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Evidence of the empirical relevance of the infant industry argument for the protection of Brazilian ethanol production

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Abstract

The infant industry argument for protection of import competing industries has a long and almost entirely theoretical history in the literature. In this paper the empirical evidence of infant industry dynamics in the Brazilian ethanol industry is investigated. In Brazil ethanol has developed into a primary automotive fuel over the past 18 years. This import substitute is attractive because it allows decreased dependence on international oil supplies while at the same time it addresses environmental concerns because it is a clean-burning renewable fuel. While ethanol was initially a high-cost alternative to imported oil, observed cost reductions have led to an increased belief that this industry may in fact warrant the subsidization it has received because of infant industry reasons. The results of this study suggest that there is no empirical evidence of economies of scale and very little technical change. There appears to be no empirical validity to the infant industry argument for subsidization of the Brazilian ethanol industry.

1. Introduction

Since 1975, Brazil has greatly expanded her reliance on domestically supplied fuel ethanol as a substitute for imported petroleum. Ethanol distilled from sugarcane, a renewable resource, is now the primary automotive fuel in Brazil [1]. It is used both in pure alcohol engines and in unmodified gasoline engines in a 20/80% ethanol/gas blend. Early estimates of the social losses associated with substituting domestic ethanol for imported petroleum are large (Seroa de Motta and de Rocha Ferriera, 1988; Geller, 1985; Barzelay and Pearson, 1982). However, the supporters of this economy-wide import substitution industry have maintained that infant industry dynamics would reverse these losses. The rationale was to endure a period of high-cost expansion until technological advances and economies of scale could be realized which would make ethanol an economically efficient substitute for oil. Because previous studies only examine 'snap-shots' of a single year of costs, no evidence was available to evaluate the promise of infant industry growth. Once again, an important development policy was based upon infant industry dynamics with no evidence to support this common claim.

Rask (1991) analyzes time-series data from 1978–1987 and shows that the costs of producing

[1] Pure alcohol car sales grew from around 10% of total car sales in 1980 to over 90% in 1989 (Rask, 1991).

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ethanol from sugarcane in Brazil dropped significantly throughout the 1980s. While the results suggest that ethanol was an efficient substitute if oil had been priced in the high \$30/bbl. range around 1980, by 1987 ethanol costs had fallen so that it was an efficient substitute for oil priced in the low \$20/bbl range. These results seem to suggest the possibility of infant industry dynamics. There is evidence of increasing sugarcane yields and increasing ethanol distillery yields over the time period. However, there is also evidence of falling agricultural wages during the deep recession Brazil experienced throughout the 1980s. Because sugarcane costs comprise approximately two-thirds of total ethanol costs and sugarcane is an extremely labor-intensive product, agricultural wages play an important role in determining ethanol costs. If falling wages and not technological progress are driving ethanol cost reductions then there is no evidence of infant industry dynamics and, consequently, far less hope for the future efficiency of this petroleum substitute.

After 18 years of experience with this infant industry, the merits of the ethanol program are still hotly debated in Brazil. Production levels continue to rise, albeit much slower than the explosive growth experienced throughout the 1980s. Capital subsidization through 1985 has led to significant excess distillation capacity. Capacity stands at 16 billion liters while annual production has remained around 12 billion in the 1990s. While direct subsidization of capital expansion has ceased, the state-owned fuel sector maintains wholesale and retail prices at levels which encourage ethanol production. The procurement prices in the high-cost northern regions are well above those in the more efficient southern states. In addition, the retail prices of gasoline, gasohol, and hydrous ethanol are kept closely in line with their relative efficiencies as motor fuels. Given the controversial history of the program and its current importance to the liquid fuel sector in Brazil, there are ongoing policy discussions about how important a role ethanol should play in the Brazilian economy.

The infant industry argument for tariff protection has a long and overwhelmingly theoretical history in the literature [2]. The basic theoretical premise of the infant industry exception to free trade is the following. Initially a domestic activity is high cost in relation to an established foreign competitor. The activity requires time to become competitive. However, because of externalities it does not pay a firm to enter the activity at free trade prices [3]. However, if allowed to develop, the industry would be economic enough to generate a rate of return which would allow it to recoup the initial losses. While costs may decline, they must do so such that the domestic firms initially starting the activity are not able to appropriate the full benefits. There must be externalities, either at the industry level or the industrial sector as a whole, which accrue to others beyond those who started the activity and incurred the initial losses. Otherwise, it would pay for the firm to incur the initial losses in order to reap the later rewards. Therefore, the industry requires a *temporary* period of protection during which its costs should fall enough so that it may compete in international markets without any further assistance.

