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How Relevant Has Been the Learning-by-Doing for Brazilian Sugarcane Ethanol Production?

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Abstract

This paper examines the role of several factors in reducing the production costs of Brazilian sugarcane ethanol, including learning-by-doing (LBD), economies of scale, rising factor prices, market competitiveness, and exogenous technological changes. Using the aggregate industry-level data over the period 1975- 2010, we find that the reduction in production costs of sugarcane ethanol was primarily driven by autonomous technological changes and unrelated to LBD. The increase in energy prices raised production costs of sugarcane ethanol, while the effects of other input prices on reducing production costs of sugarcane ethanol are found to be insignificant. By increasing the costs of procuring key inputs for ethanol production, market competitiveness had a negative effect on reducing production costs of sugarcane ethanol. The role of economies of scale in affecting sugarcane ethanol production costs is inconclusive depending on model specifications.

Keywords: Sugarcane ethanol; Production cost reductions; Learning-by-doing; Technological changes
JEL codes: O33; Q20; Q42

Resumen

En este artículo examino la importancia de los diversos factores en la reducción de los costos de producción del etanol de caña de azúcar de Brasil, incluyendo el aprendizaje basado en la experiencia, las economías de escala, el aumento de precios de los factores, la competitividad del mercado y los cambios tecnológicos exógenos. Usando datos agregados a nivel industrial durante el período 1975 - 2010, encontramos evidencias a favor de que la reducción en los costos de producción de etanol de caña de azúcar se debe a cambios tecnológicos autónomos y no al aprendizaje basado en la experiencia. Igualmente, el incremento en los precios de la energía afectó significativamente los costos de producción, mientras que los precios de otros factores no fueron tan importantes. Sin embargo, debido al aumento del costo en la obtención de estos insumos esenciales, la competitividad de mercado pudo tener un efecto negativo en la reducción de los costos de producción. Finalmente, a través de las diferentes especificaciones del modelo, no se encuentra evidencia que permita concluir sobre la dirección y la magnitud del efecto de las economías de escala.

Palabras Clave: Etanol de caña de azúcar; Reducción en los costos de producción; Aprendizaje basado en la experiencia; Cambio tecnológico
Código JEL: O33; Q20; Q42

Introduction

Biofuels are supported by governments around the world for several reasons, including energy security, climate change mitigation, and agricultural development. In Brazil, the primary biofuel supporting policy was the National Alcohol Program (Pró-Álcool) launched in 1975 that promoted the production of ethanol derived from sugarcane with a goal of reducing the fossil-fuel dependence in transportation sector. The program provided different types of policy supports, including a guaranteed purchase of ethanol by a state-owned oil company, low-interest rate loans, subsidies for both the ethanol and the automotive industries and a mandatory blending of ethanol with gasoline. The Brazilian government reduced ethanol subsidies and started the industry's deregulation in 1990s, but the blending mandate was kept1. These policies, together with the commercial success of flex-fuel vehicles (FFV) in the last decade, which accounted for 63% of light-duty vehicle sales in 2010 (ANFAVEA, 2011), have significantly stimulated the development of Brazilian sugarcane ethanol industry.

As a result of these policy incentives and the increasing number of FFVs in the fleet, sugarcane ethanol production has increased more than forty-seven folds over the 1975-2010 period to 300 billion liters (BL) in 2010 with an average growth rate of 13% per year (see Fig 1). Over the same period, unit production costs of sugarcane ethanol (including both feedstock costs and industrial processing costs) declined by 67% from R$2.2 per liter in 1975 to R$0.7 per liter in 2010, while the per-unit industrial processing costs decreased by more than 70% from R$1.0 per liter in 1975 to R$0.3 per liter in 2010. Due to the significant reductions in the production costs, currently sugarcane ethanol is considered as the only economically viable biofuel in the fuel market without any government support (OECD, 2006; Hettinga et al. 2009). Together with the potential of sugarcane ethanol in reducing greenhouse gas emissions relative to gasoline and other first-generation biofuels (such as corn ethanol and biodiesels derived from vegetable oils), Brazil is considered to have the most sustainable biofuel economy in the world and the world biofuel industry leader (Goldemberg, 2007). The purpose of this paper is to examine factors that have contributed to the reductions in production costs of sugarcane ethanol.

Several studies in the literature have attributed unit cost reductions of many products and technologies to their respective cumulative production experience, referred to as learning-by-doing (LBD) (for a review see McDonald and Schrattenholzer, 2002). In the context of biofuels, Hettinga et al. (2009)

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[1] Blending rate has fluctuated between 10% in 1976 to 25% in 2010, and it was reduced to 20% in October 2011.

examine the relationship between unit production costs of U.S. corn ethanol and cumulative corn ethanol production and estimate a learning rate (LR) of 45% where LR is defined as the percentage reduction in unit costs of production with each doubling of cumulative experience. Using the same experience curve approach, Goldemberg et al. (2004) estimate a LR of 29% for production costs of sugarcane ethanol over the period of 1985-2002. In a parallel study, van den Wall Bake et al. (2009) find a LR of 20% for the production costs of sugarcane ethanol using a longer time period spanning from 1975-2004.

However, in addition to cumulative production experiences, other factors, such as economies of scale, rising factor prices, market competitiveness, and research and development (R&D) induced technological change, can also affect costs of production. For instance, Isoard and Soria (2001) find that returns to scale are important sources of productivity growth in the solar photovoltaic (PV) and wind energy industry. Rising factor prices have led to energy-efficient innovation and the adoption of more energy-efficient technologies in several industries, such as air conditioning and water heating (Newell et al., 1999), and coal liquefaction and solar energy (Popp, 2002). Studies also suggest that the economic success of the machine tool industry in various Asian industrialized countries can be partly attributed to international competition (Fransman, 1986; Fagerberg, 1988). Moreover, Papineau (2006) and Nemet (2006) find that autonomous technological changes and knowledge spillovers are key drivers reducing unit production costs of solar PV and wind energy while LBD only has a weak effect. With the inclusion of these factors in addition to cumulative corn ethanol production, Chen and Khanna (2012) show that the LR of processing costs of U.S. corn ethanol estimated by Hettinga et al. (2009) is underestimated due to the exclusion of other explanatory variables.

