

## **Regional, Economic, and Environmental Implications of Dual Ethanol Technologies in Brazil**

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### **Abstract**

Climate change, food security, and energy efficiency have become universal challenges for global economic development and environmental conservation that demand in-depth multidisciplinary research. Biofuels have emerged as a decisive factor in the fight against global warming and air pollution from fossil fuel use, and they can play an important role in the development of poor as well as rich regions. In this work, we investigate the implications of biofuels for regional development in Brazil given its historic experience as an ethanol producer. We compare the environmental and economic impacts of the two predominant ethanol production techniques, in order to understand their effects on output, employment and income and also their potential to reduce the intensity of fossil fuel use and emissions of greenhouse gases. As we focus on a developing country, we also examine the distributional impacts of ethanol technology deployment, in terms of its potential contributions to poverty alleviation and the reduction of regional income inequalities.

The production technologies currently used to produce ethanol differ spatially in Brazil, with a capital-intensive technology being used in the Southern regions of the country, and a traditional labor-intensive technology in the Northern regions. We take advantage of this regional variation to conduct a comparative regional analysis of ethanol production technology choice. We evaluate and compare the direct and indirect relationship between output, employment, income, energy intensity, and pollution emissions at the subnational level for the two ethanol production technologies, showing quantitatively the interrelations between the ethyl alcohol industry and the rest of the economy.

We hypothesize that the adoption of capital-intensive ethanol production technology provides greater output and employment and lower environmental and energy costs than more traditional technologies and, in contrast, that the implementation of the traditional technology alleviates income inequality by increasing the income received by households in economically deprived regions.

## **1. Introduction**

There is at least one obvious certainty when examining global environmental change on a civilizational timescale: we are facing crucial years for international action and the odds against effectiveness over the next decade are indeed overwhelming. To this challenging scenario has been added the undeniable reality that our predominantly fossil-fueled society is bound to be a relatively ephemeral affair. Growth of economic activity and energy consumption, coupled with the increasing need to alleviate the pressures of human activity on the environment, has led to augmented demand for secure and sustainable forms of transport fuel. In developing countries such as Brazil, the tradeoff facing policy makers is to increase the mobility that underpins economic growth and social interaction while limiting the environmental impact and footprint of transportation.

The choice of technologies, which affects economic and social structures, is one of the most important collective decisions facing a developing country that is attempting to solve these issues. It determines who works and who does not; the pattern of income distribution, where work is done and therefore the urban/rural balance; what is produced and for whose benefit resources are used. It is thus important to recognize the implications of choosing one technology rather than another: different techniques often imply different strategies of economic development with different effects on the performance of the economy (Sen, 1968). In particular, due to the ecological urgency of consuming fewer resources and simultaneously reducing greenhouse gas emissions to tackle climate change, technology choices will have profound economic and environmental implications and will affect our societies as profoundly as information technologies have already done.

In this research we assess the extent to which the choice of modern technologies over traditional technology methods has improved socioeconomic development and environmental conditions. When analysts use a methodological framework for understanding the scope of technology choice effects, observable trends that allow them to make a realistic assessment of technology should be included. The Brazilian sugarcane ethanol industry offers such observable trends that we will exploit to understand the economic and environmental implications of modern technology.

Ethanol production technologies differ in Brazilian regions. Whereas the North and Northeast regions of the country produce ethanol in a rather traditional fashion, the South and Southeast regions of the country have made use of modern technologies, particularly in the agricultural process, but also in the industrial processes of ethanol production. Modern technologies require, by nature, large amounts of capital investments derived from technical innovations; hence, we define the traditional ethanol production processes of the Northern regions as labor-intensive, and those of the Southern regions as capital-intensive. Ethanol-technology differences are reflected in a more intensive use of labor by the labor-intensive technology and, in contrast, a more intensive use of machinery, fertilizers and other chemicals, and transportation by the modern technology (Table 1). Similarly, discrepancies are reflected in terms of productivities, agroindustrial yields, economies of scale, levels of employment and rates of human capital accumulation (Table 2).

We hypothesize that the adoption of modern ethanol-production technologies provides greater output and employment and lower environmental and energy costs than more traditional technologies, and, in contrast, that the implementation of these traditional

technologies alleviates income inequality by increasing the income received by households in economically impoverished regions. More specifically, I will answer five key research questions: In which Brazilian region can ethanol be produced most efficiently, and, if so, why? By efficiency, we mean output per unit of labor/capital/energy input. What is the optimal mix of methods for producing ethanol in order for the industry to exhibit sustained productivity gains, given that its production varies from primitive hand-production to fully automated mechanical manufacture? In turn, what production techniques would enable the ethanol industry's current emissions of greenhouse gas emissions to be significantly reduced? Does the ethanol industry promote national employment and rural development, and, if this is the case, how might the industry be a channel through which Brazil would be able to reduce its historic income inequalities?

Although the direct economic and environmental effects of the ethanol industry in Brazil are well documented, the indirect effects are less evident, and, in fact, may outweigh the direct effects of any given investment (Polenske, 2007). We conduct an empirical analysis based on an interregional input-output framework, given this method's capacity of capturing and illustrating both direct and indirect effects of any economic activity, as well as disentangling the regional effects production technologies.

This study is a contribution to the growing literature on the spatial, economic, and environmental implications of technology in four fronts. Naturally, the first contribution of this work is the treatment of ethanol as a case of technology choice, where different regions have differentiated production methods. Rather than treat the ethanol industry as a monolithic manufacturing process devoid of variations in input requirements, we account

for the variations in the attributes of the disparate regional activities that make up the sector, and, in the process, determine whether the traditional ethanol production technology might contribute to economic development more than its relatively modern counterpart. Defourny and Thorbecke (1984); Jeffrey and Khan (1997); Khan (1982, 1985); Khan and Thorbecke (1988, 1989); Leatherman and Marcouiller (1996); and Švejnar and Thorbecke (1983) have used the input-output framework to study dual technological processes, namely modern and traditional production technologies. Second, despite a burgeoning literature on the ethanol sector in Brazil and its impacts on the economy, empirical analyses that characterize the indirect effects associated with the sector's backward and forward linkages are comparatively rare particularly in the international literature (Guilhoto and Sesso Filho, 2005; Nagavarapu, 2008). Third, due to its regional nature, this research also differs from previous studies. Contrary to the majority of economic analysts who study the development of the Brazilian ethanol industry, as a national or bi-regional economic activity, we take account of important differences in technology and productivity at the regional scale. In contrast to previous efforts, namely those of Pereira da Cunha (2005), Rothman, Greenshields, and Rosillo Callé (1983), and Yuuki, Conejero, and Neves (2005), who evaluate the economic effect of an expansion of the ethanol sector without accounting for spatial differences, we conduct a five-region impact analysis. A fourth unique feature of this research is the generation of energy and pollution-emission multipliers derived from the interregional input-output system. Focusing on the environmental effects in Brazil of ethanol production, we examine sectoral energy intensities in order to study which technology is more carbon- and energy-efficient, as a means to evaluate regional impacts of emission-control policies. In contrast to the research conducted for other countries and

regions, such as Alcántara and Padilla (2003), Labandeira and Labeaga (2002), and Tarancón and Del Río (2004) for Spain; Gay and Proops (1993) for the United Kingdom; Lenzen (1998) for Australia; Proops, Faber, and Wagenhals (1993) for Germany; and Sánchez-Chóliz and Duarte (2003) for Aragón, to the best of my knowledge, few analysts in Brazil have recognized that many pollution emissions result from economic activity, and that interrelations among industries significantly affect their nature and magnitude. Notable exceptions are the research by Wachsmann (2005), who evaluates the historical sectoral changes in the Brazilian energy use and the energy-related CO<sub>2</sub> emissions, but fails to analyze the regional issue and underestimates the importance of the ethanol sector, and Hilgemberg (2004), who analyzes the effects in greenhouse gases derived from changes in sectoral demand. This study is also an improvement upon the work done by Hilgemberg (2004), as we make use of more recent energy datasets and adhere to sectoral classifications more homogeneous to national accounting international conventions, thus making the research results adequate for international comparisons and analysis.

## **2. A Literature Review of Technology Choices**

The choice of technologies, which affects economic, social, and environmental structures, is one of the most important collective decisions facing a developing country. It is crucial for the development of economic policies, as the choice of technologies determines who works and who does not; the pattern of income distribution, where work is done and therefore the urban/rural balance; what is produced and for whose benefit

resources are used. It is also critical in the design of efficient environmental policies, because technology determines how energy is used and where pollution is generated or, conversely, where it is likely to be mitigated. It is thus important to recognize the implications of choosing one technology rather than another: different techniques often imply different strategies of economic development with different effects on the performance of the economy (Sen, 1968).

Even though technology has always been viewed within economic theory as an important factor of production, it has until recently almost always been treated by economists as exogenous to the economic system (Solow, 1956), or as an inscrutable black box (Rosenberg, 1982). Economists did not consider the issue of technology choice as being very important, with the remarkable exception of the Schumpeterian school, which placed great importance on the role of invention and technological innovation in long-term economic cycles (Schumpeter, 1912; Rosenberg, 1982; Thirtle & Ruttan, 1987). The economic view of the state of technology in the economy as something that was “given” at any particular period, changing from time to time as breakthroughs, emerged from the supposedly independent activities of scientists and engineers. Economists generally assumed that, under ideal conditions, normal economic forces would lead to the adoption of optimal production systems, given a particular shock of technology available at any particular time (Willoughby, 1990).

This passive attitude towards understanding how the technology process takes place has changed dramatically over the past two decades. In the economics arena, technological change has been studied thoroughly, both from the microeconomic perspective of induced innovation, and the macroeconomic approach of diffusion (Popp, Newell, & Jaffe, 2009),

especially in the fields of incentives theory, externalities and market failure, productive innovation, public economics, and endogenous macroeconomic growth (see for instance the works of Tirole (1988), Griliches (1992, 1998), Jorgenson and Stiroh (2000), Sutton (1998), Martin and Scott (2000), David, Hall, and Toole (2000), and Romer (1994))<sup>1</sup>. Similarly, much attention has received the issue of the intensity of capital, and its impact via technology on the economic system. This capital-accumulation approach would define a primitive hand-production technology as labor-intensive, whereas the fully automated mechanical manufacture technology would be identified as capital-intensive. Within this framework, it is implied that technological change occurs as the labor-intensive becomes more capital-intensive. Both types of technologies provide several advantages and shortcomings. For instance, proponents of capital-intensive technologies (e.g., Barro and Sala-i-Martin, 2004; Hirschman, 1958; Kaldor, 1963; Sen, 1968) underscore enhanced capital accumulation and capital spillover effects, generation of efficiency, demand-induced growth, environmental cost reductions, and gains in income and employment generation. On the other hand, advocates of labor-intensive technologies (e.g., Hunt, 1989; Jain et al., 1993; Salem, 1999; Salomon et al., 1994; Pearce, 2006; Schumacher, 2000) emphasize that these gains would worsen income inequality, criticize the unsuitability of capital-intensive technologies in labor-intensive regions because they distort relative factor prices and reduce the purchasing power of the poor as capital-intensive goods tend to be more expensive than labor-intensive products, and state that industrialization is feasible in a labor-intensive

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<sup>1</sup> Our purpose in this section is not to survey exhaustively the economics literature on technology choice and change. Jaffe, Newell, & Stavins (2001), who cite the abovementioned references, review this literature in depth.



context, given that labor-intensive technologies are able to increase production regardless of the scarcity of capital.

