Growth of the Brazilian biofuel sector: an inter-temporal general equilibrium analysis (First Draft)

Cristina Vinyes & Terry Roe*

April 27, 2012

Abstract

In order to enhance energy security and independence, Brazil has supported the production and use of ethanol. Brazil's leadership in this market reveals complex inter-linkages between ethanol, sugarcane, sugar and fossil fuels. These sectors have been growing an average of 14% per year, while the country's growth rates have been very modest. This paper presents a theoretical framework for understanding the interaction between Brazil's economic growth and the evolution of these sectors as the economy transitions toward long-run equilibrium. Then, the sensitivity of these results is analyzed under two simulations; first, a reduction of the cost of financial intermediation (which the literature identifies as one of the factors affecting Brazil's growth), and second, an increase in ethanol prices by 2.6%, based on the expectation that biofuels' world demand is increasing.

*Research fellow, European Commission, JRC-IPTS center and Professor, Applied Economics Department, University of Minnesota, respectively.

1 Introduction

Approximately 90% of the world's commercially produced energy is obtained from non-renewable fossil fuels such as crude oil, coal, and gas (Birur et al. 2008). In order to enhance energy security and independence, many countries, such as Brazil, have supported the production and use of renewable energy sources such as biofuels. According to Martines et al. 2006, Brazil is the only country in the world able to produce ethanol[1] from sugarcane at sufficiently low costs to be competitive with conventional fuels on a BTU basis, costing about 0.22 USD/liter versus 0.53 USD/liter in the EU. This cost advantage is partially due to her endowment of cultivatable land and favorable climatic conditions for the production of sugarcane (FAO, 2008). Brazil accounted for 34%, 19% and 37% of the world's production of sugarcane, sugar and ethanol, respectively. Brazil ranks as the world's second largest producer and world's first largest exporter of ethanol (ANFAVEA, 2006).

As ethanol in Brazil is made from sugarcane, sugar industry developments are now increasingly linked to policy initiatives in ethanol markets. Sugar represents a particularly important component of Brazil's economy, with the sugar/ethanol industry contributing 2% to national gross domestic product (Valdes, C. 2007). The country's relatively long history as a leading sugar producer and exporter reveals a complex linkage between the production of sugarcane, sugar and ethanol that has evolved as per capita income has grown and capital deepening has occurred. Sugarcane production increased by an annual average of 4.9 percent over the 2003-06 period and by 15.9 percent per year over the 2006-08 period. Ethanol production has grown from an annual average of 8.6 percent over the 2003-05 period to an annual average of 19.3 percent over the 2006-08 period while sugar production has grown by 5.6 and 6.4 percent per year over the same respective periods (ANP, 2010). Based on wdi data, this pace of sugarcane and ethanol production has exceeded the growth in real agricultural value added, which in turn has exceeded the rate of growth of the real value added by the country's industrial and service sectors of the economy on average over the same time intervals.

Two major factors are felt to contribute to this performance. First, capital

[1] There are two primary biofuels, ethanol and biodiesel. Brazil's biofuels are mainly sugarcane-based ethanol.

deepening tends to expand production of the capital intensive sectors, which in turn tends to increase the productivity of workers[2]. As wages rise and asset income grows, households increase their consumption of home goods. For home-good supply to respond to the increased demand, upward pressures are placed on the price of home-goods which allows producers of home goods to compete for resources otherwise pulled into the capital intensive sectors of the economy (unless the home good is capital intensive, then its price will tend to decline over time).

The other contributing factor to the growth of the bio-fuel sector has been improvement in the external terms of trade, induced indirectly by the rise in fossil fuel prices. Trostle (2008) documents the increase of 60 percent in world market prices for major food commodities such as grains and vegetable oils in the span of only two years (2007-08). He attributes this rise to an increase in demand for biofuels feedstock's, as well as weather and other less important factors. Others tend to place greater emphasis on the growth in biofuels production for the rise in food prices. Mitchel's World Bank paper (2008) argues that of the 140 percent increase in the World Banks's index of food prices from January 2002 to February 2008, three-quarters of this increase was due to biofuels and the related consequences of other associated factors. *An apparent paradox is that the real price of sugarcane has fallen by an average of 28 % since 1992, while production has increased. This outcome is possiblly linked to factor and product markets re-equilibrating as economic growth occurs.*

Though there is a plethora of literature modeling the economics of biofuels, most employ cost-accounting procedures and/or partial equilibrium frameworks (for example, Zuurbeler et al. (2009) or Birur et al. (2008) to name a few). More recently, static computable general equilibrium models have appeared that depict the biofuel sector in considerable detail (Reilly et al. (2007, Banse et al. 2007 and Al-Riffai et al. 2010 to name a few). One major problem of these CGE studies is that they do not provide a validating exercise of their models' forecasts. Moreover, they disaggregate the economy into so many sectors that it is difficult to reach a causation conclusion. In addition, they fail to depict the economic forces of structural transformation in which sectors of the economy compete for economy-wide resources in the process of economic growth, and hence these models poorly capture, if at

[2]Based on authors' own calculation from growth accounting which are discussed later.

all, the effects of possible impediments to growth on the biofuel sector or the dynamic effects of changes in a countries terms of trade over time.

This paper presents a theoretical framework as well as an empirical examination of the Brazilian biofuel sector and its links to sugarcane, sugar and fossil fuel production as the economy transitions toward long-run equilibrium. The model's basic structure has as its roots the endogenous saving structure of Ramsey (1928), Cass (1965) and Koopmans (1965).

The model features four fundamental advancements over other models of economic growth appearing in the literature, for example, Echevarria (1995, 1997, 2000) and more recently, Gollin et al (2004). First, it expands these models by including seven sectors. These sectors are industry, agriculture, services, sugar cane, sugar, ethanol and fossil fuels. Second, intermediate inputs of production are modeled, which captures sectoral linkages, as noted years ago by Hirschman (1958). Jones (2007) introduces intermediate inputs into a Solow economy and shows the multiplier effects of a productivity shock far exceed the same shock without intermediates. Third, the model's state variable, capital stock, is modeled as a composite of the outputs of the various sectors of the economy as suggested by the data, this feature causes the price of the capital asset to be endogenous, which in turn gives rise to a no arbitrage condition that affects households' holding of capital and land assets. This condition is used to impute the price households are willing to pay for sector specific assets, such as land devoted to the production of sugar cane and land devoted to the production of other agricultural goods. Fourth, the model also accounts for differences in labor skills since some sectors of the economy tend to be relatively labor skill intensive and others relatively unskilled labor intensive.

The next section discusses the background of the ethanol industry in Brazil and the nature of the problem. There are two problems addressed, the first is the relatively slow growth rates of the Brazilian economy, while the energy sectors have grown to the point where Brazil is the world's largest exporter of sugar and ethanol. Several papers have identified the cost of financial intermediation as an impediment to growth (Hausmann, R. et al. 2005, and Beck, T. 2000). If this impediment is adressed, it is of interest to analyze how the higher economic growth would affect the energy sector. The second problem addressed is that growth in world demand for biofuels is expected to rise, stimulated by policies in advanced countries. This increase in demand will put upward pressure on energy prices. Given the nature of the ethanol sector in Brazil, a price rise in ethanol will be accompanied by an increase in the fossil fuel and sugar prices (Valdes, C. 2007).

The following section briefly discusses the fitting of the model to data, calibration and growth accounting exercise. In the appendix B, we add a validation exercise to assess the models fit to the data both backward and forward from the point the model is fit to the economy's transition path; there it is shown that the model fits the data surprisingly well. Section four lays out the model where intra and inter-temporal equilibrium is characterized and special features of the model are highlighted. Section 5 summarizes the comparative statics used to later analyze the baseline results in section 6.

The remainder of the paper uses the model to address several questions of relevance to the cane-sugar-ethanol nexus. First, the implication of a reduction on the cost of financial intermediation in the economy is analyzed. In this case, the most capital intensive sectors (agriculture, cane and ethanol) experience more rapid growth than the base solution, and increase their shares in GDP, while sugar cannot compete for resources and decreases its production relative to the base. Higher factor income stimulates both intermediate and final demand for service goods, and the stronger effects of capital deepening dominate the more negative domestic terms of trade for industry and fossil fuels, for which growth exceeds the base solution. Last, land competitiveness for agriculture and cane increases as well as the rate effects in order to hold the no-arbitrage condition.

The second question addressed is how the economy and more specifically the nexus, responds to an increase on energy prices. Given the strong correlation between the prices of energy and sugar, an increase of 2.6 percent in the ethanol price, represents also an increase in the fossil fuel price of 2.06 percent and 1.4 percent for sugar. The direct effect of these prices increased is the expansion of the economy's production of ethanol and fossil fuel while sugar production declines due to counter veiling forces (own price rise versus cane price rise). Therefore, the indirect effect of these price changes is the increase in derived demand for cane causing its price to rise. Last, land competitiveness for cane increases while the rate effects are unchanged.

In all cases, the model replicates and explains the paradox suggested by the data where cane prices decline over time while production rises. Depending on the simulation cane price may be higher than the base, but ultimetly, it always declines over time. This effect is consistant with the data, and only a general equilibrium model is able to capture it. As capital deepening occurs, cane expands production since it is relatively capital intensive. This allows for its price to delcine, even tough the demand for cane increases over time from the ethanol and sugar sectors. The net effect of capital deepening and cane price decline is an increase in cane production.