These factors could also have contributed to the reductions in production costs of sugarcane ethanol. As the number and installed production capacity of sugarcane ethanol mills increase, unit production costs may have moved along the U-shaped average cost curve to the right due to economies of scale, while rising prices of inputs (such as fuels, labor and sugarcane) used intensively in the production of sugarcane and ethanol are likely to induce factor-saving innovation. Ethanol production in the rest of the world (ROW) including the U.S. has also increased significantly by more than seventy-fold from 0.3 BL in 1978 to 55 BL in 2010 (Earth Policy Institute, 2012). Competition for international ethanol markets could have also led Brazil to use advanced production technology to increase its international competitiveness in producing sugarcane ethanol. It is also possible that the reductions in the production costs of sugarcane ethanol are induced by R&D-related technological changes, and unrelated to economies of scale, rising factor prices, market competitiveness, and LBD.

In this paper, we quantify the effect of different factors on the reductions in production costs of sugarcane ethanol, including LBD, economies of scale, rising factor prices, market competitiveness, and autonomous technological change. We first use a stylized cost-minimization model to illustrate the factors affecting average production costs of a product and build our hypothesis. We then perform econometric analysis to examine the statistical significance of these factors in reducing industrial processing costs and total production costs of sugarcane ethanol, respectively, over the period 1975-2010. To test the robustness of our econometric estimation, we use alternative econometric model specifications. In contrast to the findings by Goldemberg et al. (2004) and van den Wall Bake et al. (2009), we find that exogenous technological change played an important role in reducing production costs of sugarcane ethanol. The increases in rising energy costs have raised the production costs of sugarcane ethanol, while there is no evidence that LBD, labor costs and sugarcane prices are important factors affecting sugarcane ethanol production costs. The role of economies of scale is inconclusive depending on model specifications.

This paper contributes to the existing literature by showing that the economic success in Brazil’s sugarcane ethanol industry is primarily driven by R&D-induced technological process and unrelated to LBD. It also illustrates that the estimation of LR is sensitive to the inclusion of additional explanatory variables. This article is organized as follows. The next section gives a brief background about the sugarcane ethanol industry in Brazil. Section 3 describes the methodology and empirical estimation strategy, followed by the description of data sources in section 4. Section 5 discusses the main results of the analysis and section 6 concludes the paper.

1.-Background of Brazilian Sugarcane Agroindustry

Sugarcane production in Brazil dates back to 1532 and the industry for long time was considered to be very labor-intensive, but currently more capital- and technology- intensive. Sugarcane cultivation started in the Northeast then moved to the Sao Paulo area and now it has spread more towards the Western part of the country. Currently, the largest sugarcane producing region in Brazil is Central and Eastern Sao Paulo, Rio de Janeiro, and Parana (“traditional region”). Sugarcane yields ranged from 33 to 100 metric tons (MT) per hectare depending on producing regions in 2010, with a national average of 70 MT per hectare (IBGE, 2011). On average, each hectare of harvested sugarcane land produces about 9.3 MT of sugar or 5800 liters of hydrous ethanol (PECEGE, 2009). The latter can also be dehydrated to produce anhydrous ethanol (99.3% concentration), which is blended with gasoline (gasohol).

The rapid growth of Brazil's sugarcane ethanol industry can be largely attributed to government supporting policy initiatives and technological changes in domestic automobile industry. The Brazilian government launched the National Alcohol Program (Pró-Álcool) in 1975, aiming to substitute part of the automobile fossil-fuel by sugarcane ethanol. Initially, anhydrous ethanol dominated the industry in order to meet the gasoline blending mandate. After the introduction of the first ethanol-dedicated light-duty vehicle (EDV) in 1979, which runs under 100% hydrous ethanol (E100), along with the low prices of sugar in the following years, sugarcane ethanol production increased from 3.7 BL in 1980 to 11.5 BL in 1990 with hydrous ethanol comprising of more than 93% of the total ethanol production (see Fig 1). In 1980s, EDVs accounted for about 80% of the total vehicles sales, but had declined drastically since 1989 due to an ethanol supply shortage which was caused by the removal of the supporting policies and the recovery of sugar prices. According to ANFAVEA (2011), the sales of new EDVs cars dropped from 50% in 1990 to a negligible 0.1% in 1998. As a result, ethanol production since 1989 was primarily in the form of anhydrous ethanol which was tied to the gasoline blending mandate.

In 2003 Brazilian automotive industry introduced FFVs to the market, which run on any proportion of blended gasohol and E100. FFVs represented more than 70% of the total light-duty vehicle sales during the period 2003-2010 (ANFAVEA, 2011). Together with the high gasoline prices over the same period, the development of FFVs led Brazil to resume its ethanol production, reaching historical highs (average 27 BL per year during 2008-2010, see Fig 1), with hydrous ethanol accounting for more than 60% of total ethanol production. The total ethanol consumption represented 17% of total transportation fuels consumed in the country in 2010 (Empresa de Pesquisa Energetica, 2012).

2.-Methodology and Empirical Estimation Strategy

In this section, we use a cost minimization model in which one final good (e.g. sugarcane ethanol) is produced with *N* inputs to illustrate the factors that affect average costs of production and build our hypothesis and empirical strategies for econometric estimation.

