil. The results are shown in Table 5.

5.2.1. Mandatory substitution

The mandatory substitution of fuels to reach a 5% target produces a loss of welfare. This happens even when the constraint is imposed using a combination of taxes and subsidies on fuels and biofuels, respectively.[10] There is a perturbation of relative prices that explains the slight loss of welfare. In the case of biodiesel, the economy experiences a loss in terms of GDP, since market based decisions are perturbed with a constraint on the portion of biofuels to be used.

The results of the computation indicate that the necessary additional supply to match the mandatory demand is obtained not only from increased production, but also through the reduction of exports. Diesel exports compensate for the reduction in biofuel exports in the trade balance, since there are still profitable opportunities for producing diesel and selling it to the rest of the world. There is also a reduction in exports of soybean oil, for it is used to produce biodiesel. It can be seen that there is a strong increase in the domestic demand (final and intermediate) of biofuels.

Note that this result is different from that in Timilsina et al. (2010), which uses a global CGE model. The reason is that this study uses a single country model, which does not capture the effect of expansion of biofuel market in other countries. Timilsina et al. (2010) shows that global expansion of biofuels caused by national targets and mandates would increase export demand for biofuels in countries where biofuel industry has already been established (e.g., Brazil, Argentina, Indonesia). This study assumes the demand for biofuels in the rest of the world remains constant, thereby causing cuts in exports of Argentinean biodiesel when the country introduces biofuel mandate.

Quite similar results are obtained in the case of extending mandatory requirements to gasoline.[11] There are huge increases in production and domestic use of bioethanol, while exports are cut to zero. However, the macroeconomic indicators are slightly worsened as in the case of biodiesel.

Production of sugar cane is increased, but in the case of maize, the results indicate that the economy prefers to cut exports, probably due to the presence of export taxes on maize. When both cases are taken together, we can see an extraordinary

[10] Two alternative modeling strategies were considered in this simulation. The one presented here enforces the 5% target through a combination of virtual taxes on fuels and subsidies to the use of biofuels. In this modeling approach substitution between fuels and biofuels is permitted however the taxes and subsidies imposed imply a compliance of the 5% ratio. The other alternative not shown here but with similar results is fixing biofuels demand as 5% of total fuel demand by changing the shares of biofuel in total expenses of households and input output coefficients and not letting substitution between fuels and biofuels (for a more detailed explanation of how this constrains may be imposed in the model see Appendix A).

[11] According to the law, 5% must be calculated in litres. However the energy content of biofuels, especially bioethanol, is approximately 30% lower than gasoline. When this is taken into account welfare levels decrease around 10% for poor households and 20% for the richest. This additional reduction in welfare is originated in a loss of quality as measured by the energy content.

Table 5
Simulations of policy and fiscal interventions.

Indicators	Mandatory substitution for biodiesel (5%)		Mandatory substitution for biodiesel and bioethanol (5%)		Increase of export taxes, Soy and Soybean Oil (10%)		Compensated subsidy to sales of biofuels (20%)	
	*y*1	*y*5	*y*1	*y*5	*y*1	*y*5	*y*1	*y*5
Macroeconomic indicators								
GDP	−0.1	−0.1	−0.3	−0.1	−0.1	−0.2	0.0	0.0
Trade balance	−0.2	−0.1	−0.3	−0.1	−0.1	−0.2	0.0	0.0
Fiscal result	−0.1	0.0	−0.2	−0.1	−0.1	−0.1	0.0	0.0
Rate of unemployment	0.1	0.0	0.2	0.0	−0.1	0.0	0.0	0.0
Welfare indicators								
Poorest household	−0.2	−0.1	−0.3	−0.1	−0.1	−0.2	0.0	0.0
Richest household	−0.1	0.0	−0.2	−0.1	−0.1	−0.1	0.0	0.0
Sectoral activity level								
Agriculture	−0.2	−0.1	−0.3	−0.2	−1.3	−1.5	0.0	0.0
Manufactures	−0.1	0.0	−0.2	0.0	0.3	0.2	0.0	0.0
Services	−0.1	−0.1	−0.3	−0.1	0.1	0.1	0.0	0.0
Specific sectors activity level								
Soy	−0.2	−0.1	−0.3	−0.2	−9.0	−10.4	0.0	0.0
Maize	−0.3	−0.1	−0.4	−0.2	3.4	3.8	0.0	0.0
Sugar cane	−0.2	−0.1	1.3	1.8	1.3	1.5	0.0	0.0
Rest of agriculture	−0.1	−0.1	−0.2	−0.2	3.8	4.3	0.0	0.0
Soybean oil	−0.2	−0.1	−0.3	−0.2	−7.3	−8.6	0.0	−0.1
Diesel	−0.2	−0.2	−0.3	−0.3	−0.1	−0.1	0.0	−0.1
Gasoline	−0.2	−0.2	−0.3	−0.3	−0.1	−0.1	0.0	−0.1
Biodiesel	633.7	489.7	632.8	489.2	6.0	89.7	22.5	542.4
Bioethanol	−0.2	−6.3	13,514.6	15,637.6	0.2	1.2	22.7	539.3
GHG emissions index	−0.6	−0.6	−1.0	−0.8	−0.6	−0.8	0.0	0.0