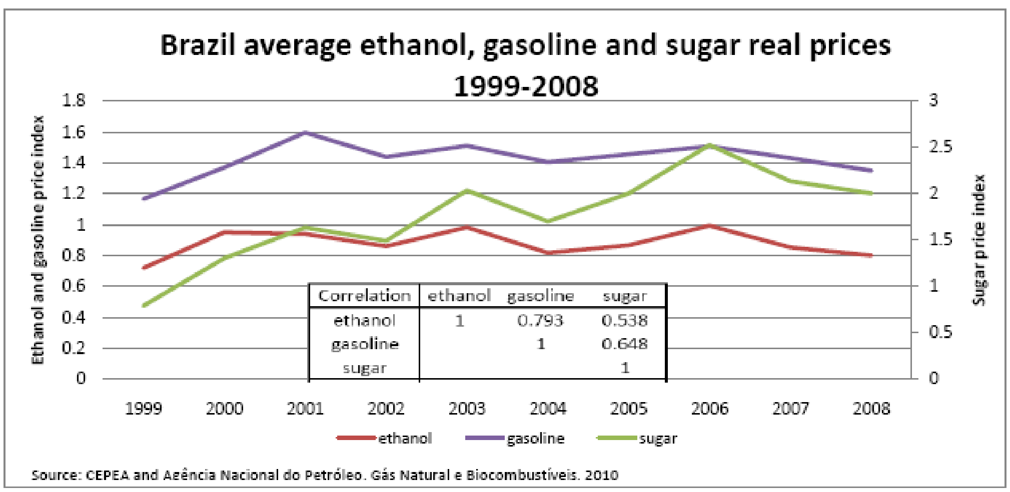
2 Background

While most of the world is initiating new ethanol research and development programs, Brazil already has a long and successful history with biofuels (Outlaw et. al.2007). This experience started in 1975, when the sharp rise in oil prices threatened the military dictatorship's ability to rule. At the time 90% of the gasoline was imported, causing fuel shortages, inflation, current account deficits, and diminished hard currency reserves. This lead the government to launch the Proalcool, the purpose of the new program was to stimulate domestic fuel ethanol supply obtained from sugarcane by means of aggressive market intervention. However, the ethanol industry had a setback in the 1990s due to cheap crude oil (Regaldo and Fan, 2007) and governmental deregulation, letting the ethanol and cane prices be determinate by market forces starting in 1997 (Portaria no. 64, March 1996). When oil prices began to soar in the recent years, ethanol became a more attractive alternative to gasoline, aided by the launch of flex-fuel vehicles (FFVs) in 2003. FFVs allows consumers to decide the mix proportion of ethanol and gasoline at every fill-up: pure gasoline, pure ethanol, and or a blend.

The growth in world demand for biofuels is stimulated by policies in advanced countries. In 2005, the EU started to require a 2% blend of ethanol in their gasoline. According to (Martines-Filho et al., 2006), this proportion is expected to increase to 5.75% by 2011. Sweden, an importer of Brazilian ethanol, now offers consumers a 20% tax break to purchase flex-fuel cars, special parking privileges, and no congestion charge for urban flex-fuel drivers. New laws to be passed in Japan will require that 3% of ethanol will be added to the gasoline. This means that a new market of 0.45 billion gallons/year will be created if this Japanese law is passed. Germany intends to add 2% in its gasoline. Negotiations are also evolving with China for ethanol exports from Brazil.

These forces put upward pressure on ethanol prices, according to the US energy information administration (2010) they are expected to increase by % 2.6. Valdes, C. (2007) reports the complex and strong relationship between ethanol, sugar and fossil fuels prices. This strong relationship is illustrated in Figure 1. On the right axis we measure ethanol and gasoline, while the left axis measures sugar. One can quickly see this high correlation that exists between these three sectors. This correlation was accentuated from 1999 when ethanol prices were completely deregulated. These data support the notion that Brazil experienced an improvement in her terms of biofuel trade in recent years. They also suggest that an analysis of these effects should consider the correlation between price changes.

Figure 1: Brazil's ethanol, gasoline & sugar average real prices 1999-2008



Another interesting aspect of the evolution of the ethanol sector in Brazil is that even though the ethanol sector has shown impressive growth rates since 2000 (14% per year on average), the Brazilian economy has exhibited relatively slow rate of economic growth overall since 1980s, with growth rates fluctuating in the two to three percent range. A substantial body of literature has tried to explain the reasons behind this stagnation, but recently, Hausmann et al. (2005) identify the cost of financial intermediation as the major constraint to growth following a growth diagnostics. If this impediment is addressed, it is likely that the rest of the economy's expansion pulls resources out from the energy sectors. At the same time, the direction could be reversed, depending on the energy sectors' relative capital intensity, which would cause them to expand relative to the rest of the economy.

3 Data and Calibration

A snapshot of the economy, aggregated to the level of the model presented in the next section, appears in table 1. The model has capitalized on available input-output data from the ERS, and from the Global Trade Analysis Project (GTAP) database, and is organized into a social accounting matrix (SAM) for the year 2004. Briefly, agriculture accounts for 9.6 percent of the country's GDP, employs about 20 percent of the work force, but only accounts for 5 percent of total wage payments, which it is mostly unskilled labor. Unskilled labor is defined according to ILO's occupation 4–9 (tradespersons, clerks, salespersons, machine operators, laborers, and farm workers) and skill workers are those in ILO occupations 1–3 (managers, professionals, and para-professionals). Sugarcane, sugar, ethanol and fossil fuels account for 0.31, 0.2, 0.65 and 0.93 percent respectively of the country's GDP. All together these sectors account for 0.8 percent of total wage payments, where the dominant share of this labor is unskilled.

Brazil has the third most advanced industrial sector in The Americas, accounting for 17 percent of the country's GDP, and employs 15 percent of the wage payments. About 13 percent of workers are classified as unskilled and 2 percent skilled. The country's service sector accounts for the remaining 71.5 percent of GDP. This sector employs about 79 percent of the total labor force, where 46 percent is unskilled and 33percent is unskilled.

The country spends 78 percent of the income, and therefore saves 22 percent. Labor is the main source of factor income with 36 percent of total factor income accruing to unskilled labor and 20 percent to skilled labor. Capital accounts for the next major share of income, equaling about 43 percent with most of the reminder of domestic income accruing to land.

Intermediate inputs account for 70.5 percent of manufactures gross output, and 63, 45, 79 and 42 percent of gross output for agriculture, cane, sugar and ethanol sectors, respectively. While own output accounts for the largest share of each sector's gross output (for industry, agriculture and service sectors), the service sector has the second largest share as an intermediate in each sector's gross output. In table 2, the relative sector factor intensities are also reported, showing that the ethanol, agriculture and cane sectors are relative capital intensive, sugar is unskilled labor intensive and the service sector is skill labor intensive. Factor intensities are important because they affect the evolution of firm level costs in transition growth and consequently differences in sectoral output.

Table 3.1: Social accounting matrix, Brazil in millions of 2004 USD.

Receipts:		Expenditures																					
		1. Activities							2. Commodoties							3. Factors				4. Institut	5. Cap.	6. Trade	7. Total
		Industry	Ag.	Cane	Services	Sugar	Ethanol	F.F.	Industry	Ag.	Cane	Services	Sugar	Ethanol	F.F.	K	L	Lh	T	HH	KA	WT	TT
1. Activities	Industry								311304														311304
	Ag.									127240												14744	141984
	Cane										3109												3109
	Services											580919											580919
	Sugar												1322									3897	5218
	Ethanol													3353								2811	6164
	F.F.														41473								41473
2. Commodi	Industry	134238	12167	526	49521	1117	179	24123												69903	38362		330136
	Ag.	4444	52272	267	9896	70	0	12												59384	895		127240
	Cane					1528	1581																3109
	Services	64993	21337	424	113012	1324	428	2590												294090	82719		580919
	Sugar			0																1322			1322
	Ethanol	1138	113	8	1858	3	4	228															3353
	F.F.	14732	3633	178	15639	71	428	9413															44094
3. Factors	K	46375	31231	1023	150904	334	2557	2873															235297
	L	38981	14138	395	138792	663	709	1770															195448
	Lh	6404	1224	14	101296	109	136	290															109473
	T	0	5868	273	0	0	143	174															6457
4. Institution	HH															235297	195448	109473	6457				546675
5. Cap. Acc	KA																			121977			121977
Trade	WT								18832	0	0	0	0	0	2621								21453
7. Total	TT	311304	141984	3109	580919	5218	6164	41473	330136	127240	3109	580919	1322	3353	44094	235297	195448	109473	6457	546675	121977	21453	

Source: GTAP and ERS (USDA), data in millions of 2004 USD

Table 3.2: Intermediate inputs usage and relative sector factor intensities

	Industry	Ag.	S.C.	Services	Sugar	Ethanol	FF
Industry[1]	0.431	0.086	0.169	0.085	0.214	0.029	0.582
Agriculture	0.014	0.368	0.086	0.017	0.014	0.000	0.000
Cane	0.000	0.000	0.000	0.000	0.293	0.256	0.000
Services	0.209	0.150	0.137	0.195	0.254	0.069	0.062
Sugar	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ethanol	0.004	0.001	0.003	0.003	0.001	0.001	0.006
FF	0.047	0.026	0.057	0.027	0.014	0.069	0.227
K intensity[2]	1.022	1.471	1.500	0.629	0.433	1.382	0.650
Lu intensity	0.739	0.369	0.302	0.550	1.498	0.138	0.314
Ls intensity	0.075	0.027	0.010	0.350	0.109	0.047	0.063

[1] Intermediate in real values divided by the gross output value

[2] Relative sector factor Intensities

The data upon which the parameters and initial conditions of the empirical model are based, are taken from three major sources, the WDI, ERS and GTAP7 data bases. First, using WDI data, a growth accounting exercise, based on perpetual inventory method, yields an estimate of the country's capital stock $K(0)$ for the base year, 2004. From an estimate of Solow's residual we obtain an estimate of the Harrod rate of factor productivity growth x, and trivially, the rate of growth of the labor force n. The rate of time preference parameter ρ is set to 0.04, a value that falls within the range commonly found in the literature[3].The estimated values are described in table 3.