2.1 *Cost Minimization Model*

Consider a representative firm that uses input x_{it} with $i \in \{1, 2, ...N\}$ to produce a final good q_t at time $t = \{t_1, t_2, ...T\}$. Assuming a Cobb-Douglas production technology, the firm's production function can be expressed as $q_t = A(Q_t, t)\prod_{i=1}^{N} x_{it}^{\alpha_i}$ with $\alpha_i > 0$, where $A(Q_t, t)$ is the total factor productivity

(TFP) at time t and an increasing function of cumulative production (Q_t) and exogenous technological progress (represented by t). Let $r = \sum_{i=1}^{N} \alpha_i$. Thus, the production function exhibits constant, increasing, or decreasing returns to scale as r =1, r > 1or r <1,respectively. In a competitive market, the firm chooses the optimal combination of x_{it} to produce a given quantity of output q_t while minimizing total costs of production. The problem can be stated as follows:

$$\underset{x_{it}}{Min} \sum_{i,t} p_{it} x_{it}$$

$$\text{S.t } q_t = A(.)\prod_{i=1}^{N} x_{it}^{\alpha_i}$$

where p_{it} denote factor prices. The first-order optimality conditions lead to:

$$\frac{p_{it}}{p_{jt}} = \frac{\alpha_i x_{jt}}{\alpha_j x_{it}} \qquad (1)$$

Total costs of production (TC_t) can be derived as:

$$TC_t = (\frac{q_t}{A(.)})^{1/r}.\prod_{i=1}^{N} p_{it}^{\alpha_i/r}.\sum_{i=1}^{N}\left[\frac{\alpha_i^{\sum_{j\neq i}\alpha_j}}{\prod_{m\neq i}^{N}\alpha_m^{\alpha_m}}\right]^{1/r} = (\frac{q_t}{A(.)})^{1/r}.\prod_{i=1}^{N} p_{it}^{\alpha_i/r}\Delta \qquad (2)$$

where $D = \sum_{i=1}^{N}\left[\frac{a_i^{\sum_{j\neq i} a_j}}{\mathrm{P}_{m\neq i}^{N} a_m^{a_m}}\right]^{1/r}$ is a constant term. Average costs of production (AC_t) can be obtained by dividing q_t on both sides of (2) as shown in equation (3).

$$AC_t = \frac{q_t^{1/r-1}}{A(.)^{1/r}}.\prod_{i=1}^{N} p_{it}^{\alpha_i/r}\Delta \qquad (3)$$

Taking the natural logarithm of each side of (3) yields:

$$\log AC_t = (\frac{1}{r}-1)\log q_t - \frac{1}{r}\log A(.) + \sum_{i=1}^{N}\frac{\alpha_i}{r}\log p_{it} + \log\Delta \qquad (4)$$

As shown in equation (4), average production costs are affected by four components, namely production level (q_t), TFP ($A(.)$), factor prices (p_{it}), and a constant term Δ. AC_t is expected to decline with both increasing returns to scale ($r>1$) and an increase in $A(.)$ that can be achieved with either the accumulation of production experience or autonomous technological changes. Moreover, with $\alpha_i > 0$, an increase in factor prices would increase average production costs if $A(.)$ remains unchanged. However, increases in factor prices could induce the firm to adopt factor-saving technology and/or improve worker' skills, which would increase $A(.)$ (Newell et al., 1999; Popp, 2002). Therefore, the net impact of changes in factor prices on unit production costs is theoretically ambiguous and requires empirical examination.

The experience curve approach in the literature links the changes in average production costs with accumulated production experience (represented by cumulative production), and their relationship is expressed by the following formula:

$$\frac{AC_t}{PI_t} = C_0 Q_t^b \tag{5}$$

$$PR = 2^b \tag{6}$$

where PI_t is price index used to adjust nominal average costs; *b* is the experience index; *C*$_0$ is a constant; and *PR* is progress ratio, denoting the rate at which unit production costs decline for each doubling of cumulative production. *LR* is expressed as $1-PR$. Taking the natural logarithm of (5) yields:

$$\log AC_t = \log C_0 + b \log Q_t + \log PI_t \tag{7}$$

Comparing equations (4) and (7), we can see that to make (7) hold, one needs to make the following assumptions: (1) constant returns to scale of production ($r=1$); (2) cumulative production is the only factor driving the cost reduction ($Q_t^b = A(.)^{-\frac{1}{r}}$); and (3) *PI*$_t$ can capture the changes in factor prices. However, if these assumptions do not hold and q_t, p_{it}, and the time trend are correlated with Q_t, using (7) to explain the reduction in unit costs of production will lead to a biased estimate of *b*.

2.2 Empirical Estimation Strategy

In the empirical estimation, we examine factors that could have contributed to the reductions in both processing costs and total production costs of hydrous sugarcane ethanol, respectively. Table 1 shows the production costs of sugarcane ethanol. As can be seen, the primary cost component of sugarcane ethanol production is feedstock cost, accounting for 63% of the total production costs in 2010. Labor and energy are another two major cost components next to feedstock costs which comprise of 9% each in total production costs of sugarcane ethanol in 2010. Hence, we use energy, labor and sugarcane prices to represent factor prices in the empirical estimation.

The TFP $A(.)$ is decomposed into three components: LBD-induced technological changes, exogenous technological changes (represented by a time trend), and market competition (denoted by ROW ethanol production). In the empirical analysis, we use equation (8) below to examine the significance of various factors in explaining the reductions in sugarcane ethanol production costs.

$$\log AC_t = \beta_0 + \beta_1 \log q_t + \beta_2 \log Q_t + \beta_3 \log E_t + \sum_{i=1}^{N} \beta_{4i} \log p_{it} + \beta_5 t + \varepsilon_t \tag{8}$$

where AC_t is the average unit production cost of sugarcane ethanol at time *t* after the adjustment of price index; q_t is sugarcane ethanol production at time *t*; Q_t is cumulative sugarcane ethanol production at time *t*; E_t is ROW ethanol production at time *t*; p_{it} are input prices at time *t* (including energy and labor prices only when examining the reductions in industrial processing costs of sugarcane ethanol); *t* is time effect capturing exogenous technological changes due to R&D; and ε_i is the error term.