Note: *y*1: 2007, *y*5: 2012. Figures are deviations from percentage change in the baseline of the corresponding year.

increase in the production of bioethanol. This is due to the limited size of the industry as of 2006 compared to the market to be addressed.

5.2.2. Export taxes

There is a slight reduction in welfare, GDP and investments following the increase of export taxes on soybean and soybean oil, as expected because of the additional distortion imposed on the economy.[12] On the other hand, the increase in export taxes on soybean and soybean oil impacts positively on production of biodiesel: production of biodiesel increases by 6% for the first year with respect to the benchmark, and exports grow almost 12%. The response is stronger in the long run, since more mobile capital is available to be allocated to the production of biodiesel. These exercises illustrate the potential relevance of indirect policy instruments on the reaction and growth of biofuel contribution.[13] There is also a reduction in production of soybean and land is reallocated to the production of maize and the rest of agricultural products. The increase in exports legal taxes on soybean and soybean oil results in a net reduction in revenue for the government, since resources are allocated to industries with a lower level of tax contribution.[14]

Production of maize and sugar cane do not show significant changes. The economy does not increase production and reduces exports. But it compensates the loss in exports of maize and sugar with exports of biofuels. The model shows a slight decrease in GDP and welfare due to the distortion.

5.2.3. Compensated subsidy to biofuel sales

For this simulation we assumed that biofuel sectors receive a 20% subsidy on the value of their total sales, and that this is compensated with a proportional reduction of all taxes. Though the sectors tend to grow as shown in Table 5, the net effect for the economy is not significant.

5.3. Sensitivity analysis

We carried out a sensitivity analysis on a very important parameter, the elasticity of substitution between biofuels and their fossil fuel counterparts. This is because the biofuel industry is still in its infancy. Perfect substitution between biofuels and fossil fuels is not possible as existing vehicle engines do not run on 100% biofuels. Technically, existing vehicle engines can handle 10–15% ethanol and up to 30% biodiesel. Therefore, we considered a low value of elasticity of substitution between biofuels and fossil fuels based on existing literature. However, as biofuel industry matures, vehicle fleet will change. In future, Argentina, like Brazil, might consider flex fuel vehicles which can run on only biofuels, only fossil fuels or any mix of them. Therefore, it would be interesting to see the sensitivity of model results if this substitution elasticity is altered. We double the elasticity of substitution between biofuels and fossil fuels for the sensitivity analysis. We find no change in results in all scenarios except

[12] Under the large country assumption (i.e., when a country has market power in the world market thereby affecting international prices) an increase in export taxes would cause an increase in international prices) and it could improve social welfare (in this context, this country translates the export tax to consumers in the rest of the world). The pass-through of export tax to international prices depends on the elasticity of demand. Under the small country assumption, which is the case in this study, an export tax on any Argentinean product would lower its competitiveness in the international market. Thus, the export tax causes reduction in export volume and therefore in production. Less production means less input including labor. Ultimately household income decreases and so does the welfare.

[13] The elimination of export taxes would not necessarily have a symmetric effect, if mobile capital were assumed to become sunk after being installed.