Table 3: Parameters and initial conditions

δ	τ	ρ	θ	x	n	K(0) in 2004 Reais
0.04	0.115	0.05	1.00	0.0014	0.0194	2×10^{12}

Source: Author estimates and calculations using WDI, ERS and GTAP

This exercise also provides a breakdown of observed growth in GDP into factor contributions. If we accept the predicted long-run rate of growth of the model's level variables, we can calculate the long-run contributions of factors to GDP growth and contrast them with estimates obtained from the data. This comparison suggests "how far" the economy is from its long-run equilibrium (SS). These results are shown in Table 4. The first column reports the contribution of capital, labor and Solow's residual to growth in GDP for the 1975-2005 period. The last column shows the contributions if the economy were in steady-state equilibrium. This comparison suggests that the country is not in long-run equilibrium so additional capital deepening needs to occur in order to lower capital's contribution and to raise the contribution of labor.

Table 4: Contributions to GDP growth.

	Contribution at t<SS	Contribution at SS
Capital change Contribution	0.4932	0.4225
Labor change Contribution	0.3520	0.5316
Technical change Contribution	0.1548	0.0459

[3] See Agenor, Pierre Richard (2005).

The second main source of data, GTAP 7, is used to construct the social accounting matrix (table 1). However, since GTAP7 lacks more detailed data on ethanol and sugar, we use USDA (ERS) data for these activities and for their use in intermediate factor demand.

We assume Cobb-Douglas functional forms for all of the model's production functions, the household utility function as well as the composite capital function. Data reported in table 1 are used to estimate the parameters of these functions, including the input-output coefficients for intermediate inputs. The model is fit to these data so as to reproduce the social accounting matrix values as though they reflect the economy at this point on the transition path for the year 2004 with initial conditions given by these data. To provide confidence that the model captures the key structural features of the Brazilian economy, a validation exercise is conducted. We solve the model backwards and forward from the 2004 base year, and contrast model forecast with time series data of total and sector GDP taken from WDI over the 1995-to 2005 period. See Appendix B for a discussion of the validation results.

4 The model

4.1 Definition of the model

The modeled environment is a small open economy that produces seven goods, industry (Q_m), agriculture (Q_a), service (Q_s), sugar (Q_z), sugarcane (Y_c), ethanol (Y_ε) and fossil fuel (Y_g). Industry, agriculture, sugar, ethanol and fossil fuels are traded in domestic and international markets while sugarcane and the service good are only traded in the domestic economy. Surgarcane and fossil fuel are intermediate goods. Households are endowed with the economy's resources which include skilled (L_s), unskilled (L_u) labor, capital (K), and sector specific resources H_j, where $j = a, c, \varepsilon$ associated with agriculture (a), sugarcane (c), ethanol (ε) and fossil fuel (g). Labor and capital evolve over time. Capital is a composite, as suggested by data, of industrial, agricultural and service good components. The sector specific resources remain constant over time and their asset value adjusts so as to satisfy arbitrage conditions. The services of these sector specific resources are traded competitively among firms within but not between sectors. Households exchange the services of labor, capital and sector specific resources H_j for wages w_u (unskilled), and w_s (skilled), capital rents r, and sector specific resource rents π_j, respectively.

4.2 Behavior of households and firms

4.2.1 Households

Households are viewed as an immortal extended family with finite lives that take account of the welfare and resources of their prospective descendents. The representative household receives utility $u : \mathbb{R}^4_{++} \rightarrow \mathbb{R}_+$ from the sequence $\{q_m, q_a, q_s, q_z\}_{t\in[0,\infty)}$ expressed as a weighted sum of all future flows of utility

$$\int_{t\in[0,\infty)} u(q_m, q_a, q_s, q_z)e^{(n-\rho)t}dt$$

which it discounts at rate $\rho > 0$. The function $u(\cdot)$ is increasing and strictly concave in q_j, is everywhere continuous, and twice differentiable, and it is homothetic. The number of households' members is assumed to be proportional to the number of workers, to grow at the exogenously given positive rate n.

The household's intra-temporal problem is to choose (q_m, q_a, q_s, q_z) to minimize the cost ϵ of composite consumption q per worker

$$\epsilon = \mathcal{E}\left(p_m, p_a, p_s, p_z\right) q \equiv \min_{q_m,q_a,q_s,q_z} \left\{ \sum_{j=q_m,q_a,q_s,q_z} p_j q_j \mid q \leq u(q_m, q_a, q_s, q_z) \right\}$$

where (p_m, p_a, p_s, p_z) are the respective prices of each good. At each instant in time, $\mathcal{E}\left(p_m, p_a, p_s, p_z\right)$ represents the price (cost) of aggregate consumption q. Shephard's lemma gives the Hicksian demand,

$$q_j = q^j(p_m, p_a, p_s, p_z)q \quad j = m, a, s, z$$

which is homogeneous of degree zero in prices p_j.

The representative household's budget constraint expressed in per worker terms is given by

$$\begin{aligned}\dot{k} &= \frac{1}{p_k}(w_u l_u + w_s l_s + kr^k(1-\tau) + \pi_a H_a + \pi_c H_c + \\ &\quad \pi_\varepsilon H_\varepsilon + \pi_g H_g - \mathcal{E}\left(p_m, p_a, p_s, p_z\right) q) - k\left(n+\delta\right) + T\end{aligned}$$

where p_k, defined below, is the price of a unit of capital stock k, and $\tau \geq 0$ is a tax on capital, the reasons for which we point out later. At the end of each period the tax revenue T is returned to the household in lump sum. This constraint is derived based on the assumption that the no arbitrage condition between the returns received by households from loans and returns to capital is satisfied, as well as the no arbitrage condition between a unit of composite capital k, and a unit of land

$$r = \frac{r^k(1-\tau)}{p_k} - \delta + \frac{\dot{p}_k}{p_k} = \frac{\pi_j}{p_{Lj}} + \frac{\dot{p}_{Lj}}{p_{Lj}} + n \tag{1}$$

where $p_{hj} = p_{Lj}/p_k$ is the price of the $j-th$ sector's specific resource per worker, p_{Lj}, relative to the unit of capital p_k,where $j = a, c, \varepsilon, g$. This condition assures that capital and land prices adjust throughout transition growth so that agents have no incentive to exchange one asset for another at any point in time.

Household's problem of maximizing the discounted present value of utility subject to the budget constraint and a transversality condition, leads to the Eurler condition

$$\frac{\dot{\epsilon}}{\epsilon} = \frac{1}{\theta}\left[\frac{r^k(1-\tau)}{p_k} - \delta - \rho - (1-\theta)\frac{\dot{p}_s}{p_s} + \frac{\dot{p}_k}{p_k}\right]$$

where here we assume unitary inter-temporal elasticity of substitution so that $\theta = 1$. Since below our variables are expressed in effective labor units, it is convenient to express this condition in effective units as well, which results in the condition, for $\theta = 1$,

$$\frac{\dot{\hat{\epsilon}}}{\hat{\epsilon}} = \frac{r^k(1-\tau)}{p_k} - \delta - \rho - x + \frac{\dot{p}_k}{p_k}$$

4.2.2 Composite capital

Recognizing that a country's stock of capital is composed of more than industrial goods, capital is modeled as a composite of the output of industrial, agriculture and services goods. These goods are presumed to be combined in a least cost manner to produce a unit of capital stock at each t. Following Roe et al. (2010), the problem is

$$p_k = c^k\left(p_m, p_a, p_s\right) \equiv \min_{y_{mk}, y_{ak}, y_{sk}} \left(\sum_{j=m,a,s} p_j \hat{y}_{jk} \mid 1 \leq F\left(\hat{y}_{mk}, \hat{y}_{ak}, \hat{y}_{sk}\right) \right)$$

where for purposes here $F(\cdot)$ is a neoclassical Cobb-Douglas function that is CRS in its arguments. Thus, at each instant in time, we have the result that the total cost of capital provision from savings $\dot{\hat{k}} + \hat{k}\left(x + n + \delta\right)$ is

$$p_k \left[\dot{\hat{k}} + \hat{k}\left(x + n + \delta\right) \right]$$

where Shephard's lemma applied to $c^k\left(p_m, p_a, p_s\right)$ retrieves the components y_{mk}, y_{ak}, y_{sk} of composite capital. Finally, note that

$$\frac{\dot{p}_k}{p_k} = \lambda_{sk} \frac{\dot{p}_s}{p_s} \tag{2}$$

where λ_{sk} is the cost share of y_{sk} in the total cost of producing an increment of capital stock in each t. Thus, the Euler condition can be restated as

$$\frac{\dot{\hat{\epsilon}}}{\hat{\epsilon}} = \frac{r^k(1-\tau)}{c^k\left(p_m, p_a, p_s\right)} - \delta - \rho - x + \lambda_{sk} \frac{\dot{p}_s}{p_s}$$

4.2.3 Firms

Firms in each sector are atomistic and identical. Firms producing industrial, service and sugar goods employ technology $f^j : \mathbb{R}^3_{++} \rightarrow \mathbb{R}_+$ defined as $Min\left\{ f^j(A\left(t\right) l_{uj}, A\left(t\right) l_{sj}, k_j), \frac{y_{mj}}{\sigma_{mj}}, \frac{y_{aj}}{\sigma_{aj}}, \frac{y_{sj}}{\sigma_{sj}}, \frac{y_{zj}}{\sigma_{zj}} \right\}$ $j = m, s, z.$, where $A\left(t\right) = e^{xt}$ and x is the Harrod rate of growth in effective labor services, l_{uj}, and l_{sj} denote the quantity of skilled and unskilled workers, respectively, σ_{mj} are input-output coefficients and y_{ij} denotes the amount of the $i-th$ sector output employed as an intermediate input in sector j. The corresponding sectoral total cost functions, expressed in units per effective economy-wide worker, are given by:

$$TC_j = \left(C^j(\hat{w}_u, \hat{w}_s, r^k) + \sum_{i=m,a,s,c,z,\varepsilon,g} p_i \sigma_{ij} \right) \hat{y}_j \quad j = m, s, z.$$

where $\hat{y}_j$ is sector $j's$ gross output per effective worker.

