BIOETHANOL AS BASIS FOR REGIONAL DEVELOPMENT IN BRAZIL: AN INPUT-OUTPUT MODEL WITH MIXED TECHNOLOGIES[1]

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ABSTRACT

Many issues of strategic importance that have emerged in recent years are contributing to the formulation of national policies for promoting biofuels worldwide. In the developed countries, such initiatives result mainly from concerns on energy security and greenhouse gases emissions. Developing countries envisage biofuels as a potential means to improve access to energy, increase income and employment, alleviate poverty, spur rural development, reduce oil imports and enhance exports of biomass products. These interests converge as to render bioethanol trade a unique opportunity for sustainable development. Despite its simplicity and ease of use, the basic input-output (i-o) model does not allow the representation of technology-differentiated sectors producing the same good or service. For instance, in Brazil, sugarcane can be collected manually or via harvesting machines and alcohol can be produced in plants appended to a sugar mill or in autonomous distilleries. An i-o model with mixed technologies was constructed for the purposes of the study. A linear technology is used to represent the sugarcane and ethanol sectors, whereas the remaining industries are characterized by the usual Leontief production function. Activity levels for the linear-technology sectors are set by a scenario analysis, avoiding the use of much more complicated mathematical tools, such as a computable general equilibrium (cge) model. The construction of the database was done in two stages. Firstly, an i-o table containing 42 sectors and 80 commodities was estimated for the base year of 2002. Secondly, the sugarcane and ethanol industries were disaggregated from the sectors they appear in IBGE economic tables, based on detailed engineering information obtained from experts and specialized publications. The extended input-output model with mixed technologies was used to analyze the socioeconomic impacts of a large-scale expansion of bioethanol production in Brazil so as to replace 5% of the estimated global demand for gasoline in 2025. The resulting direct, indirect and induced effects indicate that if ethanol production is augmented in nearly 800%, GDP would increase by a factor of 11.4%, equivalent to approximately the entire economy in the Northeast region of Brazil, and more than 5 million of jobs would be created.

KEY WORDS

Input-output modeling, energy, bioethanol, Brazil.

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INTRODUCTION

Is it possible to conceive the energy derived from sugarcane biomass as basis for national development program? This is the central question addressed here.

Many issues of strategic importance that have emerged in recent years are contributing to the formulation of national policies for promoting biofuels worldwide. In the developed countries, such initiatives result mainly from concerns on energy security and greenhouse gases emissions. Developing countries envisage biofuels as a potential means to improve access to energy, increase income and employment, alleviate poverty, spur rural development, reduce oil imports and enhance exports of biomass products. These interests converge as to render biofuel trade a unique opportunity for sustainable development.

Brazil is the largest producer of sugarcane, sugar and ethanol in the world. It is estimated that in the 2005 crop, the country harvested 437 million tonnes of sugarcane, planted on an area of 5.9 million hectares; its sugar and ethanol output reached 26.7 million tonnes and 17.0 billion liters, respectively. Brazil has obtained significant yield gains both in the agricultural and industrial stages of ethanol production since the inception of its national alcohol program (Proalcool) 30 years ago. Ethanol and gasoline costs in Brazil would be on par with each other at oil prices in the range of $30–35 a barrel.

In the simulations carried out here it was supposed that Brazil will increase its annual ethanol production in 104.55 billion liters in the period of 20 years. If exported, this additional quantity of alcohol would suffice to replace 5% of the estimated global demand for gasoline in 2025. Achieving this aim would require ethanol production to increase by a factor of 8.3 in relation to the output level of 12.62 billion liters obtained in the base year of 2002.

This scenario is not unrealistic. Brazil is conceivably the only country in the world having large areas still unused that could be devoted to energy crops. Excluding all environmentally-protected land – such as the Amazon region –, and native reserves, at least 60 million hectares (the approximate size of France territory) of land with proper soil and climate conditions for growing sugarcane without irrigation remain available in Brazil. At least 4 billion tonnes of sugarcane could be collected from this area, allowing the production of 350 billion liters of ethanol and 170 TWh of electricity (by burning bagasse in boilers), using existing technology.

METHODS

The socioeconomic impacts were evaluated by means of an extended input-output (i-o) model specially designed for the work conducted here. The basic i-o model developed by Leontief in the 1930 decade is adequate for the analysis of the intersectoral linkages in the economy. Used typically to assess the impacts on the entire productive chain resulting from a change in the final demand for the product of a given sector – exactly the case investigated here –, the basic i-o model does not allow, however, the representation of technology-differentiated sectors producing the same good or service. For instance, in Brazil, sugarcane can be collected manually or via harvesting machines and alcohol can be produced in plants appended to a sugar mill (appended distilleries) or in autonomous distilleries (plants that produce ethanol only). All these different production modes are present in the scenarios considered here. An extended i-o model was then built based on the theoretical framework proposed by Cunha (2005), which made it possible, for instance, to evaluate the effects on employment as a result of mechanizing sugarcane harvesting, an important social issue in Brazil.

The construction of the database was done in two stages. Firstly, an i-o table containing 42 sector and 80 commodities was estimated for the base year of 2002, by means of an updating method described here. It was numerically tested using the i-o tables released by IBGE from 1990 to 1996[4]. The criterion was to compare the production multipliers obtained from two i-o tables: the first is the one estimated by the updating method; the other is that released by IBGE. The average absolute deviation between the two series was calculated in 1.14% and so the updating method was validated. Secondly, the sugarcane and ethanol industries were disaggregated from the sectors they appear in IBGE economic tables, based on detailed engineering information obtained from experts and specialized publications. The different technologies employed in the sugarcane and ethanol industries were inserted in the extended i-o model in a bottom-up manner.