Empirical tests related to technology choice were conducted on a variety of specific products and countries (i.e., soap in Barbados and Bangladesh, bicycles in Malaysia, metal household utensils and cotton clothing in India, furniture making in Kenya, rice in Indonesia, textiles and paper in Colombia and Brazil, and passenger transport in Pakistan). These studies generally confirmed the hypothesis that labor-intensive technologies alleviate income inequality (Amsalem, 1983; James, 1976; Timmer, 1975; van Ginneken and Baron, 1984). Using the input-output framework, Khan and Thorbecke (1988) conclude that the traditional technology in Indonesia generates greater aggregate output effects on the whole economic system than the corresponding modern technology and that the effect of the increased production of traditional technology has a greater impact on total employment and a much greater impact on the wages of low-skilled workers than the corresponding modern alternatives. Similar findings are presented by Defourny and Thorbecke (1984) and Leatherman and Marcouiller (1996).

Likewise, other cases, such as dairy products in Finland, automobiles in the United States, irrigation systems in Egypt, and processed food in South Korea confirmed the hypothesis that capital-intensive technologies improve productivity and increasing income (Heikkilä and Pietola, 2006; Mourshed, 1996; Švejnar and Thorbecke, 1983; van Biesebroeck, 2002).

However, evidence from other studies underscore that labor-intensive technologies do not necessarily raise employment substantially. This limited employment impact may be

due to the fact that some basic products may use capital-intensive, but cheap, inputs like synthetic fiber. Second, the employment effects may be small because the macroeconomic studies are too aggregate. Taking the sugar industry in India as an example, James (1985) shows that combining crystal sugar (capital-intensive) and *gur* (labor-intensive) underestimates the effects of changes in income distribution in India. If they were taken separately, the positive employment effects would increase by 50%. Likewise, Tokman (1974) concluded that labor-intensive technologies in the Ecuadorean and Peruvian manufacturing sectors increased employment by 2.5%. Such an increase, however, was smaller than the sectoral growth rate in both countries. A similar result is obtained for the industrial sector of Venezuela, where labor-intensive technologies generated an increase in employment of 4.6%, while the increase in sectoral production was 5% (Salomon, Sagasti, and Sachs-Jeantet, 1994).

Simultaneously, empirical evidence has also underscored that capital-intensive technologies do not necessarily raise productivity and income significantly. Bhutan's agriculture sector's capital-intensive technologies have done little to increase productivity gains in paddy (rice), the prominent Bhutanese crop, as Bhutan has the second lowest productivity in Asia after Cambodia (Munro, 1989). Rybczynski (1978) cites cases of capital-intensive biogas digesters in India and South Korea that were abandoned because of insufficient methane production and inadequate supply of cow dung (Akubue, 2000). A number of iron and steel firms in China pursued premature modernization by adopting excessively capital-intensive technologies, yet their income did not increase substantially (Otsuka, Liu, and Murakami, 1998).

In some cases even capital-intensive goods (i.e., Bata shoes produced with modern technology in Ghana) may be more appropriate for the poor than their labor-intensive counterparts because the former are cheaper and more durable (van Ginneken and Baron, 1984). In Japan, capital-intensive technologies at the beginning of the 20<sup>th</sup> century in the cotton industry succeeded in increasing income, partially because of relatively free access to credit markets. Conversely, modern technologies in India failed to increase income due to human-capital and credit-market constraints (Ranis and Saxonhouse, 1983).

Just like certain technologies provide economic advantages, but at the same time create negative effects for the population and the economic system as a whole, research within the field of industrial ecology has analyzed whether technology is able to assure environmental conservation and sustainable development<sup>2</sup>.

The evidence found in the literature reflects this dichotomy. On the one hand, the proponents of innovation and more capital-intensive technologies as a means to reduce environmental stress argue that technological change has helped reduce environmental pressures by reducing greenhouse gases emissions or using resources more efficiently, especially after World War II. On the other hand, much research has questioned the benefit of technology advancement, oftentimes claiming that newer technologies have led to the dissipation of vast amounts of natural resources and growing ecological stress (Duchin & Lange, 1994). As an OECD report shows, the overall effects of technology are ambiguous.

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<sup>2</sup> Other growing bodies of literature focus on the relationship between market- and government-induced incentives (i.e., prices, taxes, permits, or environmental policies and regulations) and the direction and level of technological change, or the process through which technological innovations are diffused. For further background on these literatures, see Jaffe, Newell, & Stavins (2001, 2002).

In the case of biofuels, they might release fewer pollutants, but at the same time increase pressure on land resources (OECD, 2008). In this sense, technology is a “double-edged sword” for the environment, as it can amplify as well as alleviate the impacts of human activities (Dorf, 2001; Grübler, Nakicenovic, & Nordhaus, 2002).

Multigovernmental research has found that the replacement of labor-intensive methods with state-of-the-art, capital-intensive production techniques leads to sustained gains in efficiency and declines in pollution (United Nations, 1985; Trasatti, 1995). In Popp, Newell, & Jaffe (2009) it is mentioned that some studies that made use of a time trend to capture technological change, including the works of Berndt, Kolstad, & Lee (1993), Mountain, Stipdonk, & Warren (1989), and Sterner (1990), have found that technological innovations are energy-saving. Similarly, by using data envelopment analysis, Boyd & McClelland (1999) and Boyd & Pang (2000) suggest that technological improvements not only increase productivity but also reduce pollution. Likewise, Metcalf & Hassett (1999) underscore that using new home improvement equipment reduces significantly energy consumption. Capital-intensive technologies proved to be environmentally ineffective in Bhutan’s mountainous terrain, yet they were developed with apparent success in the hilliest regions of Japan (Munro, 1989).

Conversely, Bencheqroun & Chaudhuri (2009) show that although the adoption of technology innovations reduces each country’s damage from pollution, it gives an incentive to each country to increase its production. In the aggregate, the increase in emissions associated with the increase in production can outweigh the positive environmental impact of adopting a newer, cleaner technology. Almost three decades before, Ruttan (1971) linked technological change to environmental degradation. Cole & Elliott (2003) also argue that

capital-intensive technologies are usually pollution-intensive. A similar conclusion is reached by Hester & Harrison (1994) in their analysis of the environmental impact of the mining industry. In Popp, Newell, & Jaffe (2009) it is mentioned that in terms of energy use, Sue Wing (2008) demonstrates empirically that induced technological innovation in response to energy prices has little effect on the decline of energy intensity in the United States. Similarly, in a study of U.S. industrial energy consumption from 1958 to 1974, Jorgenson & Fraumeni (1981) find that technological change increased energy-intensity over time.

In terms of the impact of biofuels technologies on the environment, the evidence is ambiguous. Whereas some studies show that biofuels provide significant CO<sub>2</sub> emissions savings when compared to fossil fuels such as gasoline and diesel (EC, 2008; Goldemberg, 2008; ÚNICA, 2008), other studies show that biofuels worsen the climate problem and cause irreversible ecological damage (Bhutto, 2008; Ehrlich and Ehrlich, 1981; Fargione et al., 2008; Rosenthal, 2008).

### **3. Causes of Dual Ethanol Production Technologies in Brazil**

There is little doubt that disparate technological processes to produce ethanol and harvest sugarcane exist in Brazil, with the South and Southeast regions of the country having relatively mechanized technological processes, and the North and Northeast areas using labor-intensive production technologies. We examine the Brazilian ethanol sector as a case of dual technologies, and clarify where the labor-intensive and capital-intensive technological processes differ. The disparities in the ethanol production processes in Brazil cannot be understood based on pure economic, spatial, or political science theories. Rather,

such disparities are the result of economic, political, and spatial interactions, which we present below.

### *3.1. The Spatial Component*

Perhaps the most important factor determining the technology gap is of a spatial nature. In effect, Brazil has two main sugar cane growing and sugar producing regions. Brazil has two main sugar cane growing and sugar producing regions. The larger of the two is located adjacent to and in the São Paulo state region, which lies in the Southeast of Brazil. This fertile and flat region is perfectly suited for growing sugar cane, as there are ample nutrients in the soil to nourish the cane through its growing stages, and when it is time to harvest the sugar cane, the large flat fields of sugar cane are easily harvested by mechanical means. The second major sugar-producing region in Brazil is in the Northeast, and lies in the Pernambuco and Alagoas states. The terrain here is much less suited to growing sugar cane, as it is quite hilly (about 60% of the sugarcane in the Northeastern regions is on slopes between 12 and 25 degrees), and the soil quality is relatively poor because of erosion (James, 1953).

Because of this topographical aspect, sugarcane harvesting is done solely by hand in Northern Brazil (with an extremely limited number of exceptions in the states of Alagoas, Amazonas, Pernambuco, Rio Grande do Norte and Tocantins), whereas the Southern Brazilian states carry out partially mechanized harvesting. Mechanized harvesting is difficult to implement in Northern Brazil because of topographical factors: large machinery is extremely difficult to operate in hilly areas. Hand-cut cane is a less productive process than mechanized harvesting given that cane cutting is a very time-consuming activity, and

an enormous amount of labor is required. Additionally, the mechanical harvester leaves a lush layer of chopped green leaves over the harvested field, what means “coating” soil with a protective layer that conserves water, protects the soil from erosion, contributes organic matter, and recycles nutrients, which may secure good yields for the next harvest (Maciel, 2008).