[14] An additional simulation was performed, regarding a subsidy of 20% to sales of biofuels: The simulation assumes that it has to be compensated with an increase in all taxes to keep constant fiscal result in the first period. The subsidy is applied to the value added so although it is presented as a subsidy to sales (goods

(*footnote continued*)
purchase intermediate consumption and value added to be produced) it has to do with a supply subsidy. The result is an increase in production of biofuels that is fully exported.

blending mandate. This is because it would be still economic to export biofuels to international markets than using it for domestic consumption.

6. Conclusions and final remarks

Argentina has developed a world-class vegetable oil industry since 1980s. The country has emerged as one of the main exporters of oilseeds and vegetable oil to the international market. By 2011, Argentina topped the world in exporting biodiesel, which is produced from soybeans. Fluctuations in international markets of biofuels and feedstocks, and national policies related to biofuels are of concerns to various stakeholders in Argentina including the government and the industry.

Developing a computable general equilibrium model for the Argentinean economy with an explicit representation of biofuel industry, this study conducts number of simulations on two core issues: (i) changes in international prices of biofuels and feedstocks to stimulate their exports, and (ii) regulatory and fiscal policy shocks aimed to promote domestic consumption of biofuels. The assessment includes impacts on GDP, household welfare, sectoral outputs and trade balance.

Our study finds if the international prices of biodiesel, soy oil and soybeans increase, Argentina will gain in terms of GDP and social welfare. An increase in international prices of ethanol and corn is also beneficial to Argentina, but not as much as caused by the increase in price of biodiesel, soybeans and soy oil. On the other hand, a mandatory use of biofuels to substitute their fossil fuel counterparts would cause a small reduction in GDP and welfare, as such a mandate would divert exports of biofuels and its feedstocks for domestic consumption. The negative effect would, however, be declining over time. This finding differs from those in studies such as Timilsina et al. (2010), which simulate impacts of national targets and mandates introduced in 40 plus countries around the world. This is because the international mandates and targets would cause expansion of global demand for biofuels.

Our results also show how an increased export tax either on biofuels or feedstock to increase government revenues reduces GDP and social welfare. This is because an increase in export tax would lower competitiveness of Argentinean biofuels and feedstock in the international markets.

Real wages are assumed constant, and there is unemployment, at variance with the standard neoclassical model of full employment; however unemployment tends to disappear as a result of economic growth thereby causing real wages to increase. Our results are sensitive to these assumptions about labor market conditions. Additionally, the model assumes that the economy is not forward-looking, and therefore agents do not plan investments with enough anticipation, though brand new capital is allocated endogenously (as part of the solution of the model) between sectors following the higher rate of return.

The tradeoff between domestic consumption and exports of biofuels is an important issue for Argentina as the former increases welfare and GDP whereas the latter reduces them. Finding an optimal mix between domestic consumption and exports and setting domestic biofuel targets based on the mix could be an interesting expansion of the current study.

Acknowledgments

Juan Pablo Vila Martínez and Javier Maquieyra provided research assistance. The views and findings presented here should not be attributed to the World Bank. We thank John Nash and Henry Chen for their valuable comments. We acknowledge the Knowledge for Change Program (KCP) Trust Fund for the financial support.

Appendix A. The structure of the analytical model

To present the model, for now let us focus in a simplified version to highlight the basic elements of its structure. Let us consider an economy with only one domestic agent, whose utility function depends on domestic goods c, fuels c_f and services a, imported goods m and bonds held by households b^h, and labor supply L^s:

$$u\left(c,a,m,c_f,b^h,L^s\right).$$

The following equations correspond to the usual optimal conditions, which equal the marginal rate of substitution to relative prices given by the quotient between the price of domestic goods in international terms p^* and the prices of imported goods p_m^*:

$$\begin{aligned} u_c/u_m &= p^*/p_m^*.\\ u_c/u_f &= p^*/p_f.\\ u_c/u_a &= p^*/p_a\\ u_c/u_b &= p^*/p_b\\ u_c/u_L &= p^*/w \end{aligned} \tag{1}$$

The last equation corresponds to the consumption/leisure decision and w represents the wage rate. Superscript h indicates the variables corresponding to households. Domestic goods include foods and beverages. Services include transportation.