THE MODEL

The theoretical framework of the i-o model with mixed technologies can be explained by means of an example, as shown below.

An economy has seven production sectors, as follows:

- S_1: manually-harvested sugarcane;
- S_2: mechanically-harvested sugarcane;
- S_3: ethanol produced in appended distilleries;
- S_4: ethanol produced in autonomous distilleries;
- S_5: sugarcane (total);
- S_6: ethanol (total);
- S_7: rest of the economy.

These sectors appear in the matrix of transactions indicated in Table 1.

Table 1 also contains:

- Y_i : final demand for commodity produced by sector *i*;
- X_i : output of production sector *i*;
- W_j : aggregate of imports, taxes and payments to the primary factors of production (labor and capital services) used in sector *j*.

Table 1 – Transaction table for the extended i-o model

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	Y	X
S_1					X_1				X_1
S_2					X_2				X_2
S_3						X_3			X_3
S_4						X_4			X_4
S_5	$a_{51}X_1$	$a_{52}X_2$	$a_{53}X_3$	$a_{54}X_4$			$a_{57}X_7$	Y_5	X_5
S_6	$a_{61}X_1$	$a_{62}X_2$	$a_{63}X_3$	$a_{64}X_4$			$a_{67}X_7$	Y_6	X_6
S_7	$a_{71}X_1$	$a_{72}X_2$	$a_{73}X_3$	$a_{74}X_4$			$a_{77}X_7$	Y_7	X_7
W	$a_{W1}X_1$	$a_{W2}X_2$	$a_{W3}X_3$	$a_{W4}X_4$			$a_{W7}X_7$	Y_W	
X^T	X_1	X_2	X_3	X_4	X_5	X_6	X_7		

[4] The most recent input-output table (evaluated at basic prices) published by IBGE (the official statistics bureau for Brazil) refers to the year of 1996.

Transactions in Table 1 are expressed in terms of the technical coefficients a_{ij} .

By construction, all the sugarcane and ethanol inputs to sectors S_1–S_4 and S_7 and final demand (*Y*) are produced by total sugarcane (S_5) and total ethanol (S_6) sectors, respectively. It is important to note that the total output of sectors manually-harvested sugarcane (S_1) and mechanically-harvested sugarcane (S_2) are allocated in the intermediate consumption of total sugarcane sector (S_5). Analogously, total output of sectors ethanol produced in appended distilleries (S_3) and ethanol produced in autonomous distilleries (S_4) are entirely devoted to be used in total ethanol sector (S_6).

The technology used in sectors S_5 e S_6 is linear, meaning that the required inputs can be combined in any proportion. In contrast, the remaining sectors are described by the usual Leontief technology. The i-o model with mixed technologies allows the same commodity – in this case, sugarcane or ethanol – to be produced in different sectors, as discussed in Cunha (2005).

The transactions shown in Table 1 can be expressed as mathematical equations, as follows.

The technology used in the total sugarcane sector (S_5) is linear, so that

$$X_1 = a\ X_5 \tag{1}$$

$$X_2 = b\ X_5 \tag{2}$$

$$a + b = 1,\ 0 \le a \le 1,\ 0 \le b \le 1$$

Thus, the commodity produced by sector S_5 may be obtained by combining inputs from S_1 and S_2 in any proportion given by a and b . For the sectors consuming sugarcane, it does not matter how it was produced.

Similarly, for the total ethanol sector (S_6), it is possible to write

$$X_3 = g\ X_6 \tag{3}$$

$$X_4 = d\ X_6 \tag{4}$$

$$g + d = 1,\ 0 \le g \le 1,\ 0 \le d \le 1$$

The basic i-o model applied to rows corresponding to sectors S_5, S_6 and S_7 in the transaction table:

$$\begin{cases} a_{51}\ X_1 + a_{52}\ X_2 + a_{53}\ X_3 + a_{54}\ X_4 + a_{57}\ X_7 + Y_5 = X_5 \\ a_{61}\ X_1 + a_{62}\ X_2 + a_{63}\ X_3 + a_{64}\ X_4 + a_{67}\ X_7 + Y_6 = X_6 \\ a_{71}\ X_1 + a_{72}\ X_2 + a_{73}\ X_3 + a_{74}\ X_4 + a_{77}\ X_7 + Y_7 = X_7 \end{cases} \tag{5}$$

Substituting (1), (2), (3) and (4) in (5) results

$$\begin{cases} (a_{51}\ a + a_{52}\ b)X_5 + (a_{53}\ g + a_{54}\ d)X_6 + a_{57}\ X_7 + Y_5 = X_5 \\ (a_{61}\ a + a_{62}\ b)X_5 + (a_{63}\ g + a_{64}\ d)X_6 + a_{67}\ X_7 + Y_6 = X_6 \\ (a_{71}\ a + a_{72}\ b)X_5 + (a_{73}\ g + a_{74}\ d)X_6 + a_{77}\ X_7 + Y_7 = X_7 \end{cases} \tag{6}$$

The system of equations (6) is similar to the usual equilibrium conditions for the i-o model, having Y_5, Y_6 and Y_7 as exogenous variables and X_5, X_6 and X_7 as endogenous variables. The parameters a , b , g and d serve to define the sector composition of S_5 and S_6.