### *3.2. The Economic Component*

Economic factors also led to the more rapid adoption of more mechanized technologies in the South of the country. Goldemberg et al. (2004) demonstrate, using the case of Brazilian sugarcane ethanol, that economies of scale and market experience led to increased competitiveness of ethanol. Yet, the Southern region achieved lower production costs at a more rapid pace. The lower cost of production in the South is associated with this region having a higher demand for ethanol. The need of competitiveness was greater in the South because demand pressures in this region were stronger. Agricultural modernization in the South was necessary to keep up with the demand requirements of the large industrial centers of the region, namely São Paulo, Rio de Janeiro, and Belo Horizonte. Changes in the technological base of the ethanolmaking process were thus required, particularly in the South and Southeast regions of the country, where production was concentrated. Concrete manifestations of this new pattern are the increasingly integrated cane production stages, a higher level of mechanization, chemical inputs, transport capacity, sugarcane irrigation, and the substitution of permanent forms of employment with temporary labor arrangements. In addition, rising labor costs combined with low real prices for machinery and industrial inputs owing to massive infusions of subsidized credit from state governments forced

producers to modernize and mechanize. The regional unevenness of the consolidation of agribusiness capital exacerbated preexisting spatial disparities. (da Silva & Kohl, 1994)

In a less significant way, one could argue that the disparate production processes in the ethanol industry are also explained by the financial capacity of the Southern regions to invest in new technologies and, conversely, the inability of the less affluent Northern and Northeastern regions to finance their industrial growth (Costa, 2008; Gurgel, 2008; Rosillo Callé, Bajay, and Rothman, 2000).

### *3.3. The Political Component*

Politics had a deep regional impact and shaped the evolution of the ethanol industry, creating institutional mechanisms that hindered the development of the Northeastern states. The subsidies to sugarcane cultivation and alcohol production in the Northeast derived from nationalist policies to develop the ethanol industry served to consolidate archaic production systems, increased monoculture and economic dependency on one single crop, allowing inefficient producers to stay in business. Unlike the entrepreneurial South, where financial government was seen as the means to make the industry more competitive, the subsidies to the producers in the Northeast were seen as a continuation of the centuries-long production pattern characterized by the exploitation of low-wage unskilled labor and near complete lack of willingness to innovate, devote resources to research and development or take entrepreneurial risks. Rather than by profit and efficiency, the landowning aristocracy of the Northeast was said to be driven by the desire to retain control and power in the hands of the family (Lehtonen, 2007). As Lehtonen (2007, p. 18) claims, “the main reason for the stagnation in the Northeast is the virtually complete lack of investment in R&D”, while in



contrast, “the success of the São Paulo region [is the result of] their own entrepreneurial skills, [as well as] the overwhelming dominance of the region in the production of intellectual know-how in the form of research institutes and universities”.

The Constitution of 1988 introduced a number of mechanisms aimed at decentralization of power and stimulating the engagement of civil society in political processes. The National Sugar and Alcohol Institute, perceived as one of the main supporters of the Northeastern sugar producers, was abolished in 1990, which – together with the removal of subsidies – meant that the Northeast was left without agricultural research institutes with special interest in developing crops and methods specifically adapted to the region’s conditions (Lehtonen, 2007; Lima & Sicsú, 2001).

More recently, the process of technological change in the ethanol sector has also been driven by the Brazilian environmental legal framework. Aiming at environmental conservation, state regulations that require mechanized harvesting, particularly in São Paulo state and other Southern regions, have been enacted. Such regulations have rarely been passed in the Northeastern states, in part due to the difficulty of mechanizing sugarcane harvesting because of topographical factors, as it was discussed in Section 3.1. For example, the Agriculture and Environmental Protocol for the Sugarcane and Ethanol Industries signed by the Government of São Paulo in 2007 focuses on legal deadlines for ending sugarcane burning and instead implement mechanized harvesting. A similar initiative is happening in Minas Gerais with the *Protocolo de Intenções de Eliminação da Queima no Setor Sucroalcooleiro de Minas Gerais* from 2008 (Neves do Amaral, Marinho, Tarasantchi, Beber, & Giuliani, 2008).

#### **4. The Input-Output as an Analytical Tool to Measure the Impact of Dual Technologies**

The previous chapter discussed the direct economic and environmental effects of technology choice. From the analysis presented above, it is clear that technology is likely to a paramount role in the differentiated regional performance of the Brazilian ethanol sector. Yet, some questions remain: What is the optimal mix of methods and regions for producing ethanol in order for the industry to exhibit sustained productivity gains, given that its production varies from primitive hand-production to fully automated mechanical manufacture? In turn, what production techniques would enable the ethanol industry's current emissions of greenhouse gas emissions to be significantly reduced? Does the ethanol industry promote national employment and rural development, and, if this is the case, how might the industry be a channel through which Brazil would be able to reduce its historic income inequalities? We use results from an input-output model to help answer these questions.

We will introduce a brief summary of the foundations of the input-output methodology. For the reader interested in the most detailed structure of the input-output framework, Miller and Blair (2009) elaborate on additional methodological considerations and fundamental relationships, as well as the assumptions and constraints of this economy-wide model. Calculations derived from the interregional system will allow analysts to disentangle regional effects of ethanol production technologies in order to understand the linkages between economic activity and ecological processes, as well as to evaluate the relative economic importance of the ethanol industry with respect to the rest of the

economy. Even though the input-output framework is static in nature and embodies relatively rigid technology assumptions, namely no substitution of inputs, and no price effects, constraints on resources, changes in technology or economies of scale, these are offset by many compensating advantages, such as considerable interindustry detail; most important, input-output models pass the critical test that for short-term purposes they predict extremely well (Isard and Kuenne, 1953; Leontief and Strout, 1963; Moses, 1960; Polenske, 1970).

Consider now the basic equation from the general input-output model:

$$X_i = z_{i1} + z_{i2} + \dots + z_{ii} + \dots + z_{in} + C_i + I_i + G_i + E_i \quad (1)$$

Where,

$z_{ij}$  represents sales by industry  $i$  to industry  $j$  or, in other words, the monetary value of the flow from sector  $i$  to sector  $j$ .

$C_i$  represents sales by industry  $i$  to households.

$I_i$  represents sales by industry  $i$  to investors.

$G_i$  represents sales by industry  $i$  to government.

$E_i$  represents industry  $i$ 's exports.

$Y_i$  represents industry  $i$ 's total final demand and equals to the sum of  $C_i + I_i + G_i + E_i$ .

$X_i$  denotes the total output of industry  $i$ .

One of the fundamental assumptions of the input-output model is that the interindustry flows from  $i$  to  $j$  depend on the total output of sector  $j$ . The ratio of the interindustry flow from  $i$  to  $j$

(i.e.,  $z_{ij}$ ) to the total output of  $j$  ( $X_j$ ), denoted  $a_{ij}$ , is termed direct input requirement or technical coefficient.

$$a_{ij} = \frac{z_{ij}}{X_j} \quad (2)$$

Technical coefficients measure fixed relationships between a sector's output and its inputs. This reflects the input-output assumption that economies of scale in production are ignored; rather production in a Leontief system operates under an assumption of constant returns to scale.

By substituting Equation (2) into Equation (1) for industry 1,

$$X_1 = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1i}X_i + \cdots + a_{1n}X_n + Y_1 \quad (3)$$

Analogous calculations could be conducted for the other  $n-1$  industries of the economy. Bringing all  $X$  terms in Equation (3) to the left and grouping the  $X_1$ 's together in the first equation, the  $X_2$ 's together in the second equation, and so on:

$$\begin{aligned}
(1 - a_{11})X_1 - a_{12}X_2 - \dots - a_{1i}X_i - \dots - a_{1n}X_n &= Y_1 \\
-a_{21}X_1 + (1 - a_{22})X_2 - \dots - a_{2i}X_i - \dots - a_{2n}X_n &= Y_2 \\
\vdots & \\
-a_{i1}X_1 - a_{i2}X_2 - \dots + (1 - a_{ii})X_i - \dots - a_{in}X_n &= Y_i \\
\vdots & \\
-a_{n1}X_1 - a_{n2}X_2 - \dots - a_{ni}X_i - \dots + (1 - a_{nn})X_n &= Y_n
\end{aligned} \tag{3}$$

Or, in matrix terms,

$$(\mathbf{I} - \mathbf{A})\mathbf{X} = \mathbf{Y} \tag{4}$$

And the solution is given by:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} \tag{5}$$

$(\mathbf{I} - \mathbf{A})^{-1}$  is often referred to as the Leontief inverse or the total (direct and indirect) requirements matrix. It shows the input requirements, both direct and indirect, on all other producers, generated by one unit of output. Hence, each term of the matrix indicates the gross output from sector  $i$  required to produce one unit of final output in sector  $j$  (Yan, 1969).

The study of sectoral relations and dependence has generated an abundant literature in the field of input-output analysis. Traditionally, in the input-output literature offers intersectoral

linkages are measured by studying the Leontief inverse; that is, concentrating on both the direct and indirect relations.

Input-output multipliers are probably the most important tool used in regional economic impact analysis. In effect, the Keynesian multiplier is analogous to the input-output multiplier in its general structure, yet, whereas the former fails to distinguish between the sectors in which the initial expenditure changes originate, the latter recognizes that the total impact on output will vary depending on which sector experiences the initial expenditure change (Richardson, 1972). We make use of the input-output multipliers in order to estimate the effects of exogenous changes on outputs of the ethanol and sugarcane sectors, income earned by households because of the new outputs, and employment that is expected to be generated because of the new outputs (Miller and Blair, 2009)<sup>3,4</sup>.

An output multiplier for sector  $j$  measures the sum of direct and indirect requirements from all sectors needed to deliver one additional dollar of output of  $j$  to final demand. Formally, the output multiplier is the ratio of the direct and indirect effects to the initial effect alone.<sup>5</sup> It is derived by summing the entries in the column under sector  $j$  in the Leontief inverse:

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<sup>3</sup> “The notion of multipliers rests upon the difference between the initial effect of an exogenous (final demand) change and the total effects of that change. The total effects can be defined in either of two ways—as the direct and indirect effects (which means that they would be found via elements in the Leontief inverse of a model that is open with respect to households) or as direct, indirect, and induced effects (which means that they would be found via elements of the Leontief inverse of a model that is closed with respect to households). The multipliers that are found by using direct and indirect effects are also known as simple multipliers. When direct, indirect, and induced effects are used, they are called total multipliers” (Miller and Blair, 2009).

<sup>4</sup> Readers who are interested in a full discussion of additional income and employment multipliers not discussed in this paper, as well as the relationship among them should refer to Guilhoto, Sonis and Hewings (1996), Miller and Blair (2009), Richardson (1972), and Schaffer (1999).

<sup>5</sup> The multiplier will capture the additional induced effects of household income generation if the model is closed with respect to households. Due to data limitations, in this study I focus on open multipliers.

$$O_j = \sum_{i=1}^n \alpha_{ij} \quad (6)$$

Output multipliers represent total requirements per unit of final output. They form the base for the income, employment, energy, and greenhouse gas emissions multiplier.