The budget constraint of the domestic agent can be written as:

$$(1+t)p^*c+p_m^*m+p_aa+p_bb^h+p_fc_f=wL^s+\pi\eta+\pi_a\theta+rK\eta+p_bb_0^h. \tag{2}$$

while w represents wages, L^s is the supply of labor, and π and π_a are benefits in the industries producing goods and services, respectively. Parameters η and θ represent shares of domestic agents in each one of them ($0<\eta,\ \theta<1$). To simplify, we also assume that the participation in capital ownership coincides with the latter two (the rest of the world retains the complementary shares). Eq. (2) assumes that the consumer only pays taxes on the purchase of domestic tradable goods. This is a simplification given that the model includes several other taxes observed in the economy. The last term reflects the initial bonds held by the household.

The general model includes also investment decisions of households.

Tradable goods

The production function of tradable domestic goods c and exports x in terms of capital and employment is given by:

$$x+c=F(L,K). \tag{3}$$

The benefits of the tradable industry are:

$$\pi=p^*(x+c)-wL-r^*K-p_aa^d-p_fa_f^d \tag{4}$$

where r^* indicates capital remuneration and $p_a\ a^d$ are expenditures in non-tradable, which are assumed in fixed coefficients with the total value added:

$$\begin{aligned} a^d &= \alpha F(L,K)\\ a_f^d &= \alpha_f F(L,K) \end{aligned} \tag{5}$$

and a_f^d stands for the demand of fuels, which is in fixed coefficient relation with production. The maximization conditions of benefits are[15]:

$$\left(p^*-\alpha p_a-\gamma p^*-\alpha_f p_f\right)F_K-r^*=0, \tag{6}$$

$$\left(p^*-\alpha p_a-\gamma p^*-\alpha_f p_f\right)F_L-w=0, \tag{7}$$

when the levels of capital use and labor are determined optimally. In these expressions γp^* stand for expenses in intermediate tradable goods (in a Leontief relation given by γ).

Non-tradable goods and services

At the level of the non-tradable industry, the corresponding equations to define profits, optimal conditions, and the output function are:

$$\pi_a = p_a G(L_a) - wL_a - \theta G(L_a)p^* - \theta_f G(L_a)p_f, \tag{8}$$

$$a^s = G(L_a), \tag{9}$$

$$\left(p_a-\theta p^*-\theta_f p_f\right)G'(L_a)=w \tag{10}$$

The last term represents the use of tradable goods and fuels in the production of non-tradable (in fixed coefficients given by θ and θ_f respectively). It can be seen that in these equations it is assumed that the sector only employs labor to produce services. Once again, this is a simplification in this simplified version, for the general model includes capital as an argument of the production function. Moreover, capital is separated in two categories: mobile and not mobile. The latter is specific for each sector.

Public sector

The Public Sector has a budget constraint given by:

$$tp^*c+t_x x+p_b b_0^G = wL^G + p_b b^G. \tag{11}$$

The left side represents tax revenue, including export taxes, as well as bonds sales. The right side represents the purchases of labor and bonds (so that there is a net position in bonds). Notice that here we assume that the government is not participating actively in the markets for goods or services, although that does not occur in the general model. In this simplified case, the government collects taxes and uses the proceedings to hire workers and repay debt (the general model includes investments and government consumption).

External balance

Note that in this version, the external sector does not buy domestic bonds, which is also a strong assumption that we leave aside in the general model. Given these assumptions, we can obtain an equilibrium in the following current account as:

$$p^x x = p_m^* m + (1-\eta)r^*K + (1-\eta)\pi + (1-\theta)\pi_a. \tag{12}$$

The biofuels case

We need to make specific the above model to represent the agricultural sector and its components as well as the food and beverages industry and soybean oil, biodiesel and bioethanol industries, and the refineries of oil. All of them play an important role in the evaluation of simulations.

[15] We assume that the degree of homogeneity of F and G is less than one.

Household decisions on biofuels

The choice of the optimal proportion of every fuel (including biofuels) is obtained from a nested production function into the utility function, through a process of cost minimization.