We use ordinary least squares method to estimate equation (8) under the null hypothesis that independent variables are exogenous and the error term is independent and identically distributed. However, our empirical estimation suffers from two major problems that could lead to biased estimates of coefficients. First, autocorrelation in the error term could occur as a result of the use of time series data. Second, the lack of data could lead to omitted variable bias and endogeneity bias. Besides the independent variables included in equation (8), other variables could have also affected the costs of production of sugarcane ethanol, including the prices of chemical, enzymes, electrodes, maintenance equipment and bagasse (the residual cane-waste used to produce heat and power). These variables could affect cumulative production capacity (see Kahouli-Brahmi, 2008), thereby violating the assumptions $E[Q_t, \varepsilon_t] = 0$. Additionally, like other existing studies that examine technological learning in renewable energy sectors, particularly PV, wind, and ethanol (see Isoard and Soria, 2001; McDonald and Schrattenholzer, 2002; Soderholm and Sundqvist, 2007; Kahouli-Brahmi, 2008; van den Wall Bake et al., 2009), our analysis also uses a small aggregate industry-level dataset that spans the period 1975–2010. Given the data limitation, our main purpose here is to examine the robustness of the estimated LR to the inclusion of the other factors introduced in equation (8) and to compare our findings to those obtained by Goldemberg et al. (2004) and van den Wall Bake et al. (2009).

To address the problems discussed above, we conduct a number of tests to examine the appropriateness of our estimation strategy such as Durbin-Watson (DW) and Breusch-Godfrey Lagrange Multiplier (LM) statistics to test for the presence of first-order autocorrelation and the Hausman test for endogeneity of the cumulative production level.[2]

3. Data

Data collected for the econometric analysis range from 1975 to 2010. The data set includes unit total production costs of sugarcane ethanol, unit industrial processing costs of sugarcane ethanol, annual ethanol production, sugarcane prices, input costs for ethanol production in Brazil and world ethanol production.

Annual sugarcane ethanol production in Brazil is taken from Empresa de Pesquisa Energetica (2012), while world ethanol production is gathered from Earth Policy Institute (2012). We collect sugarcane prices from Instituto Brasileiro de Economia da Fundação Getulio Vargas (2012). Total production costs and industrial processing costs of sugarcane ethanol come from different sources dependent on periods. Between 1975 and 2004 costs are obtained from the same sources as reported in van den Wall Bake et al. (2009). We use hydrated ethanol price in Sao Paulo reported by CEPEA/ESALQ/USP (2012a) as a proxy to represent total production costs of sugarcane ethanol in 2005 and 2006. Production costs of ethanol after 2007 and industrial processing costs over the period 2005-2010 are compiled and organized from reports by PECEGE (2008, 2009, 2010, 2011).

Although most sugarcane mills are self-sufficient in power supply by burning the bagasse, they use other energy-related inputs, such as lubricants and fuels. As a proxy for energy costs, we use Laspeyres Energy Price Index based on energy prices and quantities consumed in Brazil reported by Empresa de Pesquisa Energetica (2012), including diesel and fuel oil, natural gas, industrial electricity and steam coal. We use the minimum legal wage in Brazil as labor costs rather than the salary paid for sugarcane production reported

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[2] When conducting the Hausman test we use lagged cumulative production level and annual production of sugarcane ethanol as instrumental variables for cumulative production.

by Instituto de Economia Agrícola (2012) because the latter may not reflect same wages of the ethanol industry; however, both historical figures are very close to each other. All prices and costs are converted to 2005 prices using the Índice Geral de Preços - Disponibilidade Interna (IGP-DI) reported by Instituto Brasileiro de Economia da Fundação Getulio Vargas (2012).

4.- Results

We first use four alternative specifications of the model presented in equation (8) to examine factors that have contributed to the reductions in unit industrial processing costs of sugarcane ethanol, excluding sugarcane prices as an explanatory variable. Model (1a) tests the validity of the experience curve approach with cumulative sugarcane ethanol production as the only explanatory variable. Model (2a) adds annual sugarcane ethanol production and factor prices to examine how these factors have affected unit processing costs of sugarcane ethanol. In model (3a) we include a time trend to examine the importance of exogenous technological changes in achieving the cost reductions. In model (4a), we incorporate ethanol production in the ROW to test the significance of market competitiveness in reducing sugarcane ethanol processing costs. We also use these four model specifications to examine the reductions in total production costs of sugarcane ethanol in models (1b)-(4b), respectively, with the inclusion of sugarcane prices as an additional explanatory variable. Results of the regression analysis are presented in Tables 2 and 3, respectively. Standard errors of the estimates of coefficients are reported in parentheses. The R^2, Adjusted R^2, DW test, and p values for Breusch-Godfrey LM, and the Hausman test statistics are also reported.

4.1 Regression analysis of industrial processing costs of sugarcane ethanol

With cumulative sugarcane ethanol production as the only explanatory variable in model (1a), we find that its coefficient is -0.255 and statistically significantly different from 0 at the $p< 0.01$ level, implying an LR of 16%, which is slightly smaller than that found (20%) by van den Wall Bake et al. (2009). However, the DW test statistic of 0.584 and the p value of Breusch-Godfrey LM of 0.001 indicate that the error terms in this model specification are positively correlated (the 5% critical values for DW test with N=36 and K=2 are d_l=1.41 and d_u= 1.52. Thus $d<d_l$). Moreover, based on the Wu-Hausman test statistic we can reject the null hypothesis of no endogeneity at the $p<0.10$ level, which indicates that omitted variables are correlated with cumulative sugarcane ethanol production. Therefore, the model (1a) is misspecified and the coefficient estimated in the model (1a) is biased.

In contrast, in regressions (2a)-(4a) with the inclusion of additional explanatory variables, the DW and Breusch-Godfrey LM test statistics show no evidence of the presence of serial correlation and the Wu-Hausman test statistics also indicate that cumulative sugarcane ethanol production is not an endogenous variable.