Baldwin (1969) argues that even if the case were made that an industry did fit the requirements to be considered for temporary protection, that tariff protection is *not* first best when contrasted with a production subsidy. This makes the Brazilian experience even more interesting because production subsidies have been the primary form of protection granted to the industry throughout its infant stage. However, the most notable aspect of the literature on infant industry protection is that it has been argued almost entirely on theoretical grounds.

Knowledge of the empirical content of the infant industry argument is lacking. This is surprising considering the widespread use of protec-

bbl, oil barrel = 42 gal (US) ≈ 159 liter.

[2] See Dasgupta and Stiglitz (1988), Grossman and Horn (1988), Succar (1987), Van Long (1975), Bardhan (1971), Clemhout and Wan (1970) and Baldwin (1969).

[3] Baldwin (1969) details many of the commonly made arguments why one might not enter an infant industry without government assistance.

tionist measures in developing countries justified by the infant industry argument. It is also important because of the current interest in strategic trade policy interventions in both developed and developing countries. There has only been one systematic empirical investigation of the relevance of the infant industry argument. Krueger and Tuncer (1982) carry out an empirical test of the validity of the infant industry argument for protected sectors in Turkey. The basis for their test is the following. They argue that the most important characteristic of an infant industry is falling unit costs of production. There are two ways that an industry's costs per unit of output can fall relative to its competitor. First, and not indicative of any basis for protection, are changes in relative factor prices. The second reason unit costs may decrease, one which may support infant industry protection, is the process of technological advancement, economies of scale, or learning by doing. Krueger and Tuncer apply production analysis techniques to separate the effects of technical progress from factor price changes. They provide evidence that output per unit input did not systematically increase faster in protected as compared to unprotected sectors in Turkey in the 1960s and early 1970s. In fact, the productivity figures they estimate are usually *below* those estimated for manufacturing sectors in other countries [4]. Section 3 of this paper follows their general methodology.

Falling unit costs of production are precisely what have been observed in the Brazilian ethanol industry in the 1980s. Because of data limitations it is impossible to directly compare the cost dynamics of ethanol production with its international competitor (OPEC). However, an investigation of the cost dynamics which characterize ethanol production provides evidence which either supports the *possibility* of infant industry dynamics or definitely rejects this argument. Sections 2 and 3 analyze detailed factor price and quantity data for sugarcane production and ethanol distillation to determine whether the dynamics causing the cost reductions belong in the category of infant industry characteristics or whether they are simply a product of factor price changes. Because of data limitations, different methodologies (a more specific and a more general) are used in estimating the source of unit cost reductions in sugarcane production and ethanol distillation. The data on sugarcane production has sufficient degrees of freedom to allow parametric estimation of a production function. However, limited degrees of freedom in the distillation dataset only allow for nonparametric productivity change estimates. Although the nonparametric method is inferior, the limited time series necessitates its use. Section 2 focuses on the sugarcane component in ethanol production while Section 3 focuses on the ethanol distillation process. Section 4 contains the conclusions.

[4] See Krueger and Tuncer (1982, p. 1148) for more detail.

2. Parametric estimates of the sugarcane production function

Parametric estimates of returns to scale and technological progress are common applications of production theory. There is a long literature on flexible applied production and dual cost functions dating back to Heady and Dillon's (1961) book *Agricultural Production Functions*. More recently Diewert and Wales (1987) perform tests on some of the most commonly used functional form specifications in applied production analysis. Their focus is how each form conforms to the constraints placed on the estimation by microeconomic theory. The most problematic violation of microeconomic theory in applied analysis is the satisfaction of the regularity conditions (negative semi-definiteness of the estimated Hessian). More often than not, unconstrained estimated cost functions do not satisfy the requirement of concavity of the cost function over much of the data [5]. Many attempts to impose concavity result

[5] See Berndt and Field (1981, chapters 2 and 10) and Diewert and Wales (1987) for a discussion of the problems associated with imposing concavity on some of the more commonly used functional forms. The translog flexible functional form is of particular interest to those authors because it is the most widely used form in applied production economics.

in a subsequent loss of flexibility of the functional form. Diewert and Wales propose the use of the symmetric generalized McFadden (SGM) functional form in cost function estimation. This form allows the researcher to test the concavity restrictions, and if they are not satisfied, they may be imposed without any loss of flexibility [6].