In economic impact studies, analysts are usually also interested in the income generating effects, which are derived from income multipliers. The income multiplier is expressed as the ratio of the direct plus the indirect income effect to the direct income effect. The direct income effect for each sector is given by the household row entry of the input-output table when expressed in input coefficient form. The direct and indirect income effect is obtained by multiplying each column entry in the standard inverse matrix (i.e., households excluded) by the supplying industry's corresponding household row coefficient from the direct coefficients table, and summing the row multiplications. Thus, the household income multiplier for sector  $j$  is given by:

$$H_j = \sum_{i=1}^n a_{n+1,i} \alpha_{ij} \quad (7)$$

Where  $a_{n+1,i}$  is the household income (i.e., the  $(n+1)$ st row) of sector  $i$ .

Economic-impact analysts are often concerned about the employment-generating effects of industrial expansion, given the primary and legitimate public policy goal of job

generation. For this reason, it is useful to derive employment multipliers from the input-output model if it is possible to estimate relationships between the value of output of a sector and employment in that sector in physical terms.

The employment multiplier is analogous in its structure to the income multiplier. The employment multiplier is thus the ratio of the direct plus indirect employment effect to the direct employment effect:

$$W_j = \sum_{i=1}^n w_{n+1,i} \alpha_{ij} \quad (8)$$

Where  $w_{n+1,i}$  is the physical labor input coefficient of sector  $i$ , which is defined as the ratio of the number of employees in sector  $i$  ( $l_i$ ) to the total output of sector  $i$  ( $X_i$ ):

$$w_{n+1,i} = \frac{l_i}{X_i} \quad (9)$$

Given this study's focus on the ethanol industry and its inherent environmental effects in the Brazilian economy, it is important to quantify energy consumption as well as the carbon dioxide emissions from energy use of ethanol, as a means to determine which technology is cleaner and consumes less energy. This is a first step to evaluate regional impacts of eventual policies for emissions control. Given the genuine and tangible interactions of industrial production and pollution, the need of studying environmental and



economic problems simultaneously becomes apparent (Forssell and Polenske, 1998). Two multipliers derived from the input-output model link economic activity and ecological processes: the energy and environmental multipliers. Both multipliers are analogous in their structure to the income multiplier.

The energy multiplier is the ratio of the direct plus indirect energy consumption effect to the direct energy consumption effect:

$$E_j = \sum_{i=1}^n \varepsilon_{n+1,i} \alpha_{ij} \quad (10)$$

Where  $\varepsilon_{n+1,i}$  is the energy input coefficient of sector  $i$ , which is defined as the ratio of the energy consumption in sector  $i$  in physical units ( $e_i$ ) to the total output of sector  $i$  ( $X_i$ ), or energy intensity:

$$\varepsilon_{n+1,i} = \frac{e_i}{X_i} \quad (11)$$

Similarly, the environmental multiplier is the ratio of the direct plus indirect carbon dioxide (CO<sub>2</sub>) emissions effect to the direct CO<sub>2</sub> emissions effect:

$$C_j = \sum_{i=1}^n c_{n+1,i} \alpha_{ij} \quad (12)$$

Where  $c_{n+1,i}$  is the CO<sub>2</sub> input coefficient of sector  $i$ , which is defined as the ratio of the CO<sub>2</sub> gas emissions in sector  $i$  in physical units ( $g_i$ ) to the total output of sector  $i$  ( $X_i$ ), or carbon intensity:

$$c_{n+1,i} = \frac{g_i}{X_i} \quad (13)$$

## **5. Macroeconomic and Environmental Effects of Labor- and Capital-Intensive Ethanol Production Technologies**

The findings of this section, traced through direct and indirect interindustry linkages within the economy, show which type of ethanol production technology contributes most to the objectives of sustainable development, namely economic growth, income, and employment generation, poverty alleviation, and energy intensity and greenhouse gases emissions reduction.

We analyze the nature and magnitude of the linkages of the traditional and modern ethanol industries at the regional level based on a multiplier analysis. In turn, we compare output, income, employment, energy, and environmental multipliers for both the conventional and the biotechnological ethanol production processes. This analysis shows the regional economic implications of the choice of technologies.

At the beginning of this study, one of the hypotheses in question was that modern technologies generate more output than traditional ones. Recent analyses have showed that modern technologies generate more output, yet such analyses did not illustrate the indirect effect of changes in the final demand of the capital-intensive ethanol sectors through the Brazilian economy. Table 3 shows the output multipliers for the ethanol and sugarcane sectors.

From Table 3, we conclude that the modern-technology Southern and Southeastern regions exhibit greater output multipliers than those of traditional-technology North and Northeast regions. In fact, the multipliers of the two largest ethanol producers, the Southeastern and Northeastern regions (3.094 and 1.969, respectively), are visibly different, with the former being 57% higher. This implies that a one Brazilian real (henceforth real) increase in final demand of the labor-intensive ethanol sector of the Northeast leads to additional money flows throughout the economy valued at 1.969 reais. In contrast, a one real increase in final demand of the capital-intensive ethanol sector of the Southeast leads to additional money flows throughout the economy valued at almost 3.094 reais. Notice that the output multiplier for the sugarcane sector is generally low. Yet, regional trends are also evident, with the biotechnology-intensive Southeast sugarcane sector generating more output than its more traditional, less technologically advanced, Northeastern counterpart. In effect, investments in the Southeast ethanol and sugarcane industries would have a greater impact in terms of total real value of output generated throughout the economy.

Comparing the employment effects of labor-intensive and capital-intensive technologies may seem intuitively unnecessary because labor-intensive technologies should

have, by definition, higher employment coefficients (Nolan, 1997). However, this defining characteristic considers only the direct employment effects of the industry in question. In order to fill this gap, we conduct an employment multiplier analysis, which includes indirect employment generation. Table 4 presents the regional employment multipliers for both the ethanol and sugarcane industries.

Contrary to expectations, the regions in which ethanol is labor-intensive generate less employment than the regions in which ethanol is capital-intensive. The Center, South, and Southeast regions exhibit greater multipliers than those of the North and Northeast. Notice that the multipliers appear to be very small. This is because they represent jobs created per real of new sectoral output, which, as usual, arises because of an additional real's worth of final demand for the sector (Miller and Blair, 2009),<sup>6</sup> and because, when compared to other industries, few laborers are used to produce ethanol. In contrast to the output multipliers, employment multipliers for the sugarcane industry are always greater than those for the ethanol sector.

Further analysis of the employment multiplier matrix shows that the major source of employment for the ethanol sectors that are labor-intensive is the ethanol sector itself along with the sugarcane sector. In contrast, the ethanol sectors that are capital-intensive generate employment mainly in the ethanol sector itself along with the electricity, gas and water

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<sup>6</sup> If the multipliers in Table 16 were multiplied by 1,000, they would represent new jobs created per 1,000 reais of new output. Hence, if the Northeast ethanol sector's final demand increased by a thousand reais, almost 10.0 new jobs would be created. Similarly, 1,000 reais of new investment in the Southeast ethanol sector would generate 10.4 new jobs in the economy. This would increase up to 21.3 new jobs had the new investments taken place in the South region. In contrast, less than 3.7 new jobs would be created if the final demand of the North ethanol sector increased. The evident result is that the biotechnology ethanol sector employs more people than the traditional ethanol sector.

industry. Similarly, whereas the regions in which sugarcane is labor-intensive generate most of the employment in the sugarcane sector itself and the manufacturing industry, the regions in which sugarcane is relatively mechanized sugarcane (particularly the South and the Southeast) also have important employment generation effects in the electricity sector (Table 4).

The transportation sector has a more prominent role in the regions that have labor-intensive sugarcane industries, given the usually larger distances needed to transport sugarcane to the ethanol distilleries (Table 5). Many distilleries in the São Paulo area are adjacent or relatively close to the sugarcane fields. About 8.4 new jobs are created in the transportation sector given a 1,000-real increase in the final demand of the labor-intensive sugarcane industry of the North. Conversely, only 1.4 jobs would be created had the final demand of the relatively mechanized sugarcane sector of the Southeast increased by 1,000 reais.

In Section 2 we discussed that technology choice also has significant effects on household income. Hence, it is important to understand how the ethanol and sugarcane sectors affect income and ultimately how growth in these industries alleviates poverty, if this is the case. Table 6 summarizes the income multipliers for the ethanol and sugarcane industries by region.

Interestingly, when accounting for the indirect effects, the modern ethanol industry of the Southeast, contrary to the findings of previous chapters, generates less income than its relatively less technologically advanced counterpart in the Northeast region. However,

differences are small. An additional real of final demand for the output of the Southeast ethanol sector would generate 0.107 reais of new household income. In contrast, an additional real of final demand for the output of the Northeast ethanol sector would generate 0.114 reais of new household income. Had the final demand of the South ethanol sector increased in 1 real, 0.174 reais of new household income would be created.

Once again, multipliers in most of the ethanol sectors are greater than those of the sugarcane industry, denoting a larger capacity for the ethanol industry to generate household income. The only exception is the Southeast region, where the income multiplier of the sugarcane industry is 42% higher than that of the ethanol industry. Further examination of the income multiplier matrix explains this fact in that the sugarcane industry in the Southeast generates far more indirect income in the manufacturing and electricity, gas and water industries.

Because this study focuses on a developing country that has struggled with the problem of uneven income distribution for decades, it is interesting and relevant to determine the role of disparate technologies in terms of regional income inequality. Such an analysis based on an interregional input-output system should always be taken with caution, given that the input-output framework per se is limited in that it does not reflect whether additional income generation benefits any socioeconomic strata in particular. This limitation could be overcome by a social accounting matrix, given this framework's capacity of providing an in-depth examination of the interrelations between the income distribution by socioeconomic household groups and their resulting consumption and savings behavior (Khan and Thorbecke, 1988; Polenske, 1989; Rose, Stevens, and Davis,

1988). In spite of this caveat, Reich and Stahmer (1984) argue that analysts can use the interregional input-output framework to examine the extent to which the modern and/or the traditional ethanol and sugarcane industries contribute to poverty alleviation by generating income in the most impoverished regions, in this case the Brazilian North and Northeast. We disaggregate the household income multiplier based on the power series approximation of the Leontief inverse, in order to examine which particular regions benefit in terms of income generation when a given industry's final demand increases<sup>7</sup>.

Table 7 shows that modern ethanol and sugarcane technologies are not able to generate as much income for the most deprived regions of the country as the traditional ethanol and sugarcane technologies. Whereas a 100-real increase in final demand of the capital-intensive ethanol and sugarcane industries in the Southeast leads to additional household income throughout the North and Northeast regions valued at 1 and 3 reais, respectively<sup>8</sup>, a final demand increase of 100 reais in the labor-intensive ethanol and sugarcane industries in the Northeast would generate additional household income for almost 10 and 6 reais in the Northern and Northeastern areas, respectively.