It is assumed that the combination of fuels demanded by households is obtained a process of cost minimization, as it is the case of transportation. That is, c_f is determined minimizing the cost of producing one unit of fuel using the basic fuel (gasoline or diesel) and the corresponding biofuel (bioethanol or biodiesel, respectively). For example, in the case of diesel:

$$\text{Min} p_{\text{diesel}} c_{\text{diesel}} + p_{\text{biodiesel}} c_{\text{biodiesel}} \tag{13}$$

Subject to

$$G_{\text{fdiesel}}(c_{\text{diesel}}, c_{\text{biodiesel}}) = c_f \tag{14}$$

G_{fdiesel} is a production function that can be subject to sensitivity by changing the associated elasticities of substitution. Therefore p_f becomes the minimum cost of one unit of the basket of fuels.

This optimization process could be constrained also to mandatory requirements that establish minimum contents of biofuels per unit of fuel used. For example, in the case of biodiesel those requirements could take the form:

$$c_{\text{biodiesel}} \geq \varphi c_{\text{diesel}} \tag{15}$$

where φ is a policy parameter.

The same process is repeated for gasoline and bioethanol, and it is also taken into account the potential substitution between fuels based on diesel and on gasoline.

Agriculture

For agriculture, land must be included into the production function. Let A_g stand for hectares of land used in production of crop g. We consider four sub-sectors: soybean, maize, sugar cane, and the rest of agricultural products. The production function will read:

$$x_g + c_g = F_g(L_g, A_g, K_g) \tag{16}$$

g=soybean, maize, sugar cane, rest of agricultural products.
and profits will be given by:

$$\pi_g = (1-tx_g)p_g^*(x_g+c_g) - wL_g - r^*K_g - p_L A_g - p_a a_g{}^d \tag{17}$$

where r^* indicates the reward to capital and tx_g stands for export taxes on crop g. Export taxes have a significant role in determining supply.

Land is a mobile factor only between agricultural industries. It includes not only land per se, but also tractors and machinery specialized in agricultural work. Its price is indicated by p_L.

The presence of land, requires to include in the model the market equilibrium condition for land, given by:

$$\Sigma A_g = A^0. \tag{18}$$

$a_g{}^d$ stands for the demand of services, one important component of which are transportation services.

The general model also includes demand for inputs produced by manufactures, though they are not shown here.

Food and beverages

Food and beverages use intensively as inputs products obtained from agriculture.

Therefore the use of agricultural products for their production competes with other uses, mainly biofuels production and direct exports. Total production is given by

$$x_{\text{fb}} + c_{\text{fb}} = F_{\text{fb}}(L_{\text{fb}}, K_{\text{fb}}) \tag{19}$$

and it is assumed that input requirements from agriculture are given by

$$a^d_{\mathrm{fbi}} = \alpha_{\mathrm{fbi}} F_{\mathrm{fb}}(L_{\mathrm{fb}}, K_{\mathrm{fb}}) \quad (20)$$

Therefore, profits of the industry can be written as:

$$\pi_{\mathrm{fb}} = p_{\mathrm{fb}}{}^*(x_{\mathrm{fb}} + c_{\mathrm{fb}}) - wL_{\mathrm{fb}} - r^* K_{\mathrm{fb}} - p_i a^d_{\mathrm{fbi}} \quad (21)$$

Notice that exports are included as a final use of foods and beverages. They are subject to taxes, not represented here for the sake of clarity only.

Soybean oil

This industry is explicitly modeled since it gives a relevant alternative use for soybean production, but also because it is integrated to the biodiesel industry. As in the cases shown above, production of soybean oil is given by:

$$x_{\mathrm{so}} + c_{\mathrm{so}} = F_{\mathrm{so}}(L_{\mathrm{so}}, K_{\mathrm{so}}) \quad (22)$$

Soybean oil production uses soybean production in fixed coefficients:

$$a^d_{\mathrm{soybean}} = \alpha_{\mathrm{soybean}} F_{\mathrm{so}}(L_{\mathrm{so}}, K_{\mathrm{so}}) \quad (23)$$

Therefore, profits of the industry can be written as:

$$\pi_{\mathrm{so}} = (1 - tx_{\mathrm{so}}) p_{\mathrm{so}}{}^*(x_{\mathrm{so}} + c_{\mathrm{so}}) - wL_{\mathrm{so}} - r^* K_{\mathrm{so}} - p^*_{\mathrm{soybean}}(1 - tx_{\mathrm{soybean}}) a^d_{\mathrm{soybean}} \quad (24)$$

Notice that profits depend on export taxes on output and on the net domestic price of soybean, i.e., net of export prices of soybean.