In its original form, the symmetric generalized McFadden is not suitable to the estimation of a cost function for an agricultural commodity because it does not allow for fixed factors of production. In this section a modified version of the cost function proposed and tested in Diewert and Wales (1987) is estimated. The modification allows the addition of fixed factors to the model of production. This specification allows for the investigation of non-neutral technical change and economies of scale, empirical issues which are central to gaining an understanding of the dynamics which have shaped the sugarcane industry. Eq. (1) is a modified SGM cost function applied to the production of sugarcane, here modeled as a three variable factor, two fixed factor production process. Total cost is a function of the prices of labor, chemicals, and machinery (p_l, p_c, p_m), quantities of fixed land and capital ($\overline{H}$, $\overline{K}$), and the level of output and technology (y, t). The remaining terms are parameters to be estimated and equation-normalizing factor quantity shares.

$$\begin{aligned}
C&\left(p_l, p_c, p_m, \overline{H}, \overline{K}, y, t\right)\\
&= g(p)y + b_{ll}p_l y + b_{cc}p_c y + b_{mm}p_m y + b_l p_l\\
&\quad + b_c p_c + b_m p_m + b_{lt}ty + b_{ct}ty + b_{mt}ty\\
&\quad + b_t\alpha_l p_l t + b_t\alpha_c p_c t + b_t\alpha_m p_m t + b_{yy}\beta_l p_l y^2\\
&\quad + b_{yy}\beta_c p_c y^2 + b_{yy}\beta_m p_m y^2 + b_{tt}\gamma_l p_l t^2 y\\
&\quad + b_{tt}\gamma_c p_c t^2 \gamma + b_{tt}\gamma_m p_m t^2 y + b_{HH}\psi_l p_l \overline{H}y\\
&\quad + b_{HH}\psi_c p_c \overline{H}y + b_{HH}\psi_m p_m \overline{H}y + b_{KK}\chi_l p_l \overline{K}y\\
&\quad + b_{KK}\chi_c p_c \overline{K}y + b_{KK}\chi_m p_m \overline{K}y \qquad (1)
\end{aligned}$$

where

$$\begin{aligned}
g(p) &= \left(s_{lc}p_l p_c + s_{lm}p_l p_m + s_{cm}p_c p_m\right.\\
&\quad \left.+ \tfrac{1}{2}s_{ll}p_l^2 + \tfrac{1}{2}s_{cc}p_c^2 + \tfrac{1}{2}s_{mm}p_m^2\right)\\
&\quad /(\theta_l p_l + \theta_c p_c + \theta_m p_m)
\end{aligned}$$

Given the above form of the cost function, the input demand system can be derived directly from Shephard's Lemma as the first derivative of the cost function in prices. The demand system for the variable factors is defined by (2), (3), and (4) in the table below. A unique feature of the SGM cost function is that the independent variables in the input demand system are not cost shares as they are in the more commonly used translog form. The independent variable of each demand equation (after dividing through by output) is the ratio of input use to output. This is preferable to the estimation of cost shares because the assumption of homoskedasticity of the errors is more plausible.

The system of Eqs. (2), (3) and (4) for each time period is estimated using an iterative seemingly unrelated regression (SUR) procedure with the following restrictions imposed [7]. Additive disturbance terms (u_i for i = labor, chemicals, and machinery) with a zero mean and a constant variance are assumed for the three demand equations. The symmetry conditions and the adding up constraints are also imposed by constraining s_{ij} and $\Sigma_{i=1}^{3} s_{ij} = 0$ for $j = 1, 2, 3$. The particular parameters of interest in the estimation are the parameters from the first and second line of each demand equation, along with the b_i, b_{it}, α_i, β_i, and γ_i from the last line of each demand equation. The s_{ij} define the Hessian from which the regularity conditions are checked [8]. The remaining parameters are all part of the elasticity measures of interest.

In the empirical work the important technical change and economies of scale elasticities are

[6] The imposition of the concavity restrictions on the estimation form involve a Cholesky decomposition of the price parameters. For more detail see Diewert and Wales (1987).

[7] The ITSUR procedure contained in PC-SAS version 6.04 was used for the demand system estimation.