It should be acknowledged that increases in final demand in the capital-intensive regions have larger spillover effects than increases in final demand in the labor-intensive regions: while 11.8% of the new household income caused by final demand increases in the Northeast sugarcane sector is generated in the South and Southeast regions, 17.3% of the

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<sup>7</sup> For more detail, his methodology is discussed in Burford and Katz (1977), Drake (1976), and Miller and Blair (2009).

<sup>8</sup> From Table 18, the Southeast ethanol sector household income multiplier equals 0.107 reais, and Table 7 shows that  $8.3+3.8=12.1\%$  of this new income is generated in the North and Northeast regions. Hence,  $0.107*0.121\approx 0.01$  reais.

new household income caused by final demand increases in the Southeast sugarcane sector is generated in the North and Northeast regions.

An additional crucial component that policy makers should consider when assessing whether labor-intensive or capital-intensive ethanol and sugarcane production processes are preferred is that of environmental conservation. In effect, energy intensity is increasing in Brazil (Polenske, Zhang, and Guerrero Compeán, 2007). Brazil is home to some of the greatest, yet extremely fragile, ecosystems of the planet, such as the Amazon, making the country highly vulnerable to climate change. At the global scale, Brazil is one of the top ten greenhouse gas emitters worldwide and the third largest CO<sub>2</sub> emitter in the developing world, after China and India (Guerrero Compeán, 2007). It signed in 1998 and ratified in 2002 the Kyoto Protocol to the United Nations Framework Convention on Climate Change, aimed at combating global warming (United Nations Framework Convention on Climate Change, 2008). Brazil and other developing countries were not included in any numerical limitation of the Kyoto Protocol because they were not the main contributors to the greenhouse gas emissions during the pre-treaty industrialization period. However, even without the commitment to reduce according to the Kyoto target, developing countries share the common responsibility that all countries have in reducing emissions.

Given that increasing energy consumption and greenhouse gases emissions are mainly explained by rapid economic development, I calculated energy and environmental multipliers for the ethanol sector in order to establish the relationship between ethanol industrial performance, energy intensity and pollution emission. This will help determine whether modern technologies are more energy and/or carbon intensive than their traditional



counterparts. Energy and environmental multipliers for the sugarcane sector were not calculated due to data limitations. Table 8 presents the energy and environmental multipliers for the ethanol industry by region. Energy and carbon intensities (megajoules per real, and grams of CO<sub>2</sub> per real, respectively) were calculated based on data from the Balanço Energético Nacional (Ministério de Minas e Energia, 2007).

The findings presented in Table 8 indicate that, when accounting for the indirect effect of an expansion of the ethanol sector final demand, the labor-intensive ethanol sector of the Northeast is the most energy- and carbon-intensive ethanol sector of the country. In contrast, the modern-technology Center and Southeastern regions exhibit the lowest energy and environmental multipliers. This reinforces the hypothesis that the capital-intensive ethanol sectors are cleaner and consume less energy than their labor-intensive counterparts. The energy multipliers of the two largest ethanol producers, the Southeastern and Northeastern regions (0.017 and 0.036, respectively), are markedly different, with the latter being 108% higher than the former. Similarly, the environmental multiplier of the Northeastern region is 181% higher than the multiplier of the Southeastern region.

This implies that if the Northeast ethanol sector's final demand increased by a thousand reais, 36 megajoules (MJ) of additional energy would be consumed and almost 1.969 kilograms of CO<sub>2</sub> would be released to the atmosphere. In contrast, if the Southeast ethanol sector's final demand increased by a thousand reais, 17 megajoules (MJ) of additional energy would be consumed and only 0.946 kilograms of CO<sub>2</sub> would be released to the atmosphere. The evident result is that the modern ethanol industry is cleaner and more energy-efficient than the traditional ethanol industry.

The above analysis has shown that, when accounting for both direct and indirect effects, different technologies have dissimilar regional economic implications. In the particular case of the ethanol industry, the interregional input-output analysis shows that technologically advanced production processes lead to more output and employment creation; yet traditional techniques generate more household income and are likely to contribute more to poverty alleviation.

In reality, despite the benefits of traditional ethanol technologies, the federal government and many state administrations, in an attempt to increase efficiency levels in the ethanol industry and reduce emissions derived from the burning of sugarcane, have made gradual efforts to adopt partially or totally the agricultural and industrial technologies of the São Paulo area in the rest of the country (Costa, 2008; De Oliveira and Vasconcelos, 2006; Perosa, 2008).

Next, we study the overall economic effects of this trend from an interregional input-output perspective. To this end, we make use of a simpler representation of the best-practice approach used by Carter (1958) and Miernyk et al. (1970). This approach assumes that if it is possible to identify the most efficient technologies within each industry (in this case, that of the Southeast), it is realistic to describe technological change for some time in the future as a process of replacing the least-efficient technical coefficients with those of the best technology currently known in the industry<sup>9</sup>.

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<sup>9</sup> The logic of this approach for projecting the technology in an input-output table in the future is that the best-practice firms, i.e., the technologically most advanced firms at present or those with the lowest labor intensities, represent the technology that will be generally in use in the future (Miller and Blair, 2009).

We assume that the ethanol and sugarcane industries of Brazil will partially adopt the technology processes currently carried out by the ethanol and cane industry of the Southeastern region, i.e., the Southeastern region is used as the “role-model” region. In terms of the input-output model, this implies that the technical coefficients of the ethanol and sugarcane sectors for all the Brazilian regions will tend to those of the Southeast as the structural change is more apparent.

The values of 20%, 50% and 95% were chosen arbitrarily and should be understood just as different magnitudes of technological change or, in other words, the rates at which the new technology will be introduced in each industry. In other words, 20% signifies that 20 percent of the industrial production in the respective region will be carried out by technological production processes virtually similar to those currently carried out in the Southeast region. The effect of a hypothetical adoption of a more biotechnological ethanol and sugarcane production process is reflected in the new regional output multipliers. The major inferences from this analysis can be drawn from Tables 9 and 10.

In these tables, we show that although the labor-intensive Northeast ethanol sector household income multiplier is higher than that of the capital-intensive Southeast ethanol industry (thus making the case for the public and private support for the traditional ethanol production technologies), the impoverished regions of the North and Northeast would generate even more output and income if more technologically advanced ethanol production processes were implemented. This would, in turn, make a more significant contribution to poverty alleviation and environmental conservation. For example, the current output multiplier of the Northeast ethanol sector is 1.247, yet if only 20% of its

ethanol manufacture were produced with more capital-intensive technologies, the output multiplier would increase to 1.617, a 30% increase. Similarly, with the exception of the ethanol sector of the South region, the adoption of the Southeast region technologies of the sugarcane and ethanol industry would create significant output increases throughout the economy.

We conclude that although traditional ethanol production technologies exhibit large employment linkages and facilitate poverty alleviation by generating income in the most impoverished regions of the country, it is the modern ethanol production technology that generates more output and is economically more mature. Furthermore, the modern industries of the Center-West and Southeast regions proved to be the most energy and carbon efficient ethanol sectors and, in contrast, higher energy and carbon intensities were found for the labor-intensive ethanol industries. In addition, we showed that a hypothetical adoption of modern technologies by the labor-intensive ethanol industries would allow them to increase their potential for output, income and employment generation, as well as reduce their energy consumption and carbon emissions.

## **6. Concluding Remarks**

The major contribution of this study to the biofuels and technology choice debates has been to examine the extent to which the choice of technologies has affected regional development and sustainability objectives. For this purpose, we used the input-output

model in order to understand the linkages between technology, economic activity, and pollution. Despite its relatively rigid assumptions, the input-output framework can be used as a basis for economy-wide modeling and is a useful planning tool for regional and national policy making.

An interregional input-output system for Brazil allowed accounting for the regional technological differences between the Northern and Southern ethanol industries for year 2002. We examined the linkages between technology, production, employment, household income, energy intensity, and carbon emissions, and we estimated the direct and indirect effects of traditional and modern production processes. We focused on Brazil because this country successfully led the most ambitious alternative fuel program ever taken into action and, in the process, caused structural changes in its ethanol industry with the potential of having important consequences on the economy and the environment. In addition, from the regional perspective, we studied the implications of accounting for the variations in the attributes of the spatially disparate activities that make up the ethanol sector, rather than treating the industry as a monolithic manufacturing process devoid of variations in input requirements.

We concluded that the major efficiency (output per unit of labor/capital/energy input) and productivity differences between the labor-intensive and capital-intensive ethanol production technologies are explained by the mechanization of sugarcane harvesting, and geographical advantages for the South region in terms of climate, soil and topography, and policy instruments that hindered the development of the Northeastern region. Other factors that also might have played a role in the productivity differences are

technical innovations in the ethanol fermentation and distillation processes and the development of new sugarcane varieties.

In general, we concluded that although traditional ethanol production technologies exhibit large employment linkages and facilitate poverty alleviation by generating income in the most impoverished regions of the country, it is the modern ethanol production technology that generates more output and is economically more mature. Furthermore, the capital-intensive industries of the Center-West and Southeast regions proved to be the most energy and carbon efficient ethanol sectors and, in contrast, higher energy and carbon intensities were found for the labor-intensive ethanol industries. In addition, we demonstrated that a hypothetical adoption of modern technologies by the labor-intensive ethanol industries would allow them to increase their potential for output, income, and employment generation. Needless to say, these findings have important economic and environmental implications.

First, with regard to technology choice, this study showed that modern technologies have strong production and income linkages and benefit from low energy and carbon intensities. Yet, careful consideration should be given to the traditional technologies because, as it may be expected from a developing country such as Brazil, they exhibit stronger linkages than new technologies with the rest of the economy in terms of employment generation, especially benefiting the economically disadvantaged regions of the North and Northeast, thus alleviating income inequality and mitigating poverty.

Second, because a hypothetical technology change towards the implementation of more modern technologies in the labor-intensive ethanol regions proved to generate significant social, economic, and environmental gains, policy measures to encourage the upgrading of traditional technologies need to be considered seriously. However, unless the government or the North and Northeast poorer ethanol producers themselves manage to finance and implement costly technical innovations (which is unlikely), a strong case exists for the continuation of traditional technologies along with the modern production techniques. For the time being, and given that significant technology changes are out of sight for the traditional ethanol sectors, one means to improve productivity would be to increase human capital levels. In the labor-intensive ethanol-producer regions, the proportion of people with at least a high school diploma is fairly low, especially when compared with the Southeast region, known to be the “more educated” ethanol industry. The average education level in the North-Northeast regions is equivalent to half the years of schooling of the Center-South.