In regression (2a) we include factor prices, namely energy price index and labor costs, and annual sugarcane ethanol production as explanatory variables in addition to cumulative sugarcane ethanol production. We find the coefficient on cumulative sugarcane ethanol production is negative and significantly different from 0 at the 1% level. Implied LR is 33% in model (2a), which doubles the LR estimated by model (1a) and is close to that estimated by Goldemberg et al. (2004) (29%). The coefficient on wage is negative and significant at the 10% level, which indicates that the increase in labor costs has provided incentives for sugarcane ethanol producers to improve workers' skill in manual and semi-manual tasks with the intent of reducing production costs. Rising energy prices are found to have an insignificant impact on sugarcane ethanol processing costs. The coefficient on sugarcane ethanol production is positive and significant at the 1% level, which suggests that there are decreasing returns to scaling up sugarcane ethanol production at the industry level.

However, the previous results do not hold when we add the time trend in model (3a). First, the coefficients on cumulative sugarcane ethanol production and annual sugarcane ethanol production are not significant. Second, in contrast to the findings in model (2a) the coefficient on energy price index is positive and significant at the 1% level, implying that the increase in energy costs has raised processing costs of sugarcane ethanol, while the increase in labor costs played an insignificant role. Lastly, the time trend coefficient is negative and significant at the 1% level. This suggests that the reductions in unit processing costs of sugarcane ethanol are primarily driven by exogenous technological improvements over time and unrelated to cumulative production and economies of scale.

Most of the results in model (3a) hold when we include market competitiveness, represented by ROW ethanol production, as an additional explanatory variable in regression (4a). As shown in the last column of Table 2, we find that the coefficient of the ROW ethanol production is significant at the 10% level and has a positive sign, suggesting that the increase in ROW ethanol production had an adverse impact on the reductions in processing costs of sugarcane ethanol. This market effect could be reflecting that the expansion of ethanol production in the ROW has led to rising costs of procuring key inputs (such as chemical and enzymes) at a point in time. Consistent with the findings in model (3a), we find that the coefficient of the time trend is still negative and significant, while the role of cumulative sugarcane ethanol production in reducing processing costs of sugarcane ethanol is insignificant. Rising energy prices have increased processing costs of sugarcane ethanol, while there is little evidence suggesting that labor costs have led to a reduction in processing costs of sugarcane ethanol. The coefficient on sugarcane ethanol production now is negative and significant at the 5% level, which shows the presence of increasing returns of scale in sugarcane ethanol production at the industry level. Compared to models (1a) and (2a), we find regressions (3a) and (4a) have higher adjusted-R^2, indicating that these two models explain a larger portion of the variability in processing costs of sugarcane ethanol.

We further examine the effect of government deregulation of sugar and ethanol industries in 1999 on sugarcane ethanol processing costs with the addition of a dummy variable in model (4a).[3] We find that the effect of this policy change was not statistically significant; this is possibly because its effect may have been captured by the time trend variable or other variables included in model (4a). The signs and statistical significance of other explanatory variables in this model specification are the same as those obtained in model (4a), which shows the robustness of our results.

4.2 Regression analysis of total production costs of sugarcane ethanol

Table 3 shows regression results on the reductions in total production costs of sugarcane ethanol. We find that the coefficient on cumulative sugarcane ethanol production is still negative and statistically different from 0 in model (1b). Again, the DW test statistic of 0.383 and the *p* value of Breusch-Godfrey LM indicate the presence of serial correlation of the error terms in this model specification, suggesting that the model (1b) is misspecified and the coefficient estimated is biased. With the inclusion of factor prices and annual sugarcane ethanol production in regression (2b), we find signs and statistical significance of the coefficients are identical to those estimated in the regression (2a). The sugarcane price coefficient estimated in the regression (2a) is positive and significant at the 1% level, which indicates that the increase in sugarcane prices has raised total production costs of sugarcane ethanol.

We then include a time trend as an additional explanatory variable in models (3b) and (4b) to examine the significance of exogenous technology progress in reducing total production costs of sugarcane ethanol. Similar to the findings in models (3a) and (4a), we find that the time trend coefficients are negative and significant at the 1% level in these two model specifications, while the coefficients on cumulative sugarcane ethanol production are not statistically significant. Once again, these results suggest that exogenous technological progress has played a key role in reducing total production costs

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[3] Results are not shown but are available upon request.

of sugarcane ethanol and the role of LBD is insignificant, unlike the findings by Goldemberg et al. (2004) and van den Wall Bake et al. (2009). The coefficients on energy price index in models (3b) and (4b) indicate that rising energy prices have increased total production costs of sugarcane ethanol, while there is little evidence that labor costs and sugarcane prices have affected total production costs of sugarcane ethanol. The role of economies of scale in affecting sugarcane ethanol production costs depends on model specifications; the coefficient is positive and significant at the 10% in model (3b), while it becomes insignificant in model (4b). As shown in the last column of Table 5, we find that the coefficient of the ROW ethanol production is still significant at the 10% level and has a positive sign, suggesting that the expansion in ROW ethanol production has led Brazilian ethanol producers to adopt innovative technologies to reduce total production costs of ethanol.

We also plot fitted values of industrial processing costs and total production costs of sugarcane ethanol obtained from models (1a)-(4a) and (1b)-(4b), respectively, against the cumulative sugarcane ethanol production over the period 1975-2010. As shown in Figs 2 and 3, models (4a) and (4b) provide more accurate fitted values than models (1a) and (1b). The differences between fitted values from the former models and the observed production costs of sugarcane ethanol in both cases are typically less than 10%. In contrast, the deviations by the latter models are significantly larger: more than two thirds of the fitted values obtained from models (1a) and (1b) have deviations greater than 10%. Therefore, models (4a) and (4b) are better at explaining the changes in the production costs of sugarcane ethanol over the period 1975-2010.

Conclusions

Production costs of sugarcane ethanol have declined substantially over the past three decades. The experience curve approach has been widely used to explain the reductions in unit production costs of sugarcane ethanol. However, by disregarding the effects of other factors, this approach may lead to biased estimates of LR due to omitted-variable and potential endogeneity issues. This paper quantifies the role of various factors that could have played in reducing the production costs of sugarcane ethanol, including LBD, economies of scale, rising factor prices, market competitiveness, and exogenous technological changes.