Agricultural, sugarcane, ethanol and fossil fuel technologies are represented by the representative firm production functions $f^j : \mathbb{R}^4_{++} \to \mathbb{R}_+$, defined as

$$\min \left\{ f^j(A(t)\, l_{uj}, A(t)\, l_{sj}, k_j, \mathcal{B}(t)\, h_j), \frac{y_{mj}}{\sigma_{mj}}, \frac{y_{aj}}{\sigma_{aj}}, \frac{y_{sj}}{\sigma_{sj}}, \frac{y_{zj}}{\sigma_{zj}} \right\} \quad j = a, c, \varepsilon, g.$$

where h_j is the quantity of the sector specific resource employed by the representative firm, and $\mathcal{B}(t) = e^{vt}$ is the exogenous growth of land productivity[4].

Given H_j fixed, and given f^j is linearly homogeneous in all inputs, the sectoral aggregate technology, denoted $F^j(A(t)\, L_{uj}, A(t)\, L_{sj}, K_j; \mathcal{B}(t)\, H_j)$, exhibits decreasing returns to scale in inputs L_{uj}, L_{sj}, and K_j.

The corresponding value added functions (in units per effective worker) for these sectors are given by

$$\pi^j(p_{vj}, \hat{w}_u, \hat{w}_s, r^k) H_j, \;\; j = a, c, \varepsilon, g$$

where p_{vj} is the $j-th$ value added price of gross output, and H_j is not treated as a choice variable at the sector level. By Hotelling's lemma, sectors' partial equilibrium supply functions are given by

$$y^j(p_{vj}, \hat{w}_u, \hat{w}_s, r^k) H_j = \pi^j_{p_j}(p_{vj}, \hat{w}_u, \hat{w}_s, r^k) H_j \qquad j = a, c, \varepsilon, g.$$

A perfectly competitive market for the services of the each sector's specific resource among sector producers implies that the shadow price $\pi^j(p_j, w_u, w_h, r)$

[4] To maintain an autonomous system of differential equations it is necessary that $\upsilon = x + n$. We refer to this restriction as a sustainability condition which assures balanced growth in the long-run.

is also the rental price that causes the market for these services to clear among individual producers. Thus, the representative firm in this sector makes zero profits since, in equilibrium, the value of output is exhausted by payments to factors,

$$p_{vj}\hat{y}_j = \hat{w}_u l_{ua} + \hat{w}_s l_{sa} + r^k \hat{k}_j + \pi^j(p_{vj}, \hat{w}_u, \hat{w}_s, r^k)h_j \quad j = a, c, \varepsilon, g.$$

4.3 Equilibrium characterization

Restricting analysis to the case where all sectors are open, i.e. $Y_j > 0 \quad j = m, a, c, s, z, \varepsilon, g$ a competitive equilibrium is defined by the positive prices $\{\hat{w}_u, \hat{w}_s, r^k, p_c, p_s\}_{t\in[0,\infty)}$of inputs and output, household consumption plans

$$\Omega^h \equiv \{q_m^*, q_a^*, q_s^*, q_z^*\}_{t\in[0,\infty)}$$

and production plans

$$\begin{aligned}\Omega^m \equiv & \{\hat{y}_m^*, \hat{y}_a^*, \hat{y}_c^*, \hat{y}_s^*, \hat{y}_z^*, \hat{y}_\varepsilon^*, \hat{y}_g^*, \hat{k}_m^*, \hat{k}_a^*, \hat{k}_c^*, \hat{k}_s^*, \hat{k}_z^*, \hat{k}_\varepsilon^*, \hat{k}_g^*, l_{um}^*, l_{ua}^*, l_{uc}^*, \\ & l_{us}^*, l_{uz}^*, l_{u\varepsilon}^*, l_{ug}^*, l_{sm}^*, l_{sa}^*, l_{sc}^*, l_{ss}^*, l_{sz}^*, l_{s\varepsilon}^*, l_{sg}^*\}_{t\in[0,\infty)}\end{aligned}$$

given initial resource endowments $\{\hat{k}(0), L_u(0), L_s(0), H_j\}$ such that the discounted present value of household utility is maximized, firms maximize profit subject to their technology at each instant of time t, and markets clear for all inputs and the outputs. In addition, the no-arbitrage condition between the values of capital and land, and the transversality condition are satisfied.

4.3.1 Intra-temporal equilibrium

Given the endogenous sequence $\{\hat{k}, \hat{\epsilon}\}_{t\in[0,\infty)}$,intra-temporal equilibrium is given by the sequence of positive values $\Omega \equiv \{\hat{w}_u, \hat{w}_s, r^k, \hat{y}_m, \hat{y}_s, \hat{y}_z, p_s, p_c\}_{t\in[0,\infty)}$ satisfying the following eight equations for each t:

- Zero profit conditions in sector m, s, z

$$\begin{aligned}C^m\left(\hat{w}_u, \hat{w}_s, r^k\right) &= p^{vm}\left(p_s\right) \\ C^s\left(\hat{w}_u, \hat{w}_s, r^k\right) &= p^{vs}\left(p_s\right) \\ C^z\left(\hat{w}_u, \hat{w}_s, r^k\right) &= p^{vz}\left(p_c, p_s\right)\end{aligned}$$

where p_{vj} is the value added price of sector j.

- Unskilled labor market clearing,

$$\sum_{j\in m,s,z} C^{j}_{\hat{w}_u}\left(\hat{w}_u,\hat{w}_s,r^k\right)\hat{y}_j-\pi^{a}_{\hat{w}_u}\left(p^{va}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_a-$$
$$\pi^{c}_{\hat{w}_u}\left(p^{vc}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_c-\pi^{\varepsilon}_{\hat{w}_u}\left(p^{v\varepsilon}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k,\right)hH_\varepsilon-$$
$$\pi^{g}_{\hat{w}_u}\left(p^{vg}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_g=\ell_u$$

- Skilled labor market clearing,

$$\sum_{j\in m,s,z} C^{j}_{\hat{w}_s}\left(\hat{w}_u,\hat{w}_s,r^k\right)\hat{y}_j-\pi^{a}_{\hat{w}_s}\left(p^{va}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_a-$$
$$\pi^{c}_{\hat{w}_s}\left(p^{vc}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)h_c-\pi^{\varepsilon}_{\hat{w}_s}\left(p^{v\varepsilon}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_\varepsilon-$$
$$\pi^{g}_{\hat{w}_s}\left(p^{vg}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_g=\ell_s$$

- Capital market clearing,

$$\sum_{j\in m,s,z} C^{j}_{r^k}\left(\hat{w}_u,\hat{w}_s,r^k\right)\hat{y}_j-\pi^{a}_{r^k}\left(p^{va}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_a-$$
$$\pi^{c}_{r^k}\left(p^{vc}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)h_c-\pi^{\varepsilon}_{r^k}\left(p^{v\varepsilon}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k,\right)H_\varepsilon-$$
$$\pi^{g}_{r^k}\left(p^{vg}\left(p_c,p_s\right),\hat{w}_u,\hat{w}_s,r^k\right)H_g=\hat{k}$$

- Clearing of the domestic market for home good including the intermediate demands,

$$\frac{\lambda_s\hat{\epsilon}}{p_s}=y_s-\sum_{j\epsilon m,a,c,s,z,\varepsilon,g}\sigma_{sj}\hat{y}_j-\hat{y}_{sk}\left[\dot{\hat{k}}+\hat{k}\left(x+n+\delta\right)\right]$$

where ℓ_u is the unskilled share of the total work force which remains constant because both labor categories grow at the same rate.

- Derived demand-supply of sugarcane[5]:

$$\sigma_{cz}\hat{y}_z-\frac{\partial\pi^{\varepsilon}\left(p_{v\varepsilon},\hat{w}_u,\hat{w}_s,r^k\right)H_\varepsilon}{\partial p_{v\varepsilon}}\frac{\partial p_{v\varepsilon}}{\partial p_c}-\pi^{c}_{p_c}\left(\hat{w}_u,\hat{w}_s,r^k,p_c\right)H_c=0$$

[5] Recall that the cost of sugar production is

To derive the inter-temporal system of equations, it is useful to reduce the dimensionality of the intra-temporal system by replacing the supply variables $\hat{y}_j$ with their functional forms, see Appendix A for the steps to solve the system of equations for three variables, p_s, p_c and $\hat{k}$.