In matrix notation, (6) becomes

$$\overline{A}\,X + \overline{Y} = \overline{X}$$

where

$$\overline{A} = \begin{bmatrix} (a_{51}\,a + a_{52}\,b) & (a_{53}\,g + a_{54}\,d) & a_{57} \\ (a_{61}\,a + a_{62}\,b) & (a_{63}\,g + a_{64}\,d) & a_{67} \\ (a_{71}\,a + a_{72}\,b) & (a_{73}\,g + a_{74}\,d) & a_{77} \end{bmatrix}$$

$$\overline{X} = \begin{bmatrix} X_5 \\ X_6 \\ X_7 \end{bmatrix}$$

$$\overline{Y} = \begin{bmatrix} Y_5 \\ Y_6 \\ Y_7 \end{bmatrix}$$

Therefore, the output values for sectors S_5, S_6 e S_7 are given by

$$\overline{X} = \left(I - \overline{A}\right)^{-1} \overline{Y} \tag{7}$$

The matrix of technical coefficients for the extended i-o model (in aggregated form) corresponding to the year of 2002 is given in Table 2. It was derived from the database (Appendix D).

Table 2 – Matrix of technical coefficients

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	X
S_1					a			X_1
S_2					b			X_2
S_3						g		X_3
S_4						d		X_4
S_5	0.0665	0.0695	0.4608	0.3975			0.0016	X_5
S_6	0.0000	0.0000	0.0000	0.0000			0.0039	X_6
S_7	0.4064	0.4999	0.1389	0.2013			0.4175	X_7
M	0.0261	0.0228	0.0038	0.0038			0.0489	
VA	0.5010	0.4078	0.3965	0.3973			0.5281	
L	0.0622	0.0103	0.0021	0.0030			0.0261	
X^T	X_1	X_2	X_3	X_4	X_5	X_6	X_7	

In Table 2, M represents imports, VA is value added and L is the occupied people (number of formal and informal jobs) (the unit for L is 1/R$ 1.000[5]). Clearly, $a_{15} = X_1/X_5 = a = 0.73$, $a_{25} = X_2/X_5 = b = 0.27$, $a_{36} = X_3/X_6 = g = 0.85$ and $a_{46} = X_4/X_6 = d = 0.15$.

Technological changes may be simulated by giving values for the sector composition parameters. For instance, to measure the impacts of mechanization in the sugarcane sector, it suffices to fix $a = 0$ and $b = 1$ and compare the result with the base case.

Table 3 shows matrix $\overline{A}$ for the base case, observed in 2002, characterized by $a = 73\%$ (manual harvest), $b = 27\%$ (machine harvest), $g = 85\%$ (appended distillery) e $d = 15\%$ (autonomous distillery).

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[5] R$ (real) is the Brazilian currency. The approximate exchange rate in April 2006 was 2.2 R$/US$.

Table 3 – Matrix $\bar{A}$ for the base case

	S_5	S_6	S_7	Y	X
S_5	0.0673	0.4070	0.0016	Y_5	X_5
S_6	0.0000	0.0000	0.0039	Y_6	X_6
S_7	0.4317	0.1920	0.4175	Y_7	X_7
M	0.0252	0.0038	0.0489	Y_W	
VA	0.4758	0.3972	0.5281		
L	0.0482	0.0029	0.0261		
X^T	X_5	X_6	X_7		

Applying a "parametric shock" characterized by a = 0% (manual harvest), b = 100% (machine harvest), g = 85% (appended distillery) and d = 15% (autonomous distillery), i.e., supposing that all the sugarcane grown in 2002 was mechanically harvested, $\bar{A}$ turns into the matrix depicted in Table 4.

Table 4 – Matrix $\bar{A}$ for the machine harvest case

	S_5	S_6	S_7	Y	X
S_5	0.0695	0.4070	0.0016	Y_5	X_5
S_6	0.0000	0.0000	0.0039	Y_6	X_6
S_7	0.4999	0.1920	0.4175	Y_7	X_7
M	0.0228	0.0038	0.0489	Y_W	
VA	0.4078	0.3972	0.5281		
L	0.0103	0.0029	0.0261		
X^T	X_5	X_6	X_7		

It may be noticed that only column for S_5 was modified. It corresponds to the column for S_2 in Table 2, since all sugarcane now is machine harvested.

The benchmark values for 2002 are as indicated in Table 5.

Table 5 – Output, value added and occupied people in 2002

	S_5	S_6	S_7	Total
Output value [R$ billion]	9.41	11.50	2,522.36	2,543.26
Value added [R$ billion]	4.48	4.57	1,332.02	1,341.06
Occupied people [1,000]	453.00	33.07	65,887.13	66,373.20

Output, value added and occupied people change in all sectors. The anticipated changes are indicated in Table 6. The resulting output values are calculated by equation (7), using the matrix of direct technical coefficients given in Table 4, assuming that final demand remains the same. Value added and occupied people are obtained by multiplying their respective coefficients (also in Table 4) by the corresponding output values.

Table 6 – Changes in output, value added and occupied people

	S_5	S_6	S_7	Total
Output value [R$ billion]	0.03	0	1.13	1.16
Value added [R$ billion]	-0.63	0	0.59	-0.03
Occupied people	-355,853	13	29,402	-326,439

The number of jobs in the sugarcane sector (sugarcane cutters, basically) decreases by 355,853 (79%). However, the quantity of occupied people in the rest of the economy sector (S_7) increases by 29,402 (0.04%). Overall, 326,439 jobs are lost.

The extended i-o model may be a valuable tool for analyzing the socioeconomic impacts on technologically-differentiated economic systems.

DATABASE

Constructing a database is frequently the most demanding task involved in input-output (i-o) modeling. As remarked by Leontief (1989):

> Theorizing requires inspiration and technical knowhow, while data gathering – particularly for practical implementation of large models – needs much sweat and tears, and always a large amount of time and money. No wonder we face overproduction of models and underinvestment – both intellectual and financial – into compilation of the data bases needed to implement them.