Third, on the energy front, government policies in support of the alternative fuel should be continued. In effect, the development of ethanol “made in Brazil” as a substitute for gasoline has inherent implications on Brazil’s energy-security policy, because as more ethanol is demanded for motor vehicles, less oil will be required. The ethanol produced, together with the oil Brazil pumps, may lead the country to declare energy independence. Besides, in the process of pursuing energy independence, reduced petroleum imports will continue to improve Brazil’s balance of payments, avoid foreign debt, and insulate Brazil from disruptions in fossil energy supply or oil price shocks. In addition, some analysts have

demonstrated that per capita investment costs in the ethanol sector may be up to 94% lower than those of the petrochemical industry (Geller, 1985) and, similarly, this study evidenced that ethanol production costs have been lower than gasoline's since 2004.

Fourth, ethanol production and use should be a primary policy objective since ethyl alcohol is a superior fuel compared to gasoline on energy and environmental grounds, especially if produced based on modern, modern production processes. Schafer and Victor (2000) demonstrate that ethanol, as a substitute for gasoline, would slow down the greenhouse gas emissions growth rate given that a gasoline-fueled car emits 8.5 times more CO<sub>2</sub> than an ethanol-fueled vehicle. This coincides with the fact that ethanol is significantly energy and carbon efficient. The use of sugarcane-based ethanol does not result in significant net emissions of greenhouse gas emissions because the carbon-dioxide emissions from the burning of ethanol in boilers are reabsorbed by photosynthesis during the growth of sugarcane in the following season. All the energy needs for its production come from bagasse. In addition, excess bagasse is used to generate additional electricity to be fed into the grid. More efficient fermentation and distillation processes make capital-intensive ethanol production processes less energy-intensive. Higher emissions in the labor-intensive ethanol industries are mainly caused by sugarcane burning and inefficient bagasse burning in old boilers. The ethanol distilleries of the Southeast have replaced at a more rapid pace old boilers of low pressure (21 bar) by new and more efficient ones (up to 80 bar) (Goldemberg, Teixeira Coelho, and Guardabassi, 2008).

Certain possible refinements and key developments could be considered by analysts to improve this study and stimulate research on relatively unexplored areas of technology



choice studies in the developing world, and particularly in Brazil. One could break down the labor-intensive and capital-intensive ethanol industries intraregionally, in order to study the economic effects of the labor-intensive ethanol distilleries still operating in the modern Southeast region or, conversely, the environmental impacts of the few capital-intensive ethanol plants in the impoverished Northeast. This would enrich the technology-choice analysis by eliminating the artificial simplifying assumption of technological dualism considered here. Likewise, the energy analysis would have been stronger had more sectorally disaggregated data been available. Lack of statistical information at the regional level was the major cause for the omission of coke as an energy input, which was reflected in the seemingly low energy- and carbon-intensities of the iron and steel sector. As pointed out by Khan and Thorbecke (1988), the inadequacy of data for multisectoral planning models is as big a handicap as inadequate conceptualization. Similarly, future research lines could involve much more sophisticated techniques of modeling and analysis, in particular geographic information systems and computable general equilibrium economic simulations, given the necessity to draw more solid empirical conclusions helpful for policy and planning processes design.

## **References**

- Akubue, A. (2000). Appropriate Technology for Socioeconomic Development in Third World Countries. *Journal of Technology Studies* , 26 (1).
- Alcántara, V., & Padilla, E. (2003). "Key" Sectors in Final Energy Consumption: An Input-Output Application to the Spanish Case. *Energy Policy* , 31 (15), 1673-1678.
- Amsalem, M. (1983). *Technology Choice in Developing Countries: The Textile and Pulp and Paper Industries*. Cambridge: The MIT Press.
- Barro, R., & Sala-i-Martin, X. (2004). *Economic Growth*. Cambridge: The MIT Press.

- Bencheekroun, H., & Chaudhuri, A. (2009). *On Cleaner Technologies in a Transboundary Pollution Game*. Montréal: mimeo.
- Berndt, E., Kolstad, C., & Lee, J. (1993). Measuring the Energy Efficiency and Productivity Impacts of Embodied Technical Change. *The Energy Journal* , 14, 33-55.
- Bhutto, A. (2008). Ethanol and Biodiesel: Fuels or Threats to Food Security? . *Online Journal* , 31-68.
- Boyd, G., & McClelland, J. (1999). The Impact of Environmental Constraints on Productivity Improvement and Energy Efficiency an Integrated Paper and Steel Plants. *The Journal of Economics and Environmental Management* , 38, 121-146.
- Boyd, G., & Pang, J. (2000). 'Estimating the Linkage between Energy Efficiency and Productivity. *Energy Policy* , 28, 289-296.
- Burford, R., & Katz, J. (1977). Regional Input-Output Multipliers without a Full I-O Table. *Annals of Regional Science* , 11 (3), 21-38.
- Carter, A. (1958). *Report on Research for 1956-1957*. Cambridge, MA: Harvard Economic Research Project.
- Cole, M., & Elliott, R. (2003). Determining the Trade–Environment Composition Effect: the Role of Capital, Labor and Environmental Regulations. *Journal of Environmental Economics and Management* , 46 (3), 363-383.
- Costa, C. (2008, March 18). Especificações tecnológicas para etanol. (R. Guerrero Compeán, Interviewer)
- da Silva, J., & Kohl, B. (1994). Capitalist "Modernization" and Employment in Brazilian Agriculture, 1960-1975: The Case of the State of São Paulo. *Latin American Perspectives* , 11 (1), 117-136.
- De Oliveira, M., & Vasconcelos, Y. (2006, April). Revolution in the Sugarcane Industry. *Agro-Business* (122).
- Defourny, J., & Thorbecke, E. (1984). Structural Path Analysis and Multiplier Decomposition within a Social Accounting Matrix Framework. *Economic Journal* , 94 (373), 111-136.
- Dorf, R. (2001). *Technology, Humans, and Society: Toward a Sustainable World*. San Diego, CA: Academic Press.

- Drake, R. (1976). A Short-Cut to Estimates of Regional Input-Output Multipliers: Methodology and Evaluation. *International Regional Science Review* , 1 (2), 1-17.
- Duchin, F., & Lange, G.-M. (1994). *The Future of the Environment. Ecological Economics and Technological Change*. Oxford: Oxford University Press.
- Ehrlich, P., & Ehrlich, A. (1981). *Extinction*. New York: Random House.
- European Commission. (2008, October 24). *Support to EU Policies: Well-to-Wheels Analysis*. Retrieved November 19, 2008, from Institute for Environment and Sustainability: <http://ies.jrc.ec.europa.eu/WTW.html>
- Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land Clearing and the Biofuel Carbon Debt. *Science* , 319 (5867), 1235-1238.
- Forssell, O., & Polenske, K. (1998). Introduction: Input-Output and the Environment. *Economic Systems Research* , 10 (2), 91-97.
- Gay, P., & Proops, J. (1993). Carbon-Dioxide Production by the UK Economy: An Input-Output Assessment. *Applied Energy* , 44 (2), 113-130.
- Geller, H. (1985). Ethanol Fuel from Sugar Cane in Brazil. *Annual Review of Energy* , 10, 135-164.
- Goldemberg, J. (2008). Biofuels: How Much, How Fast, and How Difficult. *Workshop on America's Energy Future: Technology Opportunities, Risks and Tradeoffs*. Washington, D.C.: The National Academy of Sciences.
- Goldemberg, J., Teixeira Coelho, S., & Guardabassi, P. (2008). The Sustainability of Ethanol Production from Sugarcane. *Energy Policy* , 36 (6), 2086-2097.
- Goldemberg, J., Teixeira Coelho, S., Nastari, P., & Lucon, O. (2004). Ethanol Learning Curve: the Brazilian Experience. *Biomass and Bioenergy* , 26, 301-304.
- Grübler, A., Nakicenovic, N., & Nordhaus, W. (2002). *Technological Change and the Environment*. New York: RFF Press.
- Guerrero Compeán, R. (2007). *Climate Change and Its Economic Impacts on Developing Countries: The Case of Brazil*. Cambridge, MA: Multiregional Planning Group.
- Guerrero Compeán, R. (2008). *Regional, Economic, and Environmental Effects of Traditional and Biotechnologically Enhanced Ethanol Production Processes in Brazil*. Cambridge: MCP Thesis, Massachusetts Institute of Technology.

- Guilhoto, J., & Sesso Filho, U. (2005). Estimação da matriz insumo-produto a partir de dados preliminares das contas nacionais. *Economia Aplicada* , 9 (2), 277-299.
- Guilhoto, J., Sonis, M., & Hewings, G. (1996). *Linkages and Multipliers in a Multiregional Framework: Integration of Alternative Approaches*. Discussion Paper 96-T-8, University of Illinois at Urbana-Champaign, Regional Economics Application Laboratory, Urbana.
- Gurgel, A. (2008, June 12). Desenvolvimento da indústria sucroalcooleira. (R. Guerrero Compeán, Interviewer)
- Heikkilä, A.-M., & Pietola, K. (2006). Possibilities to Switch into Capital-Intensive Technologies in Small Scale Dairy Production. *96th EAAE Seminar*, (pp. 1-10). Tänikon, Switzerland.
- Hester, R., & Harrison, R. (1994). *Mining and its Environmental Impacts*. London: Royal Society of Chemistry.
- Hilgemberg, E. (2004). *Quantificação e efeitos econômicos do controle de emissões de CO2 decorrentes do uso de gás natural, álcool e derivados do petróleo no Brasil: um modelo interregional insumo-produto*. Escola Superior de Agricultura Luiz de Queiroz. Piracicaba: Divisão de Biblioteca e Documentação ESALQ/USP.
- Hirschman, A. (1958). *The Strategy of Economic Development*. New Haven: Yale University Press.
- Hunt, D. (1989). *Economic Theories of Development*. Savage, MD: Barnes and Noble.
- Isard, W., & Kuenne, R. (1953). The Impact of Steel upon the Greater New York-Philadelphia Urban Industrial Region. *Review of Economics and Statistics* , 35, 289-301.
- Jaffe, A., Newell, R., & Stavins, R. (2002). Environmental Policy and Technological Change. *Environmental and Resource Economics* , 22, 41-69.
- Jaffe, A., Newell, R., & Stavins, R. (2001). *Technological Change and the Environment*. Washington, D.C.: Resources for the Future Discussion Paper 00-47REV.
- Jain, T., Malhotra, A., Singla, C., & Gupta, A. (1993). *Development Economics: A New Paradigm*. New Delhi: Sage Publications.
- James, J. (1976). Products, Processes and Income: Cotton Clothing in India. *World Development* , 4 (2), 143-149.
- James, J. (1985). *The Employment and Income Distributional Impact of Microelectronics: A Prospective Analysis for the Third World*. Geneva: International Labour Office.