4.3.2 Inter-temporal equilibrium

Inter-temporal equilibrium can be reduced to three first order and autonomous differential equations that express closed form functions of $\dot{\hat{k}}, \dot{p}_s, \dot{p}_c$ in terms of the level equivalents. These variables can be obtained from the:

- Euler equation

$$\boldsymbol{E}\left(p_s, p_c, \dot{p}_s\right) \equiv \dot{\hat{\epsilon}} = \hat{\epsilon}\left(\frac{\tilde{r}(p_s, p_c)(1-\tau)}{c^k\left(p_m, p_a, p_s\right)} - \delta - \rho - x + \lambda_{sk}\frac{\dot{p}_s}{p_s}\right)$$

- Budget Constraint

$$\tilde{K}\left(p_s, p_c, \hat{k}\right) \equiv \dot{\hat{k}} = \frac{1}{c^k\left(p_m, p_a, p_s\right)}[\tilde{w}^u\left(p_c, p_s\right)\ell_u + \tilde{w}^s\left(p_c, p_s\right)\left(\ell_s\right) +$$

$$\tilde{r}(p_s, p_c)(1-\tau)\hat{k} + \tilde{\pi}^a\left(p_s, p_c\right)H_a + \tilde{\pi}^c\left(p_s, p_c\right)H_c + \tilde{\pi}^\varepsilon\left(p_s, p_c\right)H_\varepsilon +$$

$$\tilde{\pi}^g\left(p_s, p_c\right)H_g - \mathcal{E}\left(p_m, p_a, p_s, p_z\right)q] - \hat{k}\left(n + \delta + x\right) + T$$

- Service goods market clearing condition

$$\hat{\epsilon} = \frac{p_s}{\lambda_s}[y_s - \sum_{j\epsilon m,s,z}\sigma_{sj}\tilde{y}^j\left(p_s, p_c, \hat{k}\right) - \sum_{j=a,c,\varepsilon,g,}\sigma_{sj}\tilde{y}^j\left(p_s, p_c\right)$$

$$TC_z = \left[C^z\left(\hat{w}, \hat{w}_h, r^k\right) + \sum_{i\epsilon m,a,s,e,g}\sigma_{iz}p_i + \sigma_{cz}p_c\right]\hat{y}_z$$

and rents to ethanol production is given by $\pi_\varepsilon = \pi^\varepsilon\left(p_{v\varepsilon}, \hat{w}, \hat{w}_h, r^k\right)H_\varepsilon$. Then, market clearing is given by

$$\frac{\partial TC_z}{\partial p_c} + \frac{\partial TC_\varepsilon}{\partial p_c} = \frac{\partial \pi^c\left(\cdot\right)H_c}{\partial p_c}$$

$$-\tilde{y}^{sk}\left(p_s, p_c\right)\left(\dot{\hat{k}} + \hat{k}\left(x+n+\delta\right)\right)]$$

where

$$\tilde{\pi}^j\left(p_s, p_c\right) \equiv \pi^j(p^{vj}\left(p_t, p_s\right), \tilde{w}^u\left(p_s, p_c\right), \tilde{w}^s\left(p_s, p_c\right), \tilde{r}(p_s, p_c))$$

These equations are linear in variables $\dot{p}_s, \dot{\hat{k}}$ and $\dot{\hat{\epsilon}}$. The equations are easily rearranged to yield one closed-form differential equation for each dot variable as a function of their corresponding level variables. To solve for the steady state, (if it exists) we set $\dot{p}_s, \dot{\hat{k}}$,and $\dot{\hat{\epsilon}}$ to zero, and solve empirically for the endogenous level variables $p_c^{ss}, p_s^{ss}, \hat{k}^{ss}$. Given these values, the intratemporal system permits the determination of the steady state values of the remaining endogenous variables, Ω, and consequently, Ω^h and Ω^m.

The time elimination method[6] is used to obtain solution values for the sequence $\{p_c, p_s, \hat{k}\}_{t\in[0,\infty)}$. The dimensionality of the model permits the calculation of the remaining endogenous variables

$$\left\{\Omega, \Omega^h, \Omega^m\right\}_{t\in[0,\infty)} \tag{3}$$

[6] See Chapter 9, Roe et al.

5 Comparative statics

The comparative static properties of the model are similar to properties discussed in the simpler model presented by Roe et al (2010), Chapter 5,and are thus briefly stated. The intra-temporal conditions admit to a comparative static analysis along the lines of the Stopler-Samuelson (Sto-Sa) and Rybcyznski (Ry) theorems of the static 2x2 model of a small open economy[7]. .The reduced form factor rental rate equations obtained from solving the zero profit conditions are homogenous of degree one in output prices, and hence Sto-Sa-like results can be obtained. That is, Sto-Sa-like in the sense that if the price of a final good that employs a factor intensively rises, it is not necessarily the case that the rental rate of this factor will rise in greater proportion to the increase in price.

The supply functions are homogeneous of degree zero in prices and of degree one in factor endowments. Consequently, Ry-like qualitative results can be obtained. When capital deepening occurs, the unit cost of capital declines, while the marginal product of labor increases in all sectors, but relatively more so in sectors that are most capital intensive (agriculture, sugarcane and ethanol in our case, see table 2 for relative factor intensities). These sectors then experience a growth in output while the sector employing labor most intensively will experience a decline in output, all else constant. However, the proportional change in output may be less than the proportional change in capital stock.

In the case of home good sectors where the domestic markets must clear, growth in total factor income causes an increase in the price of the service good that is necessary in order for the sector to compete for resources that would otherwise be pulled into the traded good sectors. This effect can be viewed as having Sto-Sa-like affects on factor rental rates[8].

We rely on the well known properties of the indirect profit function $\pi^j(\cdot)$ to explain the supply and factor demand behavior of sectors employing a

[7]See Woodland (1982) for the statement and proof of these theorems when the 2x2 model is expressed in dual form or Feenstra (2004).

[8]This prediction depends upon the relative capital intensity of the service sector. If the service sector is the most capital intensive, price of the service good falls which in turn can also result in improving the domestic terms of trade for traded goods.

sector specific resource. Overall, this logic forms the basis of our explanation below of the model's solution showing the structural transformation as the economy approaches long-run equilibrium.

To provide insights into the incentives for households to change the level of the sector specific resource H_j, we draw upon the differential equation given by the no arbitrage condition (1). Solving this differential equation yields[9].

$$\hat{p}_{h_j}(t) = \int_t^{\infty} e^{-\int_t^{\tau}(r(v)-x-n-\frac{\dot{p}_k}{p_k})dv} \frac{\hat{\pi}_j}{p_k} d\tau \tag{4}$$

where $\hat{p}_{h_j}(t)$ is the value of the $j-th$ sector specific resource per worker at time t relative to the price of capital $p_k(t)$ required for households to have no incentive to exchange one asset for another at any t[10].If the price of capital p_k was unity throughout transition, the price of land $p_{h_j}(t)$ indicates the amount of capital that could be exchanged for one hectare of land. However, since prices are adjusting to satisfy the no arbitrage condition, agents have no incentive to make such a trade. These asset values are likely to evolve differently because the evolution of sector rent $\pi_j(t)$ is not necessarily monotonic, factor intensities vary among sectors and domestic terms of trade effects also vary depending upon intermediate input demand. The "un-normalized" value of $p_{h_j}(t)$ is given by $p_{hj}(t)\, p_k(t)\, L(0)\, e^{nt}/H_j$.This is the unit value the representative household is willing to pay to acquire an additional unit of the sector specific resource H_j, all else constant. For the case of agriculture or sugarcane production where resources are likely required to convert one type of land use to another or to "harvest" other lands to make them suitable for cultivation, the evolution of $p_{h_j}(t)$ provides insights into the

[9] From the no arbitrage condition and solving for $\dot{\widehat{p}}_{hj}$ we get: $\dot{\widehat{p}}_{hj} = \widehat{p}_{hj}[r-\frac{\dot{p}_k}{p_k}-n-x]-\frac{\widehat{\pi}_j}{p_k}$ Solving the differential equation we get:

$$\widehat{p}_{hj}(t) = e^{\int_0^t(r(\tau)-n-x-\frac{\dot{p}_k}{p_k})d\tau}[\widehat{p}_{hj}(0) - \int_0^t e^{-\int_0^t(r(\tau)-n-x-\frac{\dot{p}_k}{p_k})d\tau}\frac{\widehat{\pi_j}}{p_k}dt]$$

This equation can be solved for any $T \geqq 0$,and then taking the limit as $T \to \infty$, and using the transversality condition, the equation, for any t, becomes:

$$\widehat{p}_{hj}(t) = \int_t^{\infty} e^{-\int_t^{\tau}(r(v)-n-x-\frac{\dot{p}_k}{p_k})dv}\frac{\widehat{\pi_j}}{p_k}d\tau$$

[10] See Nichols (1970) for one of the earlier derivations of this result and Roe et al (2010) for a more recent treatment. This equation is the solution to (1)

effect of economic growth on incentives to expand or contract the quantity of cultivatable lands.

6 Base model results

We present an overview of results with an emphasis first on levels of key endogenous variables and then an explanation of the underlying forces of transition growth giving rise to these results. We place relatively more emphasis on our main focus; the sugarcane - ethanol - sugar -fossil fuel sectors of the economy.

6.1 An economy-wide overview

The main results are presented in four tables. The model predicts a GDP rate of growth of 2.40 percent for the year 2005 (in constant 2004 USD), which is close to the 2.3 percent reported in the WDI for that year and close to the average annual rate over the 2000-05 period of 2.56 percent. Total GDP doubles in 30 years. However, over the fifty year period 2004-54, GDP per capita only increases from 2,972 to 3,217 in constant 2004 USD (Table 6.a, col. 1). This relatively small increase is due to the country's population growth rate in the neighborhood of 1.94 percent per annum. This increase suggests the country's potential to increase households' real income from transition growth is limited with about 79, years required to double GDP per capita, assuming the average annual rate of population growth remains at the 2004-06 average of 1.94 percent per annum. The result stands in contrast to Chile. Her GDP per capita will double in about 22 years if the rate of growth in real GDP per capita remains at the 2004-06 average while for Latin America and the Caribbean the corresponding number of years is about 32.