Biodiesel

Production of biodiesel requires labor and capital and total production is used for domestic use (indicated as c_{bd}) and for exports:

$$x_{\mathrm{bd}} + c_{\mathrm{bd}} = F_{\mathrm{bd}}(L_{\mathrm{bd}}, K_{\mathrm{bd}}, \sigma_{\mathrm{bd}}) \quad (25)$$

where (σ_{bd}) indicates the elasticity of substitution between labor and capacity.

Production requires the use of soybean oil in fixed coefficients:

$$a^d_{\mathrm{so}} = \alpha_{\mathrm{so}} F_{\mathrm{bd}}(L_{\mathrm{bd}}, K_{\mathrm{bd}}) \quad (26)$$

Capacity utilized in production is bounded by present capacity plus additional capacity

$$K_{\mathrm{bd}} \le K^0_{\mathrm{bd}} + \Delta K_{\mathrm{bd}} \quad (27)$$

This condition is motivated because there already exists sunk capacity in the sector. When (σ_{bd}) is low (the production function tends to a Leontief) then production is bounded by installed capacity, and that boundary can be relaxed using additional investments.

Therefore, profits of the industry can be written as:

$$\pi_{bd} = [(1 - tx_{\mathrm{bd}}) p_{\mathrm{bd}}{}^* + p_{\mathrm{sbd}} \beta_{\mathrm{bd}}](x_{\mathrm{bd}} + c_{\mathrm{bd}}) - wL_{\mathrm{bd}} - r_{\mathrm{bd}} K_{\mathrm{bd}} - r^* \Delta K_{\mathrm{bd}} - p_{\mathrm{ot}} a^d_{\mathrm{ot}} - p^*_{\mathrm{so}}(1 - tx_{\mathrm{so}}) a^d_{\mathrm{so}} \quad (28)$$

Notice that there are different rewards for present capacity that is specific, and not mobile, r_{bd}, and additional capacity, its opportunity cost.

In that expression we have included the demand for other industrial and chemical inputs used for production, a^d_{ot} also in fixed coefficients with total production:

$$a^d_{\mathrm{ot}} = \alpha_{\mathrm{ot}} F_{\mathrm{bd}}(L_{\mathrm{bd}}, K_{\mathrm{bd}}) \quad (29)$$

The expression $p_{\mathrm{sbd}} \beta_{\mathrm{bd}}$ indicates income obtained from sales of a joint product of the main production process.

Bioethanol

This industry uses maize and sugar cane to produce bioethanol. The production function is given by:

$$x_{\mathrm{ethj}} + c_{\mathrm{ethj}} = F_{\mathrm{ethj}}(L_{\mathrm{ethj}}, K_{\mathrm{ethj}}, \sigma_{\mathrm{ethj}}) \quad (30)$$

where ethj = ethanol from maize, ethanol from sugar cane and (σ_{ethj}) represents the elasticity of substitution between labor and capital. This parameter is analogous to the elasticity between factors in the case of biodiesel. However, in the case of bioethanol there is not installed capacity already available.

If ethanol from maize and from sugar cane are perfect substitutes then we will have

$$p^*{}_{\mathrm{ethmaize}} = p^*{}_{\mathrm{ethsugarcane}} \quad (31)$$

In that case, production requires the use of maize or sugar cane in fixed coefficients:

$$a^d_{\mathrm{ethj}} = \alpha_{\mathrm{ethj}} F_{\mathrm{ethj}}(L_{\mathrm{ethj}}, K_{\mathrm{ethj}}) \quad (32)$$

Profits in both industries will be:

$$\pi_{\mathrm{ethj}} = [(1 - tx_{\mathrm{ethj}}) p_{\mathrm{ethj}}{}^* + p_{\mathrm{seth}} \beta_{\mathrm{seth}}](x_{\mathrm{ethj}} + c_{\mathrm{ethj}}) - wL_{\mathrm{ethj}} - r^* K_{\mathrm{ethj}} - p_{\mathrm{ot}} a^d_{\mathrm{otj}} - p^*_j (1 - tx_{\mathrm{so}}) a^d_{\mathrm{ethj}} \quad (33)$$

here j stands for maize or sugar cane, and as before, a demand for chemical and industrial goods are included.