[8] For each region the estimated Hessian was in fact negative semidefinite so the regularity conditions are satisfied globally in the results.

$$\frac{\partial C(*)}{\frac{\partial p_l}{y}} = \frac{\chi_l}{y} = \frac{s_{ll} p_l + s_{lc} p_c + s_{lm} p_m}{\theta_l p_l + \theta_c p_c + \theta_m p_m} \tag{2}$$

$$-\theta_l \left[\frac{s_{lc} p_l p_c + s_{lm} p_l p_m + s_{cm} p_c p_m + \frac{1}{2} s_{ll} p_l^2 + \frac{1}{2} s_{cc} p_c^2 + \frac{1}{2} s_{mm} p_m^2}{(\theta_l p_l + \theta_c p_c + \theta_m p_m)^2} \right]$$

$$+ b_{ll} + b_l y^{-1} + b_{lt} t + \alpha_l t y^{-1} + \beta_l y + \gamma_l t^2 + \psi_l \overline{H} + \chi_l \overline{K} + u_l$$

$$\frac{\partial C(*)}{\frac{\partial p_c}{y}} = \frac{\chi_c}{y} = \frac{s_{cc} p_c + s_{lc} p_l + s_{cm} p_m}{\theta_l p_l + \theta_c p_c + \theta_m p_m} \tag{3}$$

$$-\theta_c \frac{s_{lc} p_l p_c + s_{cm} p_c p_m + s_{lm} p_l p_m + \frac{1}{2} s_{ll} p_l^2 + \frac{1}{2} s_{cc} p_c^2 + \frac{1}{2} s_{mm} p_m^2}{(\theta_l p_l + \theta_c p_c + \theta_m p_m)^2}]$$

$$+ b_{cc} + b_c y^{-1} + b_{ct} t + \alpha_c t y^{-1} + \beta_c y + \gamma_c t^2 + \psi_c \overline{H} + \chi_c \overline{K} + u_c$$

$$\frac{\partial C(*)}{\frac{\partial p_m}{y}} = \frac{\chi_m}{y} = \frac{s_{mm} p_m + s_{lm} p_l + s_{cm} p_c}{\theta_l p_l + \theta_c p_c + \theta_m p_m} \tag{4}$$

$$-\theta_m \left[\frac{s_{lm} p_l p_m + s_{cm} p_c p_m + s_{lc} p_l p_c + \frac{1}{2} s_{ll} p_l^2 + \frac{1}{2} s_{cc} p_c^2 + \frac{1}{2} s_{mm} p_m^2}{(\theta_l p_l + \theta_c p_c + \theta_m p_m)^2} \right]$$

$$+ b_{mm} + b_m y^{-1} + b_{mt} t + \alpha_m t y^{-1} + \beta_m y + \gamma_m t^2 + \psi_m \overline{H} + \chi_m \overline{K} + u_m$$

defined by (5) and (6). These are derived from differentiating the cost function with respect to time and output. The overall rate of technical progress (5) is measured by a time trend while holding constant all other variable factors in the model. It is a measure of how much 'technology' changes total costs of sugarcane production over time. F-tests are used to test the null hypothesis that $\partial \ln C(*)/\partial t = 0$.

$$\frac{\partial \ln C(*)}{\partial t} = \alpha_l p_l + \alpha_c p_c + \alpha_m p_m + b_{lt} p_l y + b_{ct} p_c y + b_{mt} p_m y + 2\gamma_l p_l t y + 2\gamma_c p_c t y + 2\gamma_m p_m t y \tag{5}$$

The second elasticity of interest measures the level of economies of scale, another possible source of infant industry dynamics. The elasticity of cost with respect to the level of output is (6). Ohta (1974) defines the inverse of this measure as the returns to scale. It measures the change in total costs in response to an expanded scale of production holding all the input prices and levels of the fixed inputs constant. Again, F-tests are used to test the null hypothesis, whether $\partial \ln C(*)/\partial \ln y = 1$, which implies constant returns to scale technology in sugarcane production.

$$\frac{\partial \ln C(*)}{\partial \ln y} = 2\beta_l p_l y + 2\beta_c p_c y + 2\beta_m p_m y + \gamma_l p_l t^2 + \gamma_c p_c t^2 + \gamma_m p_m t^2 + b_{ll} p_l + b_{cc} p_c + b_{mm} p_m + b_{lt} p_l + b_{ct} p_c + b_{mt} p_m + \psi_l p_l H + \psi_c p_c H + \psi_m p_m H + \chi_l p_l K + \chi_c p_c K + \chi_m p_m K \tag{6}$$