The mathematical structure of an i-o model is somewhat simple and its accuracy depends mainly on the correctness of the data used.

The development of an updated i-o table for studying the Brazilian sugarcane agroindustry followed two stages. Firstly, an i-o table containing 42 sectors and 80 commodities for 2002 was estimated, using an updating method that uses preliminary national accounting data published by IBGE. Secondly, the sugarcane and ethanol industries were disaggregated from the sectors they appear in IBGE economic tables, based on detailed engineering information obtained from experts and specialized publications. All the different technologies for producing sugarcane – manual or machine harvest – and ethanol – appended or autonomous distilleries – were considered in the database.

The most recent i-o table at basic prices made available by IBGE refers to the year of 1996. However, IBGE releases information on transactions evaluated at purchaser's prices for more recent years (currently up to 2002 in consolidate form) in its system of national accounts (IBGE, 2006). All these tables can be used to estimate an i-o table for 2002, as described below.

In Brazil, the i-o tables are compiled presently from 15 basic commodity-by-industry matrices, as shown in Table 7.

IBGE provides the complete set of matrices for the years 1985 and 1990–1996. However, only matrices 1 and 2 are available for the years of 1997–2002.[6] The updating exercise consists in obtaining estimates of the remaining matrices, using the complete i-o table of 1996 and the matrices 1 and 2 for 1997–2002.

[6] Tables 1 and 2 corresponding to 2003 are still under revision.

Obviously, there may be various ways for obtaining such estimates. For instance, the ***ad-hoc*** method suggested by Guilhoto and Sesso (2005) distributes row-wise the total imports, taxes and margins on products (obtained from matrix 1) using as reference the transaction values at purchaser's prices observed in matrix 2. However, this simple method may produce unexpected values. The multiple proportion correction (MPC) method described here rests on the assumption that changes of technical coefficients may be approximated by the corresponding alterations of the transaction values in matrix 2 (evaluated at purchaser's prices). This is explained in detail below.

Table 7 – The matrices of the Brazilian input-output tables

1	Supply (imports, make, taxes and margins) matrix
2	Use (absorption) matrix at purchaser's prices
3	Domestic use (absorption) matrix at basic prices
4	Imports matrix at basic prices
5	Matrix of import taxes
6	Matrix of ICMS[a] taxes on domestic commodities
7	Matrix of ICMS[a] taxes on imports
8	Matrix of IPI[b] and ISS[c] taxes on domestic commodities
9	Matrix of IPI[b] and ISS[c] taxes on imports
10	Matrix of trade margins on domestic commodities
11	Matrix of trade margins on imports
12	Matrix of transport margins on domestic commodities
13	Matrix of transport margins on imports
14	Table of other taxes and margins on domestic commodities
15	Table of other taxes and margins on imports

[a] ICMS: tax on the flow of commodities (a state sales tax)
[b] IPI: tax on industry product (a federal sales tax)
[c] ISS: tax on services (a municipal tax)

Matrices 3–15 have 80 rows (products) and 48 columns (the 42 sectors classified by IBGE, the so-called financial dummy[7] and the five components of final demand – exports, government purchases, household consumption, investments and stock changes). The standard IBGE classification of sectors and commodities are indicated in Appendices A and B, respectively. The problem thus consists in estimating 80×48×13 = 49,920 transaction values for a given year.

Let $M^{k,t}$ be the matrix *k* of the i-o table for year *t*, as defined above. Also, let $M_{i,j}^{k,t}$ be the transaction value in matrix *k* for commodity ***i*** in sector ***j*** observed or estimated in year ***t***. For instance, $M_{2,3}^{10,1998}$ denotes the estimated trade margin associated with the purchase of domestic commodity 2 by sector 3 in the year of 1998.

It is important to notice that

$$M^{2,t} = \sum_{k=3}^{15} M^{k,t} \quad (t = 1985, 1990, \ldots 2002) \tag{1}$$

i.e., the use matrix at purchaser's prices may be decomposed into transactions evaluated at basic prices ($M^{3,t}$), imports, taxes and margins.

Now let

[7] The financial dummy is used by IBGE for GDP correction.

$$A_{i,j}^{k,t} = \frac{M_{i,j}^{k,t}}{X_j^t} \quad (i = 1, \mathbf{K}, 80;\ j = 1, \mathbf{K}, 42;\ k = 2, \mathbf{K}, 15;\ t = 1985, 1990, \mathbf{K}, 2002) \tag{2}$$

where X_j^t is the total output of sector *j* in year *t*.[8] It should be pointed out that elements $A_{i,j}^{k,t}$ comprise only the rows and columns of $M_{i,j}^{k,t}$ corresponding to intermediate consumption.

It is convenient to define $A^{k,t}$ as the 80×42 matrix formed by $A_{i,j}^{k,t}$. In particular, $A_{i,j}^{2,t}$ and $A_{i,j}^{3,t}$ are the matrices of technical coefficients at purchaser's and basic prices, respectively.