- James, P. (1953). Patterns of Land Use in Northern Brazil. *Annals of the Association of American Geographers* , 43 (2), 98-126.
- Jeffrey, J., & Khan, H. (1997). Technology Choice and Income Distribution. *World Development* , 25 (2), 153-165.
- Jorgenson, D., & Fraumeni, B. (1981). Relative Prices on Technical Change. In B. Field, & E. Berndt, *Modeling and Measuring Natural Resource Substitution* (pp. 17-47). Cambridge, MA: The MIT Press.
- Kaldor, N. (1963). *Strategic Factors in Economic Development*. Ithaca: Cornell University Press.
- Khan, H. (1982). *Choice of Technology, Energy and Income Distribution: A Macroeconomic Framework*. Ithaca, NY: Cornell University.
- Khan, H. (1985). Technology Choice in the Energy and Textile Sectors in the Republic of Korea. In A. Bhalla, *Technology and Employment in Industry: A Case Study Approach* (pp. 361-387). Geneva: International Labour Office.
- Khan, H., & Thorbecke, E. (1988). *Macroeconomic Effects and Diffusion of Alternative Technologies within a Social Accounting Matrix Framework: The Case of Indonesia*. Aldershot, U.K.: Gower Publication Co.
- Khan, H., & Thorbecke, E. (1989). Macroeconomic Effects of Technology Choice: Multiplier and Structural Path Analysis within a SAM Framework. *Journal of Policy Modeling* , 11 (1), 131-156.
- Labandeira, X., & Labeaga, J. (2002). Estimation and Control of Spanish Energy-Related CO2 Emissions: An Input-Output Approach. *Energy Policy* , 30 (7), 597-611.
- Leatherman, J., & Marcouiller, D. (1996). Income Distribution Characteristics of Rural Economic Sectors: Implications for Local Development Policy. *Growth and Change* , 27 (4), 434-459.
- Lehtonen, M. (2007). *Biofuel Transitions and Global Governance: Lessons from Brazil*. Amsterdam: Amsterdam Conference on the Human Dimensions of Global Environmental Change.
- Lenzen, M. (1998). Primary Energy and Greenhouse Gases Embodied in Australian Final Consumption: An Input-Output Analysis. *Energy Policy* , 26 (6), 495-506.

- Leontief, W., & Strout, A. (1963). Multiregional Input-Output Analysis. In T. Barna, *Structural Interdependence and Economic Development* (pp. 119-149). London: Macmillan.
- Lima, J. P., & Sicsú, A. B. (2001). Revisitando o setor sucro-alcooleiro do Nordeste: o novo contexto e a reestruturação possível. *Estudos Infosucro* , 4, 20.
- Maciel, M. (2008). *Sufferings of Brazilian Sugarcane Workers*. Retrieved June 26, 2008, from Energy Resources: <http://www.hubbertypeak.com/br/SugarCaneWorkers.htm>
- Metcalf, G., & Hassett, K. (1999). Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data. *The Review of Economics and Statistics* , 81, 516-528.
- Miernyk, W., Shellhammer, K., Coccari, R., Wineman, W., Gallagher, C., & Brown, D. (1970). *Simulating Economic Development*. Lexington, MA: Lexington Books.
- Miller, R., & Blair, P. (2009). *Input-Output Analysis: Foundations and Extensions*. Cambridge, UK: Cambridge University Press.
- Ministério de Minas e Energia. (2007). *Balanço Energético Nacional 2007. Ano Base 2006. Relatório Final*. Rio de Janeiro: Ministério de Minas e Energia-Empresa de Pesquisa Energética.
- Moses, L. (1960). A General Equilibrium Model of Production, Interregional Trade, and Location of Industry. *Review of Economics and Statistics* , 42, 373-397.
- Mountain, D., Stipdonk, B., & Warren, C. (1989). Technological Innovation and a Changing Energy Mix: A Parametric and Flexible Approach to Modeling Ontario Manufacturing. *The Energy Journal* , 10, 139-158.
- Mourshed, M. (1996). Determinants of Irrigation Technology Choice in Egypt. *International Symposium on Technology and Society Technical Expertise and Public Decisions* (pp. 139-150). Princeton, NJ: Institute of Electrical and Electronic Engineers.
- Munro, L. (1989). Technology Choice in Bhutan: Labour Shortage, Aid Dependence, and a Mountain Environment. *Mountain Research and Development* , 9 (1), 15-23.
- Nagavarapu, S. (2008). *Brazilian Ethanol: A Gift or Threat to the Environment and Regional Development?* Stanford, CA: Stanford University.
- Neves do Amaral, W., Marinho, J., Tarasantchi, R., Beber, A., & Giuliani, E. (2008). Environmental Sustainability of Sugarcane Ethanol in Brazil. In P. Zuurbier, & J. van de

- Vooren, *Sugarcane Ethanol. Contributions to Climate Change Mitigation and the Environment* (pp. 113-138). Wageningen, The Netherlands: Wageningen Academic Publishers.
- Nolan, L. (1997). *An Assessment of Brazil's Alternative Fuel Program and the Agriculture, Manufacturing, Energy and Service Sectors*. Denver: University of Denver.
- Organisation for Economic Co-operation and Development. (2008). *Perspectives de l'environnement de l'OCDE à l'horizon 2030*. Paris: OECD Publications.
- Otsuka, K., Liu, D., & Murakami, N. (1998). *Industrial Reform in China: Past Performance and Future Prospects*. Oxford: Oxford University Press.
- Pearce, J. (2006). *Small is Still Beautiful: Economics as if Families Mattered*. Wilmington, DE: Intercollegiate Studies Institute .
- Pereira da Cunha, M. (2005). *Inserção do setor sucroalcooleiro na matriz energética do Brasil: uma análise de insumo-produto*. Master thesis, State University of Campinas, Campinas, Brazil.
- Polenske, K. (1970). *A Multiregional Input-Output Model for the United States*. EDA Report No. 21, Harvard Economic Research Project , Cambridge, MA.
- Polenske, K. (2007). Introduction. In K. Polenske, *The Economic Geography of Innovation* (pp. 1-12). Cambridge: Cambridge University Press.
- Polenske, K. (1989). Natural Resource Policy and Income Distribution (Book Review). *Journal of Economic Literature* , 27 (2), 649-650.
- Polenske, K., Zhang, X., & Guerrero Compeán, R. (2007). *Innovation and Energy-Intensity Trends in China and Brazil*. Shanghai: Presented at the Tongji University 100th Anniversary Innovation Forum.
- Popp, D., Newell, R., & Jaffe, A. (2009). *Energy, the Environment, and Technological Change*. Cambridge, MA: National Bureau of Economic Research, Working Paper 14832.
- Proops, J., Faber, M., & Wagenhals, G. (1993). *Reducing CO2 Emissions. A Comparative Input-Output Study for Germany and the UK*. Berlin: Springer.
- Ranis, G., & Saxonhouse, G. (1983). International and Domestic Determinants of Technology Choice by the Less Developed Countries. In B. Lucas, & S. Freedman, *Technology Choice and Change in Developing Countries: Internal and External Constraints* (pp. 7-27). Dublin: Tycooly International Publishing Ltd.

- Richardson, H. (1972). *Input-Output and Regional Economics*. New York: John Wiley & Sons.
- Rose, A., Stevens, B., & Davis, G. (1988). *Natural Resource Policy and Income Distribution*. Baltimore, MD: The Johns Hopkins University Press.
- Rosenberg, N. (1982). *Inside the Black Box*. Cambridge, UK: Cambridge University Press.
- Rosenthal, E. (2008, February 8). Biofuels Deemed a Greenhouse Threat. *The New York Times*, p. Environment.
- Rosillo Callé, F., Bajay, S., & Rothman, H. (2000). *Industrial Uses of Biomass Energy: The Example of Brazil*. Boca Raton, FL: CRC Press.
- Rothman, H., Greenshields, R., & Rosillo Callé, F. (1983). *Energy from Alcohol: The Brazilian Experience*. Lexington: The University Press of Kentucky.
- Ruttan, V. (1971). Technology and the Environment. *American Journal of Agricultural Economics*, 53 (5), 707-717.
- Salem, T. (1999). *Transformation Mechanisms: A Critique of the Political Economy of Growth*. The University of Utah, Department of Economics, Salt Lake City.
- Salomon, J.-J., Sagasti, F., & Sachs-Jeantet, C. (1994). *The Uncertain Quest: Science, Technology, and Development*. Tokyo: United Nations University Press.
- Sánchez-Chóliz, J., & Duarte, R. (2003). Analysing Pollution by Way of Vertically Integrated Coefficients, with an Application to the Water Sector in Aragón. *Cambridge Journal of Economics*, 27, 433-448.
- Schafer, A., & Victor, D. (2000). The Future Mobility of the World Population. *Transportation Research A*, 34, 171-205.
- Schaffer, W. (1999). *Regional Impact Models*. Atlanta: Georgia Institute of Technology.
- Schumacher, E. (2000). *Small is Beautiful: Economics as if People Mattered*. Vancouver: Hartley and Marks Publishers.
- Sen, A. (1968). *Choice of Techniques*. Oxford: Basil Blackwell.
- Solow, R. (1956). A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics*, 70, 65-94.



Sterner, T. (1990). Energy Efficiency and Capital Embodied Technical Change: the Case of Mexican Cement Manufacturing. *The Energy Journal* , 11, 155-167.

Sue Wing, I. (2008). Explaining the Declining Energy Intensity of the U.S. Economy. *Resource and Energy Economics* , 30 (1), 21-49.

Švejnar, J., & Thorbecke, E. (1983). The Determinants and Effects of Technological Choice. In B. Lucas, & S. Freedman, *Technology Choice and Change in Developing Countries: Internal and External Constraints*. Dublin: Tycooly International and Publishing Company.

Tarancón, M., & Del Río, P. (2004). Cambio tecnológico y emisiones de CO2: Análisis input-output y análisis de sensibilidad mediante programación lineal. *Estudios económicos de desarrollo internacional* , 4 (1), 41-68.

Thirtle, C., & Ruttan, V. (1987). The Role of Demand and Supply in the Generation and Diffusion of Technological Change. *Fundamentals of Pure and Applied Economics* , 21.

Timmer, C. (1975). The Choice of Technique in Indonesia. In C. Timmer, J. Thomas, L. Wells, & D. Morawetz, *The Choice of Technology in Developing Countries (Some Cautionary Tales)* (pp. 1-29). Cambridge: Center for International Affairs, Harvard University.

Tokman, V. (1974). Distribution of Income, Technology and Employment: An Analysis of the Industrial Sectors of Ecuador, Peru and Venezuela. *World Development* , 2 (10-12), 49-57.

Trasatti, S. (1995). Electrochemistry and Environment: the Role of Electrocatalysis. *International Journal of Hydrogen Energy* , 20 (10), 835-844.