Table 1
F-test results for regional pooling and imposing linear restrictions

N	Prob $> F_{obs}$
Pooling the cross-sections into regional time-series	
Pool São Paulo, Minas Gerais, Rio de Janeiro data into one C/S region (*Rejected*)	0.0414
Pool Pernambuco and Alagoas data into N/NE region (*Accepted*)	0.9382
Pool Minas Gerais and Rio de Janeiro data into one Center/East region. (*Accepted*)	0.8007
Restrictions on Technical Progress and Returns to Scale	
Impose no overall technical progress on São Paulo (*Accepted*)	0.2798
Impose no overall technical progress on Center/East (*Accepted*)	0.3489
Impose no overall technical progress on North/Northeast (*Rejected*)	0.0000
Impose constant returns to scale on São Paulo (*Accepted*)	0.2509
Impose constant returns to scale on Center/East (*Accepted*)	0.2475
Impose constant returns to scale on North/Northeast (*Accepted*)	0.1154

2.1. Data set and variable construction

The Institute for Sugar and Alcohol (IAA) annually surveys Brazilian sugarcane, sugar, and alcohol producers. These surveys cover between 10% and 20% of the total number of producers, and from 20% to 40% of the total sugarcane produced. Data are reported from 1975 to 1987 for the five major sugarcane producing states in Brazil (São Paulo, Rio de Janeiro, Minas Gerais, Pernambuco, and Alagoas). The surveys contain average costs of production for two types of producers in each state. The first category of producers are the *Usinas*, producers who grow sugarcane on the land owned by the sugar mill/distillery. The other producers surveyed are the *Fornecedores*. These are the independent growers that also supply sugarcane to the sugar mill/distillery. Surveys are conducted annually for five states, two types of producers per state, over a 13 year time period. The data consist of average input quantities and prices for 15 factors of production, along with expenditures on the remaining 4 factors where market prices are not available. The data, therefore, represent factor prices and quantities for an average producer, where the producers are defined by geographical area and proximity to the mill (Fornecedores being farther away).

Because of constraints in degrees of freedom, a completely disaggregated model of production cannot be estimated. The 19 inputs from the surveys are aggregated into 5 major categories [9]. The various categories of field, cutting, and administrative labor are aggregated into one labor input. Fertilizers, pesticides and herbicides are all contained in the 'chemicals' input group. Farm machinery, equipment, and transportation services are grouped together into the category 'machinery.' Therefore, labor, chemicals, and machinery are the three variable factors while land and buildings are the fixed factors of production. The land and capital measures require no aggregation. These fixed factors enter into the cost function estimation directly as quantities. While the amount of land utilized is readily available in the data, a service use of capital is constructed. Tornquist-Theil 'divisia' price and quantity indexes for labor, chemicals, and machinery are constructed from the disaggregated price and quantity data. These three sets of indices are used in the empirical estimation of the cost function. To avoid the inconsistencies that arise from independent construction of the price and quantity indices, the price index is constructed first. The quantity index is then derived from expenditures divided by the price index. The advantages of this method are discussed in Diewert (1976).

[9] A more detailed explanation of the data and the pooling procedure is available on request from the author.

2.2. Sugarcane cost function estimation results

The three factor demand equations are estimated as a SUR system without the original cost function since the cost function contains no additional information. All the parameters of the cost function are recovered from the demand equations. Many constrained and unconstrained estimations are undertaken to determine the final specification of the model in terms of regions and technological characteristics. First, F-tests are conducted to determine the amount of pooling which could be done across states. The first half of Table 1 contains these results. The results reject pooling São Paulo with any of the other four states. However, sugarcane production in Minas Gerais and Rio de Janeiro is similar enough to allow one production function to characterize technology in these two states. The two northern states of Pernambuco and Alagoas can also be pooled into a single northern region. Therefore, the remaining analysis is undertaken for three distinct areas of production, São Paulo, the Center/East (Minas Gerais and Rio de Janeiro), and the North/Northeast (Pernambuco and Alagoas).

F-tests are also performed to evaluate the statistical presence of technical change and economies of scale in the production process. The bottom half of Table 1 highlights these results. The hypothesis of any technical progress is rejected for São Paulo and the Center/East and accepted for the North/Northeast. Constant returns to scale is accepted in all the production regions of Brazil. The acceptance of most of the restrictions of no technical progress and constant returns to scale answers the question of the sources of cost reductions in sugarcane production in the 1980s quite clearly. Given that no significantly lower input usage per unit of output is found implies that the cost reductions are a product of changing factor prices. Therefore, the results of the estimation of the sugarcane cost function contradict the hypothesis (often put forth by supporters of the program) that the greatly expanded sugarcane production in the 1980s has been characterized by significant technical progress *or* economies of scale.

An estimate of the overall rate of technical progress in sugarcane production in the North is calculated using (5). Table 2 contains the estimates of the overall rates of technical change for selected years. The estimates measure the annual percent increase (decrease) in total cost holding all other factors except time constant.