We present several new findings. First, in contrast to the findings by Goldemberg et al. (2004) and van den Wall Bake et al. (2009), we find that the reductions in production costs of sugarcane ethanol were primarily driven by exogenous technological progress and unrelated to LBD. Second, rising energy prices have led to an increase in production costs of sugarcane ethanol, while the effects of other input prices on production costs of sugarcane ethanol, such as sugarcane prices and labor costs, are found to be insignificant. Third, market competitiveness played a negative role in achieving the cost reductions by increasing the costs of procuring other key inputs for ethanol production. Lastly, the role of economies of scale in reducing production costs of sugarcane ethanol is inconclusive depending on model specifications.

The results presented in this analysis have important policy implications to support the development of renewable energy like sugarcane ethanol. We show the importance of exogenous technological change in reducing the production costs of sugarcane ethanol and the role of LBD was insignificant. Therefore, it reinforces the need for government-funded research to make scientific breakthrough with an intention of reducing the costs of key inputs, rather than imposing biofuel mandates and/or providing production subsidies to increase cumulative production experience. The finding that rising factor prices did not play a positive role in reducing production costs of sugarcane ethanol suggests that policy instruments that intend to increase input prices may not be as cost-effective as the direct investment on technological development. The insignificant roles of rising factor prices could be attributed to the use of aggregate industry-level data. Hence, future research using facility-level data is needed to examine the effect of various input factors. Lastly, our results show that market competitiveness has increased costs of production of sugarcane ethanol. Therefore, trade barriers, such as import tariffs and quotas, are needed to protect domestic emerging renewable energy industries.

Anexos

TABLE 1
COSTS OF HYDROUS SUGARCANE ETHANOL PRODUCTION IN 2005 PRICES

	R$/m^3	Share
RAW MATERIAL (SUGARCANE AT THE MILL)	501.84	62.5%
LABOR	72.54	9.0%
MANAGEMENT	55.89	7.0%
CHEMICALS, ELECTRODES, LUBRICANTS AND ELECTRICITY	18.58	2.3%
MAINTENANCE (INCLUDING FUEL)	53.62	6.7%
DEPRECIATION	36.05	4.5%
RETURN TO CAPITAL	64.93	8.1%
TOTAL COST	803.45	100.0%

Source: PECEGE (2009)

TABLE 2
REGRESSION RESULTS (DEPENDENT VARIABLE: INDUSTRIAL PROCESSING COSTS OF SUGARCANE ETHANOL)A

MODEL	(1A)	(2A)	(3A)	(4A)
CUMULATIVE SUGARCANE ETHANOL PRODUCTION	-0.255 (0.0277)***	-0.584 (0.1038)***	0.208 (0.1592)	0.174 (0.1527)
ENERGY PRICE INDEX		-0.20 (0.1403)	0.253 (0.1282)*	0.221 (0.1189)*
ANNUAL SUGARCANE ETHANOL PRODUCTION		0.602 (0.1407)***	-0.162 (0.1689)	-0.494 (0.2017)**
WAGE		-0.323 (0.1848)*	0.087 (0.1502)	-0.081 (0.1552)
TIME TREND			-0.071 (0.0126)***	-0.079 (0.0128)***
ROW ETHANOL PRODUCTION				0.233 (0.0884)**
CONSTANT	9.174 (0.3150)***	10.079 (1.265)***	5.204 (1.2498)***	7.989 (1.590)***
R2	0.714	0.842	0.923	0.936
ADJUSTED R2	0.705	0.821	0.91	0.923
DW TEST STATISTICS	0.584	1.49	1.981	2.008
BREUSCH-GODFREY LMB	0	0.168	0.992	0.947
WU-HAUSMAN F TESTB	0.088	0.553	0.103	0.399

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

[b] *p* values of these test statistics

TABLE 3
REGRESSION RESULTS (DEPENDENT VARIABLE: TOTAL PRODUCTION COSTS OF SUGARCANE ETHANOL)A

MODEL	(1B)	(2B)	(3B)	(4B)
CUMULATIVE SUGARCANE ETHANOL PRODUCTION	-0.255 (0.0237)***	-0.533 (0.0713)***	-0.13 (0.1219)	-0.149 (0.1250)
ENERGY PRICE INDEX		0.015 (0.0978)	0.199 (0.0948)**	0.183 (0.0936)*
ANNUAL SUGARCANE ETHANOL PRODUCTION		0.622 (0.0908)***	0.219 (0.1306)*	0.049 (0.1654)
SUGARCANE PRICE		0.583 (0.1763)***	0.265 (0.1690)	0.251 (0.1673)
WAGE		-0.387 (0.1373)***	-0.02 (0.1498)	-0.103 (0.1575)
TIME TREND			-0.041 (0.0107)***	-0.045 (0.0117)***
ROW ETHANOL PRODUCTION				0.118 (0.0697)*
CONSTANT	9.976 (0.2693)***	7.439 (0.9685)***	5.633 (0.9367)***	7.13 (1.2601)***
R2	0.773	0.934	0.956	0.956
ADJUSTED R2	0.766	0.923	0.947	0.948
DW TEST STATISTICS	0.383	1.706	1.703	1.69
BREUSCH-GODFREY LMB	0	0.385	0.378	0.370
WU-HAUSMAN F TESTB	0.594	0.676	0.580	0.986