The demand for chemicals is given by:

$$a^d_{\mathrm{otj}} = \alpha_{\mathrm{otj}} F_{\mathrm{ethj}}(L_{\mathrm{ethj}}, K_{\mathrm{ethj}}) \quad (34)$$

Again in this case, a join product is obtained in fixed proportion with the production of biofuel with positive price p_{seth}.

There is an alternative possibility, which is to take into consideration different degrees of substitution between maize and sugarcane. Then the industry will minimize

$$p^*{}_{\mathrm{maize}} a_{\mathrm{maize}} + p^*{}_{\mathrm{sugarcane}} a_{\mathrm{sugarcae}}, \quad (35)$$

subject to obtain an unit of bioethanol.

Transportation

The transport system utilizes biofuels and oil fuels for the production of services of transportation, which are demanded by households, industries and the agricultural sector itself.

$$c_{\mathrm{trans}} + i_{\mathrm{trans}} = F_{\mathrm{trans}}(L_{\mathrm{trans}}, K_{\mathrm{transj}}) \quad (36)$$

where i_{trans} stands for the demand of manufacture and agricultural sectors.

Production requires the use of diesel or gas in different proportions, and they can also be combined with biodiesel or bioethanol. As in previous cases, it is assumed that the combination is obtained by two processes of cost minimization:

$$\mathrm{Min} p_{\mathrm{ethj}}{}^* i_{\mathrm{ethj}} + p_{\mathrm{gas}} i_{\mathrm{gas}} \quad (37)$$

Subject to

$$G_e(i_{\mathrm{ethj}}, i_{\mathrm{gas}}) = a^d_{\mathrm{gas}} \quad (38)$$

and:

$$\mathrm{Min} p_{\mathrm{bd}}{}^* i_{\mathrm{bd}} + p_{\mathrm{diesel}} i_{\mathrm{diesel}} \quad (39)$$

Subject to

$$G_{\mathrm{bd}}(i_{\mathrm{bd}}, i_{\mathrm{diesel}}) = a^d_{\mathrm{diesel}} \quad (40)$$

This process of optimization can be subject also to mandatory requirements that establish minimum contents of biofuels per unit of fuel used in transportation. For example, in the case of biodiesel those requirements would take the form:

$$i_{\mathrm{bd}} \geq \eta_i i_{\mathrm{diesel}} \tag{41}$$

where η_i is a policy parameter.

Profits of the transportation industry will be:

$$\pi_{ethj} = p_{\mathrm{trans}}(c_{\mathrm{trans}} + i_{\mathrm{trans}}) - wL_{\mathrm{trans}} - r^{*}K_{\mathrm{trans}} - \left(p_{\mathrm{ethj}} i_{\mathrm{ethj}} + p_{\mathrm{gas}} i_{\mathrm{gas}}\right) - \left(p_{\mathrm{bd}} i_{\mathrm{bd}} + p_{\mathrm{diesel}} i_{\mathrm{diesel}}\right) \tag{42}$$

Notice that prices of products and inputs are taken at their domestic parity.

Refineries of oil

Refineries use oil to produce gasoline, diesel and other fuels. It is assumed that they are obtained in fixed proportions of total production. All products can be consumed domestically or exported. The main source of domestic demand is the transportation industry. The supply of gasoline, diesel and other fuels are given by:

$$\begin{aligned} a^{s}_{\mathrm{gas}} &= \alpha_{\mathrm{gas}} F_{\mathrm{ref}}(L_{\mathrm{ref}}, K_{\mathrm{ref}}) \\ a^{s}_{\mathrm{diesel}} &= \alpha_{\mathrm{diesel}} F_{\mathrm{ref}}(L_{\mathrm{ref}}, K_{\mathrm{ref}}) \\ a^{s}_{\mathrm{fuels}} &= \alpha_{\mathrm{fuels}} F_{\mathrm{ref}}(L_{\mathrm{ref}}, K_{\mathrm{ref}}) \end{aligned} \tag{43}$$