It follows from (1) and (2) that

$$A_{i,j}^{2,t} = \frac{\sum_{k=3}^{15} M_{i,j}^{k,t}}{X_j^t} = \sum_{k=3}^{15} A_{i,j}^{k,t} \quad (i = 1, \mathbf{K}, 80;\ j = 1, \mathbf{K}, 42;\ t = 1985, 1990, \mathbf{K}, 2002)$$

so that

$$A^{2,t} = \sum_{k=3}^{15} A^{k,t} \quad (t = 1985, 1990, \mathbf{K}, 2002) \tag{3}$$

The matrices of transactions at purchaser's prices, $A^{2,t}$, $t = 1985, 1990, \mathbf{K}, 2002$, are known and may be used as a reference for estimating $A^{3,t}, \mathbf{K}, A^{15,t}$, $t = 1997, \mathbf{K}, 2002$. Accordingly, let

$$r_{i,j}^t = \frac{A_{i,j}^{2,t}}{A_{i,j}^{2,t-1}} \quad (i = 1, \mathbf{K}, 80;\ j = 1, \mathbf{K}, 42;\ t = 1997, \mathbf{K}, 2002)$$

The main assumption of the updating method described here is that

$$A_{i,j}^{k,t} \approx r_{i,j}^t\, A_{i,j}^{k,t-1} \quad (i = 1, \mathbf{K}, 80;\ j = 1, \mathbf{K}, 42;\ k = 3, \mathbf{K}, 15;\ t = 1997, \mathbf{K}, 2002) \tag{4}$$

The initial conditions for recursive equations (4) are the known matrices $A^{3,1996}, \mathbf{K}, A^{15,1996}$.

These approximations respect (3) since

$$\sum_{k=3}^{15} r_{i,j}^t A_{i,j}^{k,t-1} = r_{i,j}^t \sum_{k=3}^{15} A_{i,j}^{k,t-1} = r_{i,j}^t\, A_{i,j}^{2,t-1} = A_{i,j}^{2,t} \quad (i = 1, \mathbf{K}, 80;\ j = 1, \mathbf{K}, 42;\ t = 1997, \mathbf{K}, 2002)$$

The financial dummy and the final demand components are estimated similarly. For the final demand components, for instance, (2) is redefined as

$$A_{i,j}^{k,t} = \frac{M_{i,j}^{k,t}}{\sum_{i=1}^{80} M_{i,j}^{k,t}} \quad (i = 1, \mathbf{K}, 80;\ j = 44, \mathbf{K}, 48;\ k = 2, \mathbf{K}, 15;\ t = 1985, 1990, \mathbf{K}, 2002) \tag{5}$$

Next, each $M^{k,t}$ is obtained from the corresponding matrix $A^{k,t}$ using (2) or (5). Clearly, equations (1) are satisfied.

For a given *t*, the matrices $M^{3,t}, \mathbf{K}, M^{15,t}$ have to be consistent with the columns of imports, taxes and margins represented in matrix 1. For example, it is necessary, for all *t*, that $\sum_{j=1}^{48} M_{i,j}^{4,t}$ be the total import of commodity *i* in matrix 1. However, this is not expected to occur.

[8] The sectoral output are known for the years of 1985 and 1990–2002.

A simple multiple proportion correction is then applied on matrices 3–15 so as to guarantee the consistency with matrix 1. Since this will eventually violate (1), in the following step matrices 3–15 are corrected once more, this time to make them consistent with matrix 2. This iterative process is repeated until consistency of matrices 3–15 with matrices 1 and 2 is simultaneously obtained within a given margin of tolerance. Up to now there is not any theoretical result assuring that the method will ultimately converge. Nevertheless, in the experiments conducted, the method was able to produce consistent matrices.

The method described above was numerically tested, as follows. It was applied to the 1990–1996 i-o tables released by IBGE to obtain an estimate of the 1996 transaction matrix at basic prices. The criterion was to compare the production multipliers calculated from two i-o tables: the first is the one estimated by the method; the other is that released by IBGE. The result is shown in Appendix C. The average absolute deviation between the two series is about 1.14%. The values diverged by more than 1.5% for only seven sectors. This demonstration experiment suggests that tables updated by the proposed method may be reliable in i-o applications.

A one-to-one correspondence between producing sectors and commodities is commonly assumed in i-o models. However, the make matrix provided by IBGE shows sectors producing more than one commodity. Consequently, it was necessary to obtain first a normalized i-o table considering that each sector produces only one commodity. The industry-by-industry approach and the industry-based technology assumption were adopted (Miller and Blair, 1985). The industry-technology hypothesis considers that in each sector primary and secondary commodities are produced using the same inputs in the same proportion, but in quantities that are proportional to their output. The errors introduced by this normalization process are not significant since primary commodities constitute over 90% of total production in 40 of the 42 sectors detailed in the IBGE i-o tables.

The sugarcane and ethanol industries were then disaggregated from the sectors they appear in IBGE i-o tables. Sugarcane is in the primary sector of agriculture, forestry and fishing. Ethanol is included in the sector of chemicals (excluding pharmaceuticals).

Disaggregating a sector requires that some information be given about its intermediate consumption, imports, taxes and payments to the factors of production.

Sugarcane and ethanol are included in the *products* classified by IBGE, as indicated in Appendix B, and so the corresponding rows in the commodity-by-industry use table were maintained in the normalized direct requirement matrix.

It is often necessary to gather engineering information about cost proportions for labor and the main products used in the sectors to be split. A preliminary cost description for the sugarcane and ethanol sectors were obtained by consulting experts and technical publications in the sugarcane agroindustry. The transaction values for these sectors were simply subtracted from the corresponding columns in the normalized use matrix, so that further numerical adjustments were not necessary.

Finally, the database was calibrated to be consistent with the main socioeconomic indicators observed in 2002, such as employment and average wage. The following parameters were considered valid for 2002:

- Sugarcane harvest: 73% manual, 27% mechanized;
- Sugarcane production: 320.65 million tonnes (84.3% and 15.7% for the center-south and north-northeast regions, respectively);
- Jobs in the sugarcane sector: 41.3% and 58.7% for the center-south and north-northeast regions, respectively;

- Average wage in the sugarcane sector: in the north-northeast states, it is 41.7% of the one observed in the center-south region;
- Ethanol distilleries: 85% appended, 15% autonomous (in volume produced).