The evolution of factor earnings is reported in table 6.a. Over the 2004-14 period, per worker earnings increased from \$2,636 to \$2,684 for unskilled workers and from \$6,717 to \$6,842 for skilled workers, (table 6.a, columns 3 and 4). This increase averages about 1.9 percent for each category. The stock of capital per worker increases by 2.4 percent.

Table 6.a: Evolution of GDP, factor earnings per worker and savings to GDP in constant 2004 USD, model results.

	GDP /cap.	K /wkr	U wage /wkru	S wage /swkr	K earnings	Exp /wkr	Sav /GDP
2004	2972	26305	2636	6717	2595	4428	0.270
2014	3029	26942	2684	6842	2645	4522	0.268
2024	3079	27452	2728	6954	2688	4601	0.268
2034	3126	27904	2769	7059	2729	4673	0.267
2044	3171	28329	2810	7162	2769	4743	0.267
2054	3217	28744	2850	7265	2809	4811	0.267

	AG.Farm Earn /(farm wkr)	S.C.Farm Earn /(farm wkr)	Ethnaol earn /(E. wkr)	FF. Earn /(f.f. wkr)	Price of S.C.	Price of Service
2004	928	1794	5232	3397	1.000	1.000
2014	947	1827	5329	3459	0.998	1.001
2024	964	1857	5415	3515	0.998	1.001
2034	979	1885	5497	3568	0.997	1.001
2044	993	1912	5577	3620	0.997	1.001
2054	1008	1939	5657	3672	0.997	1.001

The level of gross output of all sectors relative to the year 2004 is shown in the top panel of table 6.b. Gross output of the economy's major sectors, industry, agriculture, and service, double within the 2034 to 2044 time range.

Table 6.b: Evolution of sectoral production and share in GDP

	Relative to 2004: Gross production of						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.23	1.25	1.23	1.24	1.21	1.25	1.23
2024	1.52	1.55	1.51	1.53	1.48	1.54	1.52
2034	1.87	1.92	1.86	1.88	1.81	1.90	1.88
2044	2.30	2.36	2.29	2.32	2.22	2.35	2.31
2054	2.84	2.91	2.82	2.86	2.74	2.89	2.85
	Sector share in GDP						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	0.168	0.096	0.003	0.715	0.002	0.006	0.009
2014	0.167	0.097	0.003	0.715	0.002	0.007	0.009
2024	0.167	0.097	0.003	0.715	0.002	0.007	0.009
2034	0.167	0.097	0.003	0.715	0.002	0.007	0.009
2044	0.167	0.098	0.003	0.715	0.002	0.007	0.009
2054	0.167	0.098	0.003	0.715	0.002	0.007	0.009

The bottom panel of the table shows these sectors maintain their shares of about 16 percent, 9 percent and 71 percent of GDP, respectively, over time, and hence the change in the structure of the economy is relatively modest.

Primary agriculture's share in GDP typically for most countries decline as GDP grows. Brazilian agriculture seems not typical of other countries. Over the 2000-08 period, primary agriculture as a share of GDP has fallen for Chile (from 6.1 to 4.2 percent), Mexico (from 4.2 to 3.7 percent), the US (from 1.2 to 1.1 percent), as well as on average for middle income countries (from 11.0 to 9.6 percent), while for Brazil, primary agriculture has trended upward from 6.5 to 6.7 percent over this period (WDI).

The model's agricultural sector, which includes food processing (and hence a larger share in GDP than reported by WDI) appears consistent with these data. Owing to the relatively high growth rate of output, ethanol increases its share in GDP from 0.6 percent in 2004 to 0.7 percent in 2054, and doubles output by the year 2034. The growth in ethanol production exceeds the growth in production of sugar, which indicates that a greater proportion of cane production, over time, is being allocated to ethanol than to the production of sugar.

The growth rates in sectoral gross output of the major sectors of the economy (industry, agriculture and services) are not markedly different, although agriculture shows a higher annual rate of growth than all other sectors (Table 6.c and 6.d). Since the model features balanced growth, all sectors converge to the same rate of growth in the long-run. Four sectors converge to this long-run rate from above; from the highest to the lowest rate of convergence these are agriculture, ethanol, service and fossil fuels. From the highest to the lowest rate of convergence from below are Sugar, sugarcane and industry.

These patterns of growth are determined by contributing factors shown in the tables. They are calculated using the model's supply functions. The factors are internal terms of trade, capital stock, labor force growth, and technical change effects. For sector with specific factors, we find it useful to measure the resource effects through their effects on wages and capital rents.

Table 6.c: Growth decomposition for industry, agriculture and services

Industry		Contribution of		
Year	Growth in Gross Output	Value added price	Capital Stock	Effective Labor
2004	0.0209	-0.0121	0.1941	-0.1610
2014	0.0209	-0.0059	0.1887	-0.1619
2024	0.0209	-0.0028	0.1861	-0.1624
2034	0.0209	-0.0014	0.1848	-0.1626
2044	0.0209	-0.0007	0.1842	-0.1627
2054	0.0209	-0.0003	0.1839	-0.1627

Agriculture		Contribution of				
Year	Growth in Gross Output	Value added price	Unskilled wage	Skilled wage	Interest rate	Technical change
2004	0.0228	-0.0003	-0.0015	-0.0001	0.0038	0.0209
2014	0.0218	-0.0001	-0.0007	-0.0001	0.0018	0.0209
2024	0.0213	-0.0001	-0.0003	0.0000	0.0009	0.0209
2034	0.0211	0.0000	-0.0002	0.0000	0.0004	0.0209
2044	0.0210	0.0000	-0.0001	0.0000	0.0002	0.0209
2054	0.0209	0.0000	0.0000	0.0000	0.0001	0.0209

Service		Contribution of		
Year	Growth in Gross Output	Value added price	Capital Stock	Effective Labor
2004	0.0214	0.0006	0.0000	0.0209
2014	0.0211	0.0003	0.0000	0.0209
2024	0.0210	0.0001	0.0000	0.0209
2034	0.0209	0.0001	0.0000	0.0209
2044	0.0209	0.0000	0.0000	0.0209
2054	0.0209	0.0000	0.0000	0.0209

Table 6.d: Growth decomposition for cane, sugar, ethanol and fuels

Sugarcane

Year	Growth in Gross Output	Value added price	Unskilled wage	Skilled wage	Interest rate	Technical change
2004	0.0204	-0.0023	-0.0009	0.0000	0.0027	0.0209
2014	0.0206	-0.0011	-0.0004	0.0000	0.0013	0.0209
2024	0.0207	-0.0005	-0.0002	0.0000	0.0006	0.0209
2034	0.0208	-0.0003	-0.0001	0.0000	0.0003	0.0209
2044	0.0208	-0.0001	0.0000	0.0000	0.0001	0.0209
2054	0.0208	-0.0001	0.0000	0.0000	0.0001	0.0209

Sugar

		Contribution of			
Year	Growth in Gross Output	Value added price wrt cane	Value added price wrt services	Capital Stock	Effective Labor
2004	0.0184	0.9345	-0.2178	-11.4408	10.7425
2014	0.0196	0.4591	-0.1067	-11.3069	10.9741
2024	0.0202	0.2240	-0.0520	-11.2414	11.0896
2034	0.0206	0.1089	-0.0253	-11.2096	11.1465
2044	0.0207	0.0529	-0.0123	-11.1941	11.1742
2054	0.0208	0.0256	-0.0059	-11.1866	11.1877

Ethanol

Year	Growth in Gross Output	Value added price	Unskilled wage	Skilled wage	Interest rate	Technical change
2004	0.0223	0.0002	-0.0003	-0.0001	0.0016	0.0209
2014	0.0215	0.0001	-0.0001	0.0000	0.0007	0.0209
2024	0.0212	0.0001	-0.0001	0.0000	0.0004	0.0209
2034	0.0210	0.0000	0.0000	0.0000	0.0002	0.0209
2044	0.0209	0.0000	0.0000	0.0000	0.0001	0.0209
2054	0.0209	0.0000	0.0000	0.0000	0.0000	0.0209

F.F.

Year	Growth in Gross Output	Value added price	Unskilled wage	Skilled wage	Interest rate	Technical change
2004	0.0211	-0.0001	-0.0004	-0.0001	0.0008	0.0209
2014	0.0210	0.0000	-0.0002	0.0000	0.0004	0.0209
2024	0.0209	0.0000	-0.0001	0.0000	0.0002	0.0209
2034	0.0209	0.0000	0.0000	0.0000	0.0001	0.0209
2044	0.0209	0.0000	0.0000	0.0000	0.0000	0.0209
2054	0.0209	0.0000	0.0000	0.0000	0.0000	0.0209

We next use these results to explain the main economic forces determining the country's growth path.

6.2 Major economic forces of transition growth

The basic economics of transition growth can be explained as follows. As capital deepening occurs[11], the relatively most capital intensive sectors of the economy (e.g., agriculture, ethanol, sugarcane) experience a Rybczynski-like (Ry) effect by employing proportionately more capital, which increases the productivity of labor in these sectors relative to the labor intensive sectors of the economy (service for skilled labor and industry and sugar for the unskilled labor). The rise in the productivity of labor in the capital intensive sectors, all else constant, causes these sectors to increase the quantity of labor demanded which can only be obtained by an increase in the wage rates. Labor intensive sectors thus experience a rise in production costs in spite of the decline in the rental rate of capital. The effect of these forces dampens, as the economy reaches its long-run equilibrium. Because of price changes for the service good and sugarcane, these capital deepening effects can be dampened or outweighed by changes in the domestic terms of trade.