The main sources of demand for gasoline and diesel are exports and domestic use by households, firms and transportation:

$$\begin{aligned} a^{s}_{\mathrm{gas}} &= x_{\mathrm{gas}} + i_{gas} + c_{gas} + a^{i}_{\mathrm{gas}} + a^{s}_{\mathrm{gas}} a^{s}_{\mathrm{diesel}} \\ &= x_{\mathrm{diesel}} + i_{\mathrm{diesel}} + c_{diesel} + a^{i}_{\mathrm{diesel}} + a^{s}_{\mathrm{diesel}} \end{aligned} \tag{44}$$

In the case of the rest of fuels, exports and consumption by manufactures are the main uses:

$$a^{s}_{\mathrm{fuels}} = x_{\mathrm{fuels}} + c_{\mathrm{fuels}} \tag{45}$$

Therefore, profits of the industry can be written as:

$$\pi_{\mathrm{ref}} = \sum_{\mathrm{allfuels}} p_{\mathrm{fuel}}{}^{*}\left(1 - t_x^{\mathrm{fuel}}\right) a^{s}_{\mathrm{fuel}} - wL_{\mathrm{ref}} - r^{*}K_{\mathrm{ref}} - p^{*}_{\mathrm{oil}}\left(1 - t_x^{\mathrm{oil}}\right)\eta_{\mathrm{oil}} F_{\mathrm{ref}}(L_{\mathrm{ref}}, K_{\mathrm{ref}}) \tag{46}$$

here η_{oil} is the input requirement of oil per unit of production of the refineries.

The Ghg emissions index

This index Ghgei_t is computed as:

$$\mathrm{Ghgei}_t = (\mathrm{Ghge_t}/\mathrm{Ghge_0})100 = \left(\sum_{\mathrm{j}} e_j A_j^t \Big/ \sum_{\mathrm{j}} e_j A_j^0\right)100$$

e_j are emissions of activity j (estimated following UN environmental reports of Argentina) and A_j^t is the activity level of period t.

References

Al-Riffai P., Dimaranan, B., Laborde, D., 2010. Global Trade and Environmental Impact Study of the EU Biofuels Mandate. Study carried out by the International Food Policy Institute (IFPRI) for the Directorate for Trade of the European Commission, March.

Böhringer, C., Rutherford, T., 2008. Combining bottom-up and top-down. Energy Economics, 574–596.

Brooke, A., Kendrick, D., Meeraus, A., 1992. GAMS: A User's Guide. Scientific Press, Release 2.25.

Cámara Argentina de Energías Renovables, 2009. Estado de la Industria Argentina de Biodiesel. Reporte Primer Trimestre 2009: mercados débiles, incremento de conflictos comerciales internacionales y propuesta de solución para la Argentina, Abril.

Chisari, O., 2009. Economic assessment of gains and losses of biofuels production in Argentina. Unpublished study prepared for the World Bank.

Chisari O., Romero, C., et al. 2009. Un modelo de equilibrio general computable para la Argentina, UNDP, Buenos Aires.

Diao, X., Diaz-Bonilla, E., Robinson, S., Orden, D., 2005. Tell Me Where It Hurts, An' I'll Tell You Who to Call: Industrialized Countries' Agricultural Policies and Developing Countries. IFPRI Discussion Paper 84. Washington, D.C.: International Food Policy Research Institute.

Ferris, M., Pang, J., 1997. Engineering and economic applications of complementarity problems. SIAM Review 39 (4), 669–713.

INDEC, 2001. Matriz de Insumo Producto Argentina 1997. Ministerio de Economía, Insituto Nacional de Estadística y Censos.

Robinson, S., Cattaneo, A., El-Said, M., 2001. Updating and estimating a social accounting matrix using cross entropy methods. Economic Systems Research 13 (1), 47–64.

Rutherford, T., 1999. Applied general equilibrium modeling with MPSGE as a GAMS subsystem: an overview of the modeling framework and syntax. Computational Economics 14 (1–2).

Timilsina, G., Beghin, J., van der Mensbrugghe, D., Mevel, S., 2010. The Impacts of Biofuel Targets on Land-Use Change and Food Supply: A Global CGE Assessment, Policy Research Working Paper 5513, The World Bank, Washington, DC.

World Bank, 2009. Country Partnership Strategy for the Argentine Republic for the Period 2010–2012. Report No. 48476-AR, May 6.