The derived i-o coefficients are shown in Appendix D. It can be observed that the ratio between employment coefficients for the manual and mechanical harvest is about 6. The sugarcane output of R$ 100,000 requires six jobs in the manual mode or just one if harvest is mechanized.

SIMULATIONS

An i-o model with mixed technologies and the corresponding database, containing the 45 sectors listed in Appendix D, were used to simulate the direct, indirect and induced socioeconomic impacts of a large scale expansion of ethanol production in Brazil. Annual production of ethanol is assumed to increase by 104.55 billion liters in 20 years, so as to replace 5% of the estimated global demand for gasoline in 2025. The impacts were measured in three different metrics: output value, added value (GDP) and occupied people (formal and informal jobs).

About 27% of the sugarcane grown in Brazil in 2002 was collected using harvesting machines; it is estimated that in 2005, 35% of sugarcane crop were mechanically harvested. Brazil produced 320.65 million tonnes of sugarcane in 2002. A total of 318 sugarcane mills were in operation in 2002 – 199 of them produced both sugar and ethanol, 104 were autonomous distilleries and just 15 produced only sugar. Ethanol produced in autonomous distilleries corresponded to 15% of the total output of 12.62 billion liters obtained in the base year of 2002.

It is supposed that the expansion of ethanol production will be based on autonomous distilleries, processing only mechanically-harvested sugarcane. This is the expected technological setting for the scenario considered here.

Consequently, autonomous distilleries will constitute 90.85% of the total ethanol produced (in volume) by plants in operation in 2025. In terms of the basic parameters for the extended i-o model, a = 0% (manual harvest), b = 100% (machine harvest), g = 9.15% (appended distillery) and d = 90.85% (autonomous distillery).

Two types of economic shock were considered in the numerical experiments carried out here. A parametric shock is used to simulate the expected structural changes in the economy, as explained before. Since it is assumed that the additional ethanol production will be devoted to exports only, a conventional shock on final demand is put into effect, as described below.

The ratio between the additional output to be accomplished by 2025 (104.55 billion liters) and the quantity produced in 2002 (12.62 billion liters) is 8.28. Therefore, ethanol production will increase by 828% in 20 years. Multiplying the output value of the ethanol sector observed in 2002 (R$ 11.50 billion) by 8.28 yields R$ 95.22 billion, which represents the monetary increment to be applied to the final demand for ethanol.

The socioeconomic impacts resulting from the changes described above are assessed for each of the following stages: (i) investments in production, storage and transportation capacity and (ii) operation of the resulting plants.

The socioeconomic impacts in the investment stage are due to the installation of 615 autonomous distilleries – each having capacity for producing 170 million liters of ethanol from 2 million tonnes of sugarcane yearly –, construction of the pipeline infrastructure and, also, enlargement of port facilities. The estimated investments of R$ 195.81 billion (in values of 2005)[9] would promote, on the average, for each year from 2005 until 2025, about 487,300 jobs and a GDP increase of R$ 12.47 billion (in values of 2002)[10].

The socioeconomic impacts for the operation stage – comprising the direct, indirect and induced effects on GDP and occupied people – are outlined in Table 8.

Table 8 – Summary of the socioeconomic impacts on GDP and occupied people

	Total effect	*2002 value*	*Increase*
GDP [R$ billion]	153.75	1,346.03	11.4%
Occupied people [1,000]	5,342.85	66,373.20	8.0%

Expanding ethanol production in Brazil by 104.55 billion liters would bring as benefit a GDP increase of 11.4% and an increment of 8.0% in the employment level.

The GDP share for the state of Rio de Janeiro (the second largest among the Brazilian states) was 12.7% in 2003 – this corresponds roughly to the income increment given in Table 8. Since the estimated 615 plants to be constructed will cover about 21.5 million hectares, the economic effects will be distributed over a vast area of Brazilian territory. This may assist Brazil in easing its regional income disparities.

CONCLUSIONS

It was shown that the socioeconomic impacts of the "cane-of-energy" initiative in Brazil will be significant. The resulting direct, indirect and induced effects indicate that if ethanol production is augmented in nearly 800%, GDP would increase by a factor of 11.4%, equivalent to approximately the entire economy in the Northeast region of Brazil, and more than 5 million of jobs would be created. The estimated investments of $80 billion would support, on the average, during 20 years, almost 500 thousand jobs and an additional GDP of nearly R$ 12.5 billion (in values of 2002), considering the direct, indirect and induced effects.

A preliminary ad-hoc analysis for the standard module of 15 ethanol distilleries considered in the overall study, show that an income of R$ 2.34 billion and almost 75 thousand jobs would be created locally – consistent with a community of 200,000 inhabitants –; the corresponding gross regional product (GRP) per job is R$ 31.2 thousand, which is nearly 55% larger than the average value for the national economy in 2002. The result suggests that economic growth could occur with an improvement in the spatial income distribution.

An interregional i-o model is currently under construction. It will be used to measure more accurately the socioeconomic effects of installing the standard module of ethanol distilleries in different areas. The size of the cluster was calculated so that transporting the ethanol produced locally by pipeline is economically viable. It will comprise an area of 525,000 hectares and produce 2.55 billion liters of ethanol and 1,200 GWh of electricity.

A large-scale national development plan based on biofuels may assist Brazil in reducing its disparities of wealth. The ethanol produced will help the world to avoid a large amount of greenhouse gases emissions from the use of fossil fuels. It could also constitute a valuable

[9] R$ 195.81 billion corresponds approximately to US$ 80 billion using the official average exchange rate for 2005 of 2.4341 R$/US$.

[10] It was assumed that R$ 1 in 2002 is equivalent to R$ 1.2921 in September 2005.

instrument to somewhat regulate global fuel supply, preventing market instabilities that are expected to occur during the difficult transition to the post-petroleum era.