The terms of trade effect arise from domestic changes in intermediate input and final good demand. The rise in factor income from growth in wages, the stock of capital and sector specific factor rents, augments the quantity demanded of all final goods, as well as the quantity for intermediate inputs employed in production. In order for the service sector's market to clear, its price must rise (Table 6.a), as shown by the contribution of an increase in the sector's value added price to growth in service sector output (Table 6.c), to compete for the resources that would otherwise be employed in the capital intensive sectors. The price of the service good therefore also converges from below to its long-run value. If a sector is capital intensive and its output price is determined in the domestic market, as is the case with sugarcane, then it is possible for capital deepening to lower the cost of production to such a degree that the domestic market for sugarcane clears at a lower price (Table 6.a). In this case, the price of sugarcane declines and converges from above to its long-run value. This effect lowers the cost of sugarcane as an input into the processing of ethanol and sugar.

For agriculture, industry and ethanol, the positive effects of capital deep-

[11] In transition growth, the growth in capital stock exceeds the rate of growth in the labor force. All else equal, these Rybczynski effects exceed the same effects from the growth in the labor supply.

ening dominate the effects of growth in labor services (as can be seen for these sectors by contrasting the capital stock column with the effective labor column and the interest rate effect column with the wage effect column, Table 6.c and 6.d). Ethanol recieves an additional positive effect from price effects due to the decline in sugarcane prices, which accounts for about 25 percent of the total cost of ethanol production. These are the major effects causing the growth of these sectors to converge from above to their long-run rate of output growth.

The service sector's main source of growth is due to growth in effective labor supply followed by the positive terms of trade effect while capital effect is virtually null. Fossil fuel production's convergence from above to its long-run equilibrium, though only slightly higher than that of industry, is due to its capital intensity and hence the lowering of cost due to the decline in capital rents tending to dominate the negative effects of the rise in wages for skilled and unskilled workers. Like industry, agriculture and ethanol's domestic terms of trade effects are negative. The magnitude of these effects depend upon the share of service good, as an intermediate input, in their total production costs. Ethanol producers also pay for sugarcane, whose price is endogenous. Since the price paid for sugarcane falls, as discussed below, this tends to dampen the negative effect of the rise in price of the service good that ethanol producers must purchase as an intermediate input.

Only sugarcane and sugar experience output growth convergence from below to their long-run growth rate. Brazil is one of the world's major sugarcane producers, and data show cane production to be capital intensive. The rise in the price of the service sector (a non-traded good) contributes to a decline in the internal terms of trade for the internationally traded goods. In the case of sugarcane, its price declines over time, while its production rises. The model validates well the observed decline in cane price, Appendix B, figure 6. This apparent paradox is due to the fact that cane is a relatively capital intensive sector, cane production expands as capital deepening occurs, which puts downward pressure on cane price. On the other hand, the increase in cane demand from ethanol and sugar sectors pressure the cane price to rise. The net effect is a decline in cane price because the capital deepening effect outweighs the demand effect. Hence the negative effects reported in Table 6.d, column 3. The positive effect of capital deepening on cane production (Table 6.d, column 6) outweighs the negative sugarcane price effect on production. Over time, the negative effect from the decline in sugarcane price dampens relative to the positive effect of capital accumulation. The net result of these effects causes increasing growth in cane production.

For the sugar sector, the decline in cane prices has positive effects on its production but this is dampened by the increase in the service good price (Table 6.d, column 3 and 4). The net effect is positive since cane accounts for 29.3 percent of the total cost of sugar production versus about 25 percent for services as an intermediate input. The growth in labor services has also a positive effect since sugar is unskilled labor intensive. These effects dominate the effect of capital deepening (which is negative, since sugar is the least capital intensive). The net dampening effect of these forces causes an increase in the growth of sugar production over time.

Capital deepening has also an effect on the value of sector specific resource as given by equation (1). The results reported in table 6.e are expressed in terms of value per hectare for the case of agriculture and sugarcane. These are the prices that need to prevail so that agents have no incentive to sell one asset in exchange for another. These sector specific resources are mostly embodied by land, although they also include pasture land and other resources specific to just that sector. Table 6.e shows that over time, land in these sectors is becoming scarce relative to the capital asset.

Table 6.e: Price of land evolution for agriculture and sugarcane

Year	Ag. value of land/Ha	Cane value of land/Ha	Growth rate	Growth rate
2004	485	1221		
2014	596	1491	22.94%	22.07%
2024	725	1807	21.62%	21.20%
2034	872	2170	20.30%	20.09%
2044	1035	2572	18.62%	18.52%
2054	1202	2987	16.19%	16.14%

Since returns to capital are falling in the presence of capital deepening, while returns to land remain relatively constant over the transition path (Table 6.f), the price of land in either sector rises in order to sustain the no arbitrage condition (Table 6.e). Land in agriculture has a different price from that in cane because they really are different resources. From equation 1, one can see that the differences in land values between agriculture and sugarcane are largely determined by the differences between the returns to land of each sector $(\pi_a(t) - \pi_c(t))$ since the rest of the variables are the same for each sector. Table 6.f shows the evolution of the returns to land for agriculture and sugarcane and their respective growth rates. The positive growth rates for agriculture signal that the returns to agriculture land converge from above the steady state, on the other hand, the negative growth rates for cane signal that cane returns to land converge from bellow to its steady state values[12]. Given these growth rates it follows that growth in cane land price is smaller than the growth in agricultural land price (Table 6.f).

Table 6.f: Returns to land evolution for agriculture and sugarcane.

Year	πa/Ha	πc/Ha	Growth rate	Growth rate
2004	18.18	47.00		
2014	18.44	46.68	1.40%	-0.68%
2024	18.56	46.53	0.67%	-0.33%
2034	18.62	46.46	0.33%	-0.16%
2044	18.65	46.42	0.16%	-0.08%
2054	18.66	46.40	0.08%	-0.04%

Last, the evolution of land prices also suggests how much a household is willing to pay for an incremental increase in the stock of the sector specific resource, all else constant. To convert other lands to agricultural or to cane land almost surely requires resources to carry out. So it is unknown whether the results suggest incentives for "harvesting" of other otherwise unused lands. If so, one might expect incentives exist to expand land areas in cane and agriculture.

[12] Total differentiation of agriculture and cane rents will determine convergency:

$$\frac{\dot{\pi}_a}{\pi_a} = \underbrace{-\overbrace{\frac{L_a \hat{w}_u}{\pi}\frac{\dot{\hat{w}}_u}{\hat{w}_u}}^{(-)} \overbrace{-\frac{L_a \hat{w}_s}{\pi}\frac{\dot{\hat{w}}_s}{\hat{w}_s}}^{(-)} \overbrace{-\frac{K_a}{\pi}\frac{\dot{r}^k}{r^k}}^{(+)}}_{(+= \text{from above})} \text{ and } \frac{\dot{\pi}_c}{\pi_c} = \underbrace{\overbrace{\frac{Y_c^p}{\pi}\frac{\dot{p}}{p}}^{(-)} \overbrace{-\frac{L_a \hat{w}_u}{\pi}\frac{\dot{\hat{w}}_u}{\hat{w}_u}}^{(-)} \overbrace{-\frac{L_a \hat{w}_s}{\pi}\frac{\dot{\hat{w}}_s}{\hat{w}_s}}^{(-)} \overbrace{-\frac{K_a}{\pi}\frac{\dot{r}^k}{r^k}}^{(+)}}_{(-=\text{from below})}$$

6.3 Effects of a decrease in the cost of domestic financial intermediation

The cost of financial intermediation is reported to be 11.5 percent in Brazil (Caprio and Levine, 2001), which it is significantly higher than the average for many other Latin American and upper middle income grouping of countries. In order to analyze the effect of this tax in the Brazilian energy sectors, this is reduced to 8.5 percent with respect to the base. Lowering intermediation costs increases the capital interest received by households while lowering the capital rental payments of firms, for each t. Those sectors that are most capital intensive experience more rapid growth than in the base solution. The effects on the economy thus modify the forces discussed for the base solution, but do not reverse them. Discussion is focused on the degree these forces are modified.

Table 6.g reports the results of this simulation relative to the base solution. Lowering the cost of financial intermediation results in a higher level of GDP, 2.2 percent higher by 2024, but the rate of growth converges to the same rate as the base, x+n. Consequently, growth rates are higher in the earlier periods of transition than the base.

Table 6.g: Effect of a domestic financial intermediation cost reduction relative to the baseline.

	GDP	Real exp.	Savings	Cane Price	Service Price	Cane to Sugar	Cane to Ethanol
2004	1.000	0.974	1.071	1.000	1.000	1.000	1.000
2014	1.015	0.995	1.052	0.995	1.002	0.943	1.032
2024	1.022	1.006	1.043	0.993	1.003	0.913	1.048
2034	1.025	1.011	1.039	0.991	1.003	0.899	1.056
2044	1.027	1.013	1.036	0.991	1.003	0.891	1.059
2054	1.028	1.014	1.035	0.991	1.004	0.888	1.061

Now, households have an incentive to save more, but still are able to increase the real expenditure's relative to the base solution (Table 6.g, column 3 and 4).

The capital intensive sectors (agriculture and ethanol in this case) experience stronger Ry-like effects, increasing output compared to the base line results by 6.4 percent for agriculture and by 4.8 percent for ethanol by 2024

(Table 6.h). At the same time, their shares in GDP increase at a higher rate than the base (Table6.h, column 3,4 and 7). The case of cane is special, because even though it is capital intensive, its production increases at a decreasing rate of growth with respect to the base over time; this is due to its price declining at a higher rate than the base. Growth in cane production is 1.7 percent lower by 2024 than in the base (Table 6.h, column 4). The decline in cane prices "off-sets" the positive effect of capital deepening.