União da Indústria de Cana-de-Açúcar. (2008). *Questões ambientais. Quais os benefícios ambientais da produção e uso do etanol?* Retrieved July 14, 2008, from Respostas às questões mais frequentes: <http://www.unica.com.br/FAQ/>

United Nations. (1993). *Convention on Biological Diversity*. Treaty Series Vol. 1760, I-30619, Rio de Janeiro.

United Nations Framework Convention on Climate Change. (2008, May 13). *Status of Ratification*. Retrieved July 12, 2008, from Kyoto Protocol: [http://unfccc.int/files/kyoto\\_protocol/status\\_of\\_ratification/application/pdf/kp\\_ratification.pdf](http://unfccc.int/files/kyoto_protocol/status_of_ratification/application/pdf/kp_ratification.pdf)

United Nations. (1985). *Industrial Charcoal Making*. Rome: FAO Forestry Department.

van Biesebroeck, J. (2002). The Effect of Technology Choice on Automobile Assembly Plant Productivity. *The Economic and Social Review* , 33 (1), 65-73.

van Ginneken, W., & Baron, C. (1984). *Appropriate Products, Employment and Technology - Case Studies on Consumer Choice and Basic Needs in Developing Countries*. London: Macmillan.

Wachsmann, U. (2005). *Mudanças no consumo de energia e nas emissões associadas de CO2 no Brasil entre 1970 e 1996 - Uma análise de decomposição estrutural*. PhD Dissertation, Universidade Federal do Rio de Janeiro, Coordenação dos Programas de Pós-Graduação de Engenharia, Rio de Janeiro.

Willoughby, K. (1990). *Technology Choice: A Critique of the Appropriate Technology Movement*. London: Intermediate Technology Publications.

Yan, C. (1969). *Input-Output Economics*. New York: Holt, Rinehart and Winston.

Yuuki, P., Conejero, M., & Neves, M. (2005). Avaliação dos impactos econômicos da produção de biodiesel no Brasil. *XLIII Congresso da SOBER*. Ribeirão Preto.

## LIST OF TABLES

**Table 1. Composition of Output by Regions (Input per Unit of Output, in %), Brazil, 2002**

<b>Input</b>	<b>North</b>	<b>South</b>
Sugarcane	37.9	41.5
Manufacturing	8.5	9.3
Fertilizers and chemicals	2.3	2.5
Machines, equipment, and construction	0.4	0.4
Energy and water	3.4	3.8
Commerce	1.4	1.5
Transportation	1.0	1.0
Services	1.6	1.8
Labor	5.8	3.8
Taxes	6.4	6.4
Imports	1.2	1.8
Gross operating profit	30.1	26.1
Total output	100.0	100.00

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 2. Ethanol Industry, Selected Indicators by Region, Brazil, 2006**

	<b>North</b>	<b>South</b>
Sugarcane harvested area (in 1,000 km <sup>2</sup> )	11.4	50.0
Sugarcane production (in millions of tonnes)	64.5	392.8
Ethanol production (in millions of m <sup>3</sup> )	1.7	16.2
Sugarcane yields (in tonnes/km <sup>2</sup> )	5,647.7	7,851.2
Ethanol production costs (in 12/2005 R\$/l)	1.5	1.1
Average monthly wage (in 12/2005 R\$)	599.1	985.7
Total employment (in thousands)	20.0	60.3
Productivity (in m <sup>3</sup> of ethanol per worker)	87.4	268.1
Employees per 1,000 R\$ of output	9.6	6.4
Percentage of workers with less than four years of schooling	57.1	19.1
Percentage of informal workers*	27.1	11.2
Total firms*	82	230
Total investment in innovation (in millions of R\$)*	15.5	163.5
Investment in innovation as a percentage of total income*	1.9	2.2
Investment in innovation per worker (in R\$)*	507.1	3,961.5
Reduction in CO <sub>2</sub> emissions due to technology (in tonnes)	52.3	3,400.3

\* Data for 2005. Note: km<sup>2</sup> = square kilometer; m<sup>3</sup> = cubic meter; R\$ = Brazilian real; l = liter; CO<sub>2</sub> = carbon dioxide. Source: The authors, based on data provided by Instituto de Pesquisa Econômica Aplicada; Ministério de Agricultura, Pecuária e Abastecimento; Ministério do Trabalho e Emprego; Dias de Moraes; Agência Nacional do Petróleo, Gás Natural e Biocombustíveis.

**Table 3. Output Multipliers for the Ethanol and Sugarcane Industries by Region, Brazil, 2002  
(Output Generated per Unit of Final Demand)**

<b>Region</b>	<b>Ethanol</b>	<b>Sugarcane</b>
<b>North</b>	1.247	1.179
<b>Northeast</b>	1.969	1.700
<b>Center-West</b>	2.734	1.717
<b>South</b>	3.325	1.624
<b>Southeast</b>	3.094	2.949

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 4. Employment Multipliers for the Ethanol and Sugarcane Industries by Region, Brazil, 2002,  
(Jobs Generated per Unit of Final Demand)**

<b>Region</b>	<b>Ethanol</b>	<b>Sugarcane</b>
<b>North</b>	0.004	0.190
<b>Northeast</b>	0.010	0.934
<b>Center-West</b>	0.012	0.266
<b>South</b>	0.021	0.502
<b>Southeast</b>	0.010	0.378

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 5. Disaggregation of the Regional Employment Multipliers (Jobs Generated per Unit of Final Demand) for the Ethanol and Sugarcane Industries, by Economic Activity, Brazil, 2002, (Percent)**

Sector	Ethanol					Sugarcane				
	N	NE	CW	S	SE	N	NE	CW	S	SE
<b>Sugarcane</b>	14.1	21.2	25.7	11.9	18.3	89.2	62.9	62.7	65.5	36.4
<b>Agriculture</b>	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.2
<b>Mining</b>	0.1	1.3	1.2	0.3	3.2	0.2	2.1	1.4	0.7	4.5
<b>Ethanol</b>	80.4	51.0	36.8	30.2	32.7	0.1	0.2	0.2	0.1	0.4
<b>Manufacturing</b>	4.3	11.0	17.6	3.4	17.5	8.2	15.0	18.5	4.8	27.6
<b>Electricity</b>	0.7	9.3	12.4	53.2	23.1	0.7	8.2	6.0	26.7	23.8
<b>Construction</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>Trade</b>	0.3	1.9	1.2	2.0	2.0	1.1	3.5	1.6	0.6	3.0
<b>Transportation</b>	0.1	3.7	4.6	2.5	2.5	0.4	7.0	9.0	1.4	3.6
<b>Private services</b>	0.0	0.5	0.5	0.4	0.4	0.1	0.8	0.5	0.2	0.5
<b>Public services</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>Total</b>	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<b>Employment Multiplier</b>										

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 6. Income Multipliers for the Ethanol and Sugarcane Industries by Region, Brazil, 2002 (Income Generated per Unit of Final Demand)**

Region	Ethanol	Sugarcane
<b>North</b>	0.081	0.046
<b>Northeast</b>	0.114	0.069
<b>Center-West</b>	0.129	0.058
<b>South</b>	0.174	0.065
<b>Southeast</b>	0.107	0.152

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 7. Disaggregation of the Regional Income Multipliers (Income Generated per Unit of Final Demand) for the Ethanol and Sugarcane Industries by Region Where Income Was Generated, Brazil, 2002, (Percent)**

Region where income is generated	Ethanol					Sugarcane				
	N	NE	CW	S	SE	N	NE	CW	S	SE
<b>North</b>	99.5	3.6	3.2	0.4	8.3	99.2	2.6	1.4	0.4	12.1
<b>Northeast</b>	0.1	79.2	2.1	0.3	3.8	0.1	83.6	1.0	0.3	5.2
<b>Center-West</b>	0.1	3.7	82.6	1.3	4.5	0.1	2.0	90.8	0.4	5.5
<b>South</b>	0.2	8.5	8.3	97.0	22.2	0.4	8.0	4.9	98.0	28.0
<b>Southeast</b>	0.1	5.0	3.7	0.9	61.1	0.2	3.8	1.9	0.9	49.2
<b>Total Multiplier</b>	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 8. Energy and Environmental Multipliers for the Ethanol Industry by Region, Brazil, 2002**  
(Energy Consumed and CO<sub>2</sub> Gas Emitted per Unit of Final Demand)

Region	Energy Multiplier	Environmental multiplier
<b>North</b>	0.018	1.421
<b>Northeast</b>	0.036	1.969
<b>Center-West</b>	0.013	0.721
<b>South</b>	0.018	1.004
<b>Southeast</b>	0.017	0.945

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 9. Output Multipliers Derived from Hypothetical Structural Changes in the Ethanol and Sugarcane Production Technologies, Brazil, 2002, (Output Generated per Unit of Final Demand)**

	Ethanol					Sugarcane				
	N	NE	CW	S	SE	N	NE	CW	S	SE
<b>Current output multiplier</b>	1.247	1.969	2.734	3.325	3.094	1.179	1.700	1.717	1.624	2.949
<b>New output multiplier (20%)*</b>	1.617	2.195	2.801	3.279	3.095	1.547	1.963	1.978	1.903	2.950
<b>New output multiplier (50%)</b>	2.172	2.534	2.916	3.211	3.097	2.087	2.347	2.357	2.308	2.952
<b>New output multiplier (95%)</b>	3.006	3.042	3.081	3.110	3.099	2.870	2.896	2.897	2.892	2.954

\* The percentages in parentheses represent magnitudes of technological change (i.e., 20% signifies 20 percent of the industrial production in the respective region will be carried out by technological production processes virtually similar to those currently carried out in the Southeast region, or  $0.8\alpha_j^R + 0.2\alpha_j^{SE}$ ,  $R = N, NE, CW, S, SE$ ).

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.

**Table 10. Percentage Change in the Output Multiplier Derived from Hypothetical Structural Changes in the Ethanol and Sugarcane Production Technologies, Brazil, 2002, (Percent)**

	Ethanol					Sugarcane				
	N	NE	CW	S	SE	N	NE	CW	S	SE
<b>New output multiplier (20%)*</b>	29.7	11.5	2.7	-1.4	0.0	31.3	15.5	15.2	17.1	0.0
<b>New output multiplier (50%)</b>	74.3	28.7	6.7	-3.4	0.1	77.1	38.0	37.3	42.1	0.1
<b>New output multiplier (95%)</b>	141.2	54.5	12.7	-6.5	0.1	143.5	70.4	68.8	78.0	0.2

\* Differences are with respect to the current technology output multiplier. The percentages in parentheses represent magnitudes of technological change (i.e., 20% signifies 20 percent of the industrial production in the respective region will be carried out by technological production processes virtually similar to those currently carried out in the Southeast region).

Source: The authors, based on data provided by Centro de Estudos Avançados em Economia Aplicada.