[a] Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

[b] *p* values of these test statistics

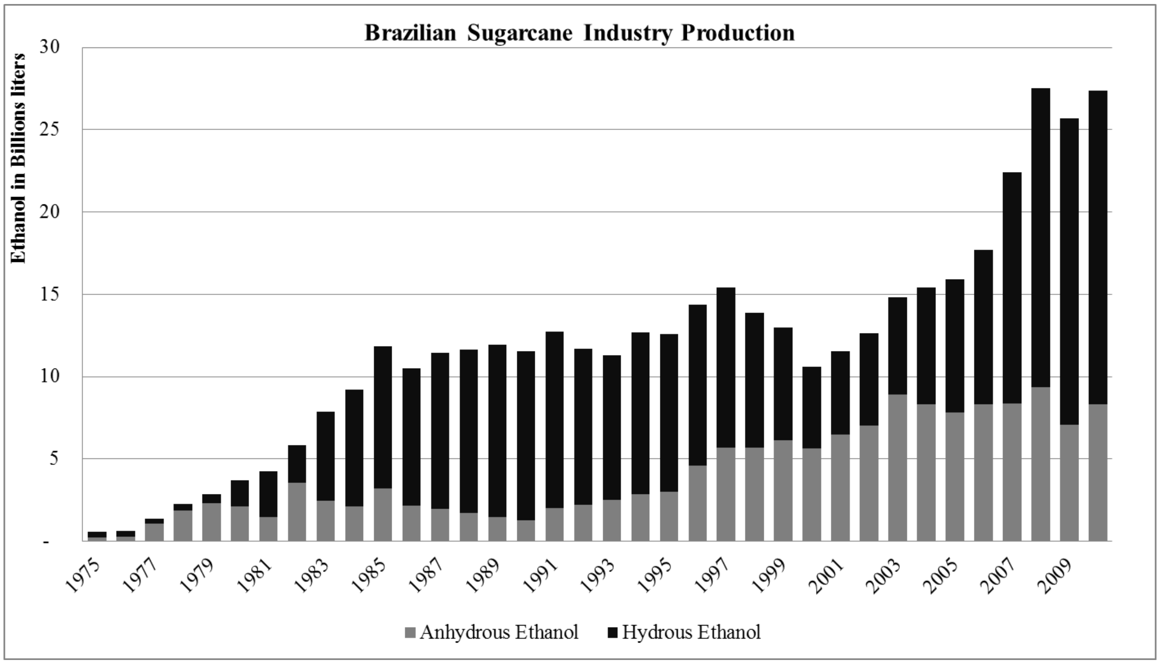

Fig. 1. Sugar and ethanol production in Brazil over 1975-2010.
Source: UNICA (2012)

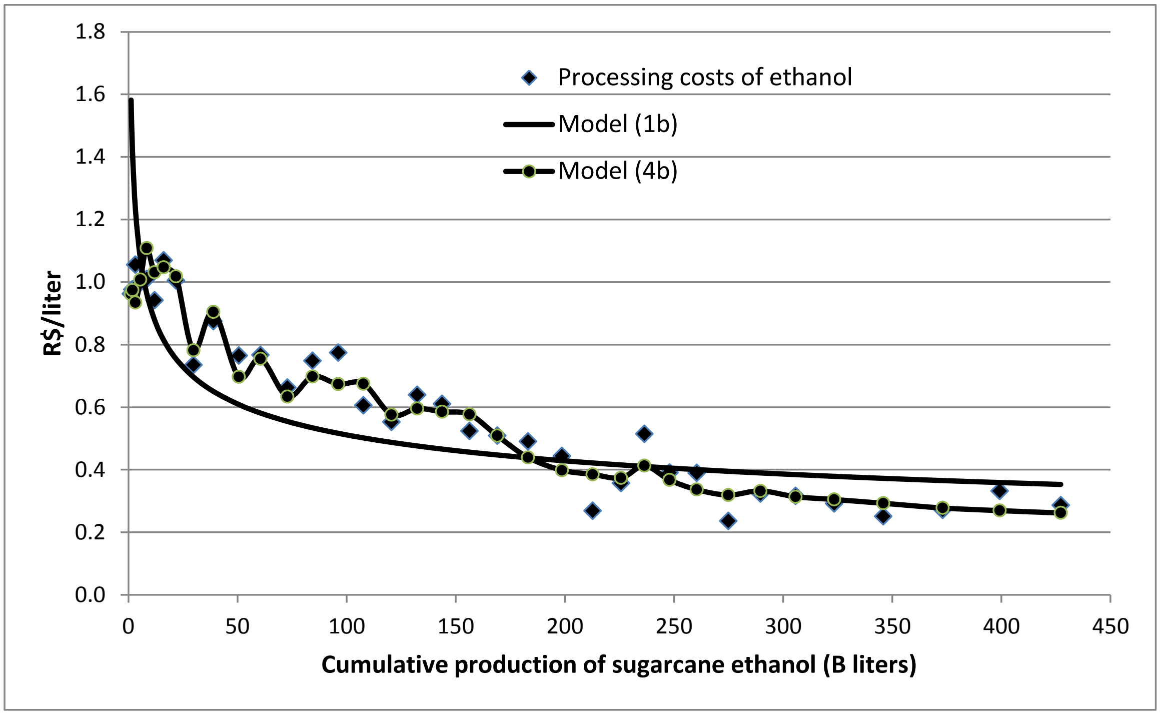

Fig. 2. Model fitted values of industrial processing costs of sugarcane ethanol (2005 prices)