The only clear pattern to emerge in the estimates is the change from costs increasing over time to costs decreasing in the second half of the sample period for the usinas. While the magnitudes are quite small, the estimates of technical progress may be capturing the time lag involved in getting new sugarcane fields operating at full capacity. They may also be a result of the production expansion in the more favorable regions of the North. While most of the original production takes place on relatively mountainous land, much of the expansion was achieved through the cultivation of the *Regiao de Tabuleiro*. This is a flat plateau which closely resembles the topography found in the more fertile southern regions of Brazil. The increased production coming from this region may account for much of the minor technical progress measured in the Northeast.

Table 3 contains the parameters of the cost function which are recovered from the demand

Table 2
The effects of technical change on sugarcane total cost in Northern Brazil

Year	Pernambuco		Alagoas	
	Fornecedores	Usinas	Fornecedores	Usinas
1975	0.024%	0.025%	0.025%	0.028%
1980	0.017%	0.004%	0.017%	0.013%
1984	0.004%	−0.0001%	0.007%	−0.003%
1987	0.001%	−0.010%	0.010%	−0.010%

system estimation. The cells with a '–' designation reflect the imposition of the restrictions on technology or economies of scale so there are no unconstrained model parameter estimates to report. Most of the parameter estimates are efficiently estimated and the adjusted R^2 for the various demand equations range from 0.17 to 0.78. The flexible functional form was able to capture a substantial amount of the variation in the dependent variables considering the dataset is a combination of micro time series and cross-section.

Table 3
Parameter estimates for the modified SGM sugarcane cost function

Parameter	São Paulo	Center/East	North/East	Parameter	São Paulo	Center/East	North/East
s_{lc}	216223	45044	32093	α_l	–	–	168.4
	[1.90]	[4.20]	[0.59]		–	–	[4.35]
s_{lm}	290921	15784	134820	α_c	–	–	−144.1
	[4.41]	[2.24]	[3.21]		–	–	[4.19]
s_{cm}	52585	−1577	27860	α_m	–	–	−22.94
	[0.78]	[0.22]	[0.94]		–	–	[1.26]
b_{ll}	205.5	205.0	6511319	β_l	−7.34	−13.98	−7.29
	[7.37]	[13.01]	[2.64]		[3.05]	[2.02]	[0.81]
b_{cc}	62.82	104.15	−7806494	β_c	−1.88	14.20	5.79
	[3.17]	[7.75]	[3.86]		[1.62]	[2.37]	[0.79]
b_{mm}	115.8	109.38	1587680	β_m	−1.66	−5.52	−1.92
	[10.71]	[14.85]	[1.82]		[1.85]	[2.31]	[0.92]
b_l	−639.6	4.38	331130	γ_l	–	–	1.65
	[2.58]	[0.59]	[4.33]		–	–	[2.64]
b_c	501.8	−3.23	285631	γ_l	–	–	−1.98
	[2.29]	[0.49]	[4.21]		–	–	[3.85]
b_m	149.2	5.15	45515	γ_m	–	–	−0.4037
	[1.32]	[1.51]	[1.26]		–	–	[1.83]
b_{lt}	–	–	−6558	ψ_l	517.4	317.5	1982
	–	–	[2.64]		[2.72]	[0.79]	[5.69]
b_{ct}	–	–	7862	ψ_c	136.2	−1131	176.1
	–	–	[3.86]		[1.57]	[3.37]	[0.63]
b_{mt}	–	–	1601	ψ_m	56.53	−32.55	54.91
	–	–	[1.82]		[1.15]	[0.2]	[0.50]
				χ_l	−0.0045	−0.0089	0.0013
					[1.81]	[0.88]	[0.27]
				χ_c	0.0013	0.0073	0.0023
					[1.18]	[0.89]	[0.59]
				χ_m	0.0002	0.0113	0.0024
					[0.28]	[2.88]	[1.53]

Demand equation	SP Adj-$R2$	C/E Adj-$R2$	N/E Adj-$R2$
Labor	0.17	0.29	0.57
Chemicals	0.60	0.31	0.26
Machinery	0.78	0.38	0.40
Degrees of freedom	58	133	124
N	25	50	50

* Note: The t-statistics are given in the brackets below each parameter estimate.