As a suggestion for further work, it would be interesting to investigate the penetration of emergent technologies in the sugarcane agroindustry, such as the production of ethanol by hydrolysis of the cellulose contained in bagasse. A computable general equilibrium model could be used to analyze the competition for the use of sugarcane bagasse in the production of alcohol and electricity (Scaramucci et al., 2006).

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APPENDIX A

STANDARD IBGE SECTOR CLASSIFICATION

Code	*Description*
1	Agriculture, forestry and fishing
2	Mining and quarrying
3	Petroleum and gas extraction
4	Non-metallic mineral products
5	Iron and steel
6	Non-ferrous metals
7	Fabricated metal products, except machinery and equipment
8	Machinery, tractors and equipment nec
10 (*)	Electrical machinery and apparatus, nec
11	Office, accounting and computing machinery
12	Motor vehicles (automobiles, trucks and buses)
13	Other vehicles and automotive parts
14	Wood and products of wood and cork
15	Pulp, paper, paper products, printing and publishing
16	Rubber products
17	Chemicals excluding pharmaceuticals
18	Coke, refined petroleum products and nuclear fuel
19	Fertilizers and others chemicals
20	Pharmaceuticals
21	Plastics products
22	Textiles
23	Clothing products
24	Footwear products
25	Coffee products
26	Other vegetables processing
27	Meat
28	Dairy products
29	Sugar
30	Vegetable oil mills
31	Other food products
32	Miscellaneous manufacturing
33	Electricity, gas and water supply
34	Construction
35	Wholesale and retail trade
36	Transport
37	Post and telecommunications
38	Finance and insurance
39	Personal services
40	Business services
41	Real state activities
42	Public administration
43	Private households with employed persons

(*) Sector 9 is nonexistent.

APPENDIX B
STANDARD IBGE PRODUCT CLASSIFICATION

Code	*Description*	*Code*	*Description*
0101	Coffee, raw	2001	Pharmaceuticals
0102	Sugarcane	2101	Plastic products
0103	Rice, raw	2201	Natural textile fibers
0104	Wheat, unmilled	2202	Natural fabrics
0105	Soya, unmilled	2203	Artificial textile fibers
0106	Cotton	2204	Artificial fabrics
0107	Corn	2205	Other textiles
0108	Cattle and swine	2301	Clothing
0109	Milk, unprocessed	2401	Leather and footwear
0110	Poultry	2501	Coffee products
0199	Other agricultural products	2601	Rice, processed
0201	Iron ores	2602	Wheat flour
0202	Other minerals	2603	Other food products
0301	Petroleum and gas	2701	Meat
0302	Coal	2702	Poultry products
0401	Non-metallic products	2801	Processed milk
0501	Basic steel products	2802	Other dairy products
0502	Rolled steel	2901	Sugar
0601	Non-ferrous products	3001	Vegetable oil, raw
0701	Other metallurgic products	3002	Vegetable oil, processed
0801	Machinery and equipment	3101	Other food and feed
0802	Tractors	3102	Beverages
1001	Electrical equipment	3201	Miscellaneous products
1101	Electronic equipment	3301	Electricity, gas and water supply
1201	Automobiles, trucks and buses	3401	Construction products
1301	Other vehicles and parts	3501	Trade margin
1401	Wood and furniture industries	3601	Transport margin
1501	Pulp and paper	3701	Post and telecommunications
1601	Rubber products	3801	Insurance
1701	Non-petrochemical chemical products	3802	Financial services
1702	Ethanol	3901	Accommodation and food services
1801	Gasoline	3902	Other services
1802	Fuel oil	3903	Private education and health services
1803	Other refined products	4001	Business services
1804	Basic petrochemical products	4101	Real estate
1805	Resins	4102	Imputed rent
1806	Gasohol	4201	Public administration
1901	Chemical fertilizers	4202	Public health services
1902	Paints, varnishes and lacquers	4203	Public education services
1903	Other chemicals	4301	Private households with employed persons

APPENDIX C
PRODUCTION MULTIPLIER COMPARISON (1996)

Code	*Description*	*IBGE*	*Estimated*	*Deviation*
1	Agriculture, hunting and fishing	1.669	1.670	0.08%
2	Mining and quarrying	2.042	2.020	-1.07%
3	Petroleum and gas extraction	1.599	1.589	-0.62%
4	Non-metallic mineral products	2.079	2.070	-0.41%
5	Iron and steel	2.598	2.595	-0.10%
6	Non-ferrous metals	2.229	2.256	1.20%
7	Fabricated metal products, except machinery and equipment	2.330	2.321	-0.40%
8	Machinery, tractors and equipment nec	1.804	1.821	0.98%
10 (*)	Electrical machinery and apparatus, nec	2.271	2.286	0.65%
11	Office, accounting and computing machinery	1.664	1.735	4.23%
12	Motor vehicles (automobiles, trucks and buses)	2.184	2.375	8.78%
13	Other vehicles and automotive parts	2.334	2.237	-4.17%
14	Wood and products of wood and cork	2.057	2.035	-1.06%
15	Pulp, paper, paper products, printing and publishing	2.208	2.179	-1.32%
16	Rubber products	2.171	2.096	-3.43%
17	Chemicals excluding pharmaceuticals	2.035	2.013	-1.09%
18	Coke, refined petroleum products and nuclear fuel	1.894	1.939	2.37%
19	Fertilizers and others chemicals	2.077	2.058	-0.93%
20	Pharmaceuticals	1.842	1.835	-0.38%
21	Plastics products	1.934	1.943	0.50%
22	Textiles	2.234	2.229	-0.20%
23	Clothing products	2.219	2.210	-0.41%
24	Footwear products	2.206	2.123	-3.74%
25	Coffee products	2.492	2.492	-0.02%
26	Other vegetables processing	2.244	2.225	-0.82%
27	Meat and meat products	2.369	2.366	-0.14%
28	Dairy products	2.440	2.437	-0.12%
29	Sugar	2.533	2.520	-0.50%
30	Vegetable oil mills	2.604	2.594	-0.37%
31	Other food products	2.343	2.325	-0.76%
32	Miscellaneous manufacturing	1.911	1.908	-0.19%
33	Electricity, gas and water supply	1.570	1.564	-0.36%
34	Construction	1.610	1.602	-0.52%
35	Wholesale and retail trade	1.642	1.641	-0.04%
36	Transport	1.760	1.698	-3.52%
37	Post and telecommunications	1.264	1.259	-0.47%
38	Finance and insurance	1.400	1.397	-0.20%
39	Personal services	1.597	1.581	-1.03%
40	Business services	1.412	1.409	-0.28%
41	Real state activities	1.064	1.064	-0.05%
42	Public administration	1.416	1.415	-0.09%
43	Private households with employed persons	1.119	1.118	-0.13%