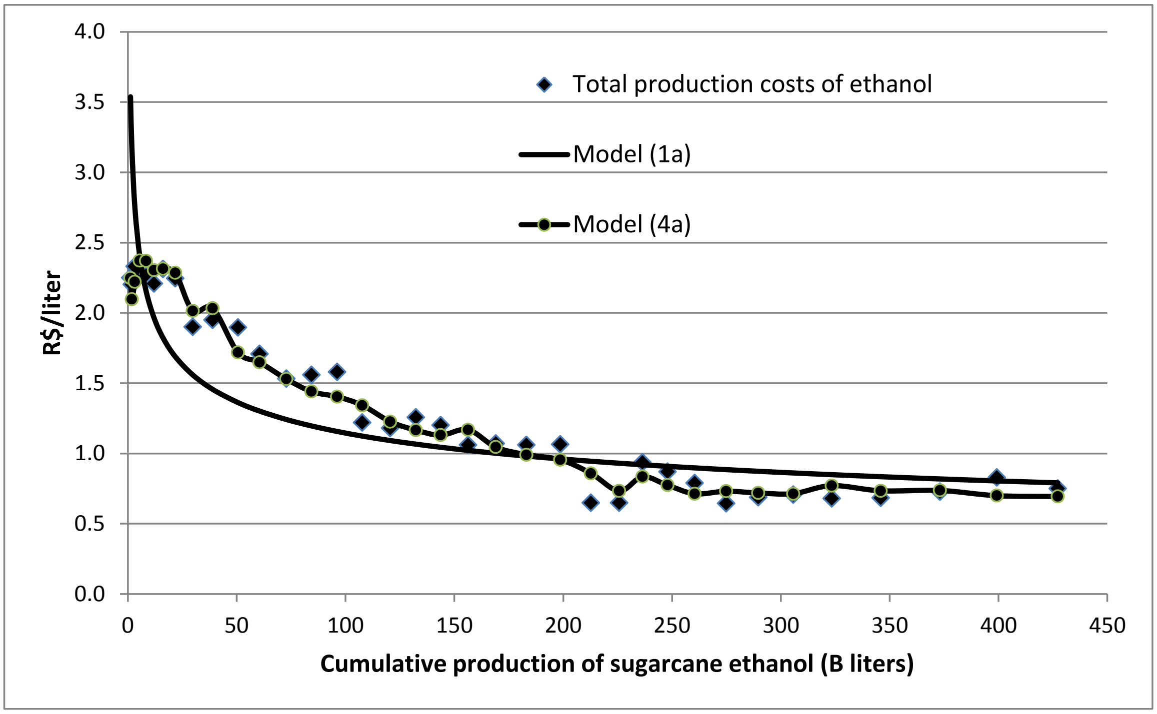

Fig. 3. Model fitted values of total production costs of sugarcane ethanol (2005 prices)

References

ANFAVEA., 2011. Anuário da Indústria Automobilística Brasileira. Associação Nacional dos Fabricantes de Veículos Automotores (National Association of Motor Vehicle Manufacturers; Brazil).

CEPEA/ESALQ/USP., 2012. Indicadores de Preços [WWW Document]. URL http://cepea.esalq.usp.br/indicador/. Last date accessed February 16, 2012.

Chen, X., Khanna, M., 2012. Explaining the reductions in US corn ethanol processing costs: Testing competing hypotheses. Energy Policy 44, 153–159.

Earth Policy Institute., 2012. Data Center [WWW Document]. URL http://www.earth-policy.org/data_center/C23 . Last date accessed February 1st, 2012.

Empresa de Pesquisa Energetica., 2012. Balanço Energético Nacional.

Fagerberg, J., 1988. International Competitiveness. The Economic Journal 98, 355–374.

Fransman, M., 1986. International competitiveness, technical change and the state: The machine tool industry in Taiwan and Japan. World Development 14, 1375–1396.

Goldemberg, J., 2007. Ethanol for a Sustainable Energy Future. Science 315, 808–810.

Goldemberg, J., Coelho, S.T., Nastari, P.M., Lucon, O., 2004. Ethanol learning curve—the Brazilian experience. Biomass and Bioenergy 26, 301–304.

Hettinga, W.G., Junginger, H.M., Dekker, S.C., Hoogwijk, M., McAloon, A.J., Hicks, K.B., 2009. Understanding the Reductions in US Corn Ethanol Production Costs: An Experience Curve Approach. Energy Journal 37, 190–203.

IBGE., 2011. Produção Agrícola Municipal [WWW Document]. URL http://www.sidra.ibge.gov.br/bda/agric/default.asp?z=t&o=11&i=P . Last date accessed March 3, 2012.

Instituto Brasileiro de Economia da Fundação Getulio Vargas., 2012. Indicadores de Preços.

Instituto de Economia Agrícola, 2012. Banco do Dados.

Isoard, S., Soria, A., 2001. Technical change dynamics: evidence from the emerging renewable energy technologies. Energy Economics 23, 619–636.

Kahouli-Brahmi, S., 2008. Technological learning in energy-environment-economy modelling: A survey. Energy Policy 36, 138–162.

McDonald, A., Schrattenholzer, L., 2002. Learning Curves and Technology Assessment. International Journal of Technology Management 23, 718–745.

Nemet, G.F., 2006. Beyond the learning curve: factors influencing cost reductions in photovoltaics. Energy Policy 34, 3218–3232.

Newell, R.G., Jaffe, A.B., Stavins, R.N., 1999. The Induced Innovation Hypothesis and Energy-Saving Technological Change*. Quarterly Journal of Economics 114, 941–975.

OECD., 2006. Agricultural Market Impacts of Future Growth in the Production of Biofuels.

PECEGE., 2008. Custos de Produção de Cana-De-Açúcar, Açúcar e Etanol no Brasil: Safra 2007/2008.

PECEGE., 2009. Custos de Produção de Cana-De-Açúcar, Açúcar e Etanol no Brasil: Safra 2008/2009.

PECEGE., 2010. Custos de Produção de Cana-De-Açúcar, Açúcar e Etanol no Brasil: Safra 2009/2010.

PECEGE., 2011. Custos de Produção de Cana-De-Açúcar, Açúcar e Etanol no Brasil: Safra 2010/2011.

Papineau, M., 2006. An economic perspective on experience curves and dynamic economies in renewable energy technologies. Energy Policy 34, 422–432.

Popp, D., 2002. Induced Innovation and Energy Prices. The American Economic Review 92, 160–180.

Soderholm, P., Sundqvist, T., 2007. Empirical challenges in the use of learning curves for assessing the economic prospects of renewable energy technologies. Renewable Energy 32, 2559–2578.

UNICA (União da Indústria de Cana-de-Açúcar)., 2012. Unica Data [WWW Document]. 2012. URL http://www.unicadata.com.br/

van den Wall Bake, J.D., Junginger, M., Faaij, A., Poot, T., Walter, A., 2009. Explaining the Experience Curve: Cost Reductions of Brazilian Ethanol from Sugarcane. Biomass and Bioenergy 33, 644–658.

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