3. A nonparametric estimation of productivity changes in ethanol distillation

The distillation of the ethanol from the sugarcane is the final stage of the production process. The distillation costs are less important in terms of overall costs than are the sugarcane costs. However, the expansion of production through new distilleries which may embody new technology, and the accumulated experience with large-scale production, may be sources of cost-savings. Because detailed distillery factor price and quantity data are not available for as many years as the sugarcane data, parametric estimation of a cost function similar to that estimated in Section 2 is not possible. However, nonparametric techniques can be used to separate the effects of technical change or learning by doing from the effects of factor price changes on unit cost reductions. These estimates provide the final piece of evidence against any significant infant industry characteristics driving the previously observed reductions in unit ethanol costs.

3.1. An empirical measure of technical change in ethanol distillation

Variants of the measure of technical change employed in this section may be found in Krueger and Tuncer (1982) and Chambers (1988). Define the total cost of distillation as:

$$C_{\mathrm{d}} = \sum_{i}^{n} p_i \chi_i \tag{7}$$

where p_i represents factor prices and x_i represents factor quantities. The change in costs from one period to the next is:

$$\mathrm{d}\ C_d = \sum_{i}^{n} \mathrm{d}\ p_i\ \chi_i + \sum_{i}^{n} \mathrm{d}\ \chi_i\ p_i \tag{8}$$

Finally, the unit cost change between period t and period $t+1$ can be written as (9) to make use of factor shares of total cost.

$$\mathrm{d}\left(\frac{C_{\mathrm{d}}}{Q_{\mathrm{d}}}\right) = \sum_{i}^{n} \frac{\mathrm{d}p_i}{p_i}\frac{p_i\chi_i}{C_{\mathrm{d}}}\frac{C_{\mathrm{d}}}{Q_{\mathrm{d}}} + \sum_{i}^{n} \frac{\mathrm{d}\chi_i}{\chi_i}\frac{p_i\chi_i}{C_{\mathrm{d}}}\frac{C_{\mathrm{d}}}{Q_{\mathrm{d}}} - \frac{\mathrm{d}Q_{\mathrm{d}}}{Q_{\mathrm{d}}}\frac{C_{\mathrm{d}}}{Q_{\mathrm{d}}} \tag{9}$$

Using the notation of α_i for the ith factor share of total costs, (9) can be rewritten as:

$$\dot{C}_{\mathrm{d}} = \sum_{i}^{n} \alpha_i \frac{\mathrm{d}p_i}{p_i} + \sum_{i}^{n} \alpha_i \frac{\mathrm{d}\chi_i}{\chi_i} - \frac{\mathrm{d}Q_{\mathrm{d}}}{Q_{\mathrm{d}}} \tag{10}$$

Thus, the proportionate change in ethanol costs per unit output is the share weighted sum of the changes in input prices plus the share weighted sum of the changes in input usage less the change in ethanol output. The primary concern of this section is the magnitude of the proportionate change in input usage per unit of output, the last two terms in (10). This is because changing factor prices do not provide a case for infant industry protection, so one can ignore the first term on the right-hand side of (10). We are left with a formulation almost identical to that of total factor-productivity growth, i.e., the rate of growth of output less the share-weighted rate of growth of inputs [10]. For purposes of this study the relevant measure reported is the share-weighted growth rate of inputs per unit of output.

$$\mathrm{TFP} = \sum_{i}^{n} \alpha_i \frac{\mathrm{d}\chi_i}{\chi_i} - \frac{\mathrm{d}Q_{\mathrm{d}}}{Q_{\mathrm{d}}} \tag{11}$$

This measure of total factor-productivity will help determine whether ethanol distillation has infant industry characteristics. The rate of decrease of inputs per unit output measures productivity changes in the ethanol distillation process. While this is not a direct test of ethanol productivity gains vs. petroleum productivity gains, it does provide evidence which complements the results of Section 2.

3.2. Ethanol distillery data set

The data set used in the construction of the productivity indices is from the same source and has similar coverage to that described in the sugarcane section. The main difference is that the time series for which disaggregated factor price

[10] For a detailed examination of the literature on productivity measures and their uses see Capalbo and Antle (1988) and Chambers (1988).

Table 4
Average annual rates of growth of inputs/output, 1984–1987

Region/State	Autonomous	Annexed
São Paulo:	−3.23%	−3.16%
Center/East:	−3.01%	−2.37%
North/Northeast:	−2.06%	−2.89%

and quantity data is available only from 1984 through 1987. There are also some differences in factor groups. The main inputs to the distillation process (besides the sugarcane juice) are labor, chemicals, energy (wood, oil, electricity), and capital. The data cover the same areas of production including the state of São Paulo, and the regions of the Center/East (Minas Gerais, Rio de Janeiro) and the North/Northeast (Pernambuco, Alagoas). The data also distinguish between ethanol produced from the older, original annexed distilleries and that produced from the new autonomous distilleries in each state/region. Thus the results are reported for the six main types of production units in Brazil. These are the autonomous distilleries in São Paulo, the Center/East, and the North/Northeast, along with the annexed distilleries in the same three regions.