(*) Sector 9 is nonexistent.

APPENDIX D
TECHNICAL COEFFICIENTS (2002)

Description	S_1 (*)	S_2 (*)	S_3 (*)	S_4 (*)
Sugarcane	0.0665	0.0695	0.3975	0.4608
Ethanol	0.0000	0.0000	0.0000	0.0000
Gasohol	0.0062	0.0062	0.0003	0.0003
Chemicals excluding pharmaceuticals	0.0020	0.0020	0.0000	0.0000
Rest of agriculture, hunting and fishing	0.0142	0.0124	0.0000	0.0000
Sugar	0.0000	0.0000	0.0700	0.0000
Mining and quarrying	0.0000	0.0000	0.0000	0.0000
Petroleum and gas extraction	0.0000	0.0000	0.0000	0.0000
Non-metallic mineral products	0.0042	0.0037	0.0000	0.0000
Iron and steel	0.0000	0.0000	0.0000	0.0000
Non-ferrous metals	0.0000	0.0000	0.0000	0.0000
Fabricated metal products, except machinery and equipment	0.0014	0.0014	0.0000	0.0000
Machinery, tractors and equipment nec	0.0133	0.0327	0.0258	0.0248
Electrical machinery and apparatus, nec	0.0001	0.0001	0.0018	0.0018
Office, accounting and computing machinery	0.0001	0.0001	0.0006	0.0006
Motor vehicles (automobiles, trucks and buses)	0.0001	0.0001	0.0005	0.0005
Other vehicles and automotive parts	0.0000	0.0000	0.0008	0.0008
Wood and products of wood and cork	0.0011	0.0011	0.0002	0.0002
Pulp, paper, paper products, printing and publishing	0.0005	0.0005	0.0025	0.0025
Rubber products	0.0000	0.0000	0.0000	0.0000
Coke, refined petroleum products and nuclear fuel	0.1581	0.1880	0.0036	0.0040
Fertilizers and others chemicals	0.1080	0.0941	0.0174	0.0255
Pharmaceuticals	0.0000	0.0000	0.0000	0.0000
Plastics products	0.0022	0.0022	0.0012	0.0012
Textiles	0.0014	0.0014	0.0004	0.0004
Clothing products	0.0000	0.0000	0.0001	0.0001
Footwear products	0.0002	0.0002	0.0000	0.0000
Coffee products	0.0000	0.0000	0.0000	0.0000
Other vegetables processing	0.0000	0.0000	0.0000	0.0000
Meat	0.0000	0.0000	0.0000	0.0000
Dairy products	0.0000	0.0000	0.0000	0.0000
Vegetable oil mills	0.0000	0.0000	0.0000	0.0000
Other food products	0.0000	0.0000	0.0000	0.0000
Miscellaneous manufacturing	0.0006	0.0006	0.0034	0.0034
Electricity, gas and water supply	0.0000	0.0000	0.0000	0.0000
Construction	0.0000	0.0000	0.0023	0.0023
Wholesale and retail trade	0.0250	0.0250	0.0154	0.0154
Transport	0.0179	0.0179	0.0285	0.0285
Post and telecommunications	0.0005	0.0005	0.0062	0.0062
Finance and insurance	0.0043	0.0043	0.0112	0.0112
Personal services	0.0001	0.0001	0.0002	0.0002
Business services	0.0412	0.1015	0.0070	0.0070
Real state activities	0.0001	0.0001	0.0009	0.0009
Public administration	0.0035	0.0035	0.0010	0.0010
Private households with employed persons	0.0000	0.0000	0.0000	0.0000

(*) S_1: manual harvest; S_2: mechanical harvest; S_3: appended distillery; S_4: autonomous distillery.

COEFFICIENTS FOR IMPORTS, TAXES, PRIMARY FACTORS AND JOBS (2002)

Description	S_1 (*)	S_2 (*)	S_3 (*)	S_4 (*)
Imports	0.0261	0.0228	0.0038	0.0038
Net taxes on products	0.0239	0.0239	0.0043	0.0043
Labor	0.2905	0.0835	0.0462	0.0462
Capital services	0.1866	0.3005	0.3069	0.3060
Net taxes on production	0.0000	0.0000	0.0400	0.0400
Number of formal and informal jobs [1/R$ 1.000]	0.0622	0.0103	0.0030	0.0021

(*) S_1: manual harvest; S_2: mechanical harvest; S_3: appended distillery; S_4: autonomous distillery.