3.3. Results

Table 4 contains the rates of growth of ethanol inputs per unit of output for the three main production regions and two types of distilleries in Brazil. The estimates are quite similar to those presented in Krueger and Tuncer (1982), and also are in the range of the 2–4% productivity growth estimates cited in other aggregate productivity studies. These results support the hypothesis that there are no extra-ordinary productivity growth rates in the ethanol industry that would likely characterize an industry which warranted infant industry protection.

Table 5 contains estimates of individual factor productivities for the five main inputs into the distillation process. The results are reported for autonomous and annexed distilleries in the three regions.

While there is a wide variance in the growth rates of the different inputs per unit of output over the period, a few regularities do appear. First, because sugarcane is the primary cost component in the distillation of ethanol, the total factor productivity measures in Table 4 are driven by the underlying measures presented here. Rates of sugarcane use vary from −0.3% to −4% annually. Secondly, there does appear to be evidence that the newer autonomous distilleries are integrating more energy co-generation technology than the older, annexed distilleries. Evidence of increased use of the *bagasse*, the stalk by-product of the sugarcane crushing process, as a fuel source is born out by the negative measures of energy input usage for the autonomous distilleries. However, the annexed distilleries have increased their energy consumption per unit of output, possibly because of the inability to fully adopt the newer co-generation technology.

4. Conclusions

For policy-makers interested in the possibility of substituting ethanol for gasoline refined from

Table 5
Specific factor analysis – average annual growth rates of input/output, 1984–1987

Distillery/Region	Labor	Chemicals	Energy	Capital	Sugarcane
Autonomous					
Sao Paulo	3.63%	−3.31%	−0.62%	9.98%	−3.63%
Center/East	−10.93%	−2.12%	−11.16%	−3.59%	−0.71%
North/Northeast	−9.12%	−15.91	−11.82%	3.17%	−0.26%
Annexed					
Sao Paulo	6.88%	−16.53%	29.56%	50.59%	−4.09%
Center/East	−3.79%	0.37%	15.74%	−29.92%	−2.74%
North/Northeast	−15.19%	−27.32%	11.61%	−25.02%	−1.89%

imported oil, the experience of the Brazilian ethanol program is an important one. Brazil has been producing ethanol on a large-scale since 1975 and the eighteen years of reliance upon this petroleum substitute have produced a mixed record. Overall this import substitution program has been extremely costly. However, there are a few years where cost reductions coupled with oil price increases have made this an economic alternative to imported oil. A possible area of promise is the observation that costs have decreased during the 1980s. Rapidly declining costs over time is a characteristic that an infant industry should exhibit. This would appear to support the backers of the program who rely on the infant industry argument for subsidization of production.

A major component of the empirical evidence needed to justify infant industry protection is cost reductions independent of factor price changes. In this paper both parametric and nonparametric techniques are used to separate the effects of factor price changes from technical progress or economies of scale. A modified symmetric generalized McFadden cost function for sugarcane production which allows for disembodied technical change and increasing returns to scale is estimated. No evidence of increasing returns to scale in sugarcane production is found for any region of Brazil. No technical progress is found for production in the southern states of Brazil (80% of total production) while extremely small rates of technical progress are estimated for the northern states. Nonparametric index number analysis is used to estimate the average growth rates of inputs per unit of output for ethanol distillation. Again, rates of growth are consistently at or below average rates estimated from other manufacturing studies for different countries. No infant industry dynamics appear to be at work in the Brazilian ethanol industry. There is simply no evidence of extra-ordinary increases in factor productivity over time.

Given that (1) there is little or no technological progress in sugarcane production, (2) sugarcane costs are over two-thirds of ethanol costs, and (3) ethanol distillation productivity is increasing at approximately 3%, the observed decline in unit costs must be a product of factor price changes. Factor price changes are not a reason to provide support to infant industries. Because of the labor-intensive nature of sugarcane production, the observed decline in real wages in the agricultural sector may well explain most of the decline in unit costs. These results reinforce the hypothesis that the ethanol industry is not characterized by any infant industry cost dynamics. The evidence cited here suggests that the outlook for the future social benefits of ethanol production in Brazil will be determined more by the path of oil world prices than by any significant future downward trend in ethanol production costs.

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