The decline in cane prices lowers the cost of ethanol and sugar production relative to the base. However, the differences in the cost of ethanol and sugar production cause the growth in ethanol production to rise faster than base and sugar production to rise slower than base. Hence, relative to base, intermediate demand for cane in the production of ethanol rises and it falls for sugar (Table 6.g, column 7 and 8). Ethanol production rises relative to base because of the positive effects of capital deepening and a decline in cane prices that dominate, to a greater extent than that of the base, the larger negative terms of trade effect and the rise in wage effects. All these effects together cause ethanol and agriculture's production to exceed the growth in output of the rest of the sectors.

Thus, agriculture, cane and ethanol's increased competition for resources again comes at the expense of the relatively labor intensive sectors, sugar and service, which experience an even higher rise in production costs compare to the base. The service sector competes for resources by increasing its price even more now, 0.3 percent more than the base by 2024 (Table6.g, column 6).

On the other hand, the sugar sector cannot increase its price, so it is less able to compete for these resources relative to the base solution. At the same time, sugar production costs have raised compared to the base, since the price of services and wages increased relative to base. Therefore, sugar production increases over time at a decreasing rate compare to the base, by 2024 it is 8.7 percent lower now than the base (Table 6.h, column 6). The only positive effect on sugar production cost is the decline on cane prices but this effect is not sufficient to outweigh the negative effects. Effectively, sugar has to compete for cane with the ethanol sector, which has become relatively more competitive due to the mentioned effects.

Industry and fossil fuel sectors cannot increase their prices to compete for resources. Nevertheless, relative to base, the "stronger" Ryb effects of capital deepening dominate the more negative terms of trade effects so growth in their gross outputs exceed the base solution.

Reducing the cost of financial intermediation thus increases agriculture, cane and ethanol production, while higher factor income stimulates both intermediate and final demand for service goods (Table 6.h).

Table 6.h: Effect of a domestic financial intermediation cost reduction for each sector relative to base.

	Relative to baseline: Gross production of						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	1.001	1.000	1.000	1.000	1.000	1.000	0.998
2014	1.002	1.043	0.989	1.012	0.943	1.032	1.002
2024	1.002	1.064	0.983	1.018	0.913	1.048	1.004
2034	1.002	1.075	0.980	1.021	0.899	1.056	1.005
2044	1.002	1.080	0.979	1.022	0.891	1.059	1.006
2054	1.002	1.082	0.978	1.023	0.888	1.061	1.006
	Share of sector value added in GDP						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	1.001	1.000	1.000	1.000	1.000	1.000	0.983
2014	0.987	1.028	0.966	1.000	0.934	1.020	0.972
2024	0.979	1.041	0.949	1.000	0.900	1.029	0.967
2034	0.976	1.048	0.941	1.000	0.884	1.034	0.965
2044	0.974	1.051	0.937	1.000	0.876	1.036	0.964
2054	0.973	1.052	0.936	1.000	0.872	1.037	0.963

Last, the decrease in the cost of capital intermediation also has an effect on the land value for agriculture and cane. The results in table 6.i are expressed relative to the base values, and can be observed that land value competitiveness of agricultural and cane increases as well as the rate effects. This is due to the fact that now capital deepening occurs more rapidly and since both sectors are relatively capital intensive, their land prices now need to increase more relative to the base in order to hold the no-arbitrage condition.

Agriculture's land price rises then by 10.9 percent in earlier years and up to 14.4 percent in the long run relative to the base. In the case of cane, the land price raises by around 2 percent compare to the base for all periods, this increase is more modest than in agriculture because the capital deepening effect is dampened by the cane price effect, which now decreases more rapidly than in the base.

Table 6.i: Price of land evolution for agriculture and sugarcane relative to the base.

Year	Ag. value of land/Ha	Cane value of land/Ha	Growth rate	Growth rate
2004	1.109	1.023		
2014	1.138	1.029	2.63%	0.58%
2024	1.150	1.029	1.03%	0.04%
2034	1.152	1.026	0.22%	-0.27%
2044	1.150	1.021	-0.23%	-0.47%
2054	1.144	1.015	-0.52%	-0.64%

Now, agriculture and cane firms have more command over the economy's resources, so the returns to agricultural land rises by 4.2 percent in 2004, but increases up to 8 percent in the long run with respect to the base. In the case of cane, since the price of cane is falling more rapidly now, this is not overcomed by capital deepening and therefore, returns to cane land decrease with respect to the base by 2 percent in ealier periods and up to 4 percent in the long run.

Table 6.j: Returns to land evolution for agriculture and sugarcane.

Year	πa/Ha	πc/Ha	Growth rate	Growth rate
2004	1.000	1.000		
2014	1.042	0.980	4.25%	-2.05%
2024	1.063	0.969	2.00%	-1.03%
2034	1.073	0.965	0.96%	-0.51%
2044	1.078	0.962	0.47%	-0.25%
2054	1.081	0.961	0.23%	-0.12%

6.4 Effects of a price increase in the ethanol sugar and fossil fuel sectors

The world demand for Brazilian ethanol is expected to increase since many countries are changing their policies to encourage the substitution of biofuels for fossil fuels (Martines-Filho et al., 2006). While it is well known that primary commodity prices are highly correlated (Krichene 2008), the production of ethanol has been one of the factors linking the increase in world corn and sugar prices to the rise in the price of fossil fuels (Trostle 2008, Mitchell, 2008) The correlation between Brazilian ethanol, sugar and gasoline prices are shown in Figure 2. A report from the U.S. Energy Information Administration (2010) expects the real price of ethanol to increase by 2.6% next year. Therefore, increasing the price of ethanol in the model requires that we also account for the correlation with real market prices of sugar and petroleum. Using the correlation coefficients reported in Figure 2, implies that an increase in the real price of ethanol of 2.6 percent is likely to be associated with an increase in the price of sugar of 1.4 percent and an increase in the real price of fossil fuel of 2.06 percent.

The impact of these price changes on the economy and on the sugarcane - ethanol - sugar - fossil fuel markets in particular, depend mostly on the following fours factors: first, the positive external terms of trade effect of a rise in the price of ethanol and sugar, which Brazil exports. Second, the negative terms of trade effect of the rise in fossil fuel prices, which Brazil imports. Third, the domestic terms of trade effects from the change in the cane prices (non-internationally traded good), and last, the relative factor intensities of the various sectors as factor markets re-equilibrate and sectoral production costs change. The resulting net effect of these four features in some cases are counter veiling, as they move in opposite directions; in the case of sugar the positive external terms of trade is dampened by the domestic terms of trade, which are explained below.

Nevertheless, the fundamental forces of transition growth of the base model remain unchanged, only changes in their magnitudes are altered, and in terms of GDP and other macro-aggregates, little change is found. We thus begin the discussion of the results by focusing on the sectors most strongly affected by the price changes.

The direct effects of raising ethanol, sugar and fossil fuel prices are the expansion of the economy's production of ethanol, and fossil fuel relative to the base solution, while sugar production declines (due to the net effect of the four factors mentioned above). Ethanol increases gross output production by 12.2 percent per annum, fossil fuel increases by about 2.3 percent per annum, while sugar production decreases by 2 percent per annum initially and by 2.4 percent in later years (Table 6.k).

Table 6.k: Effect of a price increase in ethanol, sugar and fossil fuels sectors on gross production and sector shares relative to base.

	Relative to baseline: Gross production of						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	0.994	1.001	1.052	1.000	0.980	1.122	1.023
2014	0.994	1.001	1.052	1.000	0.978	1.122	1.023
2024	0.994	1.001	1.052	1.000	0.977	1.122	1.022
2034	0.994	1.001	1.052	1.000	0.977	1.122	1.022
2044	0.994	1.001	1.052	1.000	0.976	1.122	1.022
2054	0.994	1.001	1.052	1.000	0.976	1.122	1.022
	Share of sector value added in GDP						
Year	Industry	Agricu-lture	Cane	Services	Sugar	Ethanol	Fossil Fuel
2004	0.994	1.001	1.063	0.999	0.980	1.170	1.020
2014	0.994	1.001	1.063	0.999	0.978	1.170	1.019
2024	0.994	1.001	1.063	0.999	0.977	1.170	1.019
2034	0.994	1.001	1.063	0.999	0.976	1.170	1.019
2044	0.994	1.001	1.063	0.999	0.976	1.170	1.019
2054	0.994	1.001	1.063	0.999	0.976	1.170	1.019

Cane is employed in the production of ethanol and sugar. One of the indirect effects of these price changes is an increase in derived demand for cane causing its price to raise by 0.5 percent relative to base, and to remain above its base for all t (Table l). Nevertheless, as in the base solution, the cane price converges to its long-run equilibrium from above.

Table 6.l: Effect of a price increase in ethanol, sugar and fossil fuels sectors relative to base.

	GDP	Cane Price	Service Price	Cane to Sugar	Cane to Ethanol
2004	1.000	1.005	1.000	0.980	1.122
2014	1.000	1.005	1.000	0.978	1.122
2024	1.000	1.005	1.000	0.977	1.122
2034	1.000	1.005	1.000	0.977	1.122
2044	1.000	1.005	1.000	0.976	1.122
2054	1.000	1.005	1.000	0.976	1.122

The effect of a cane price rise relative to the base can be divided into the direct and the indirect effect on the domestic internal terms of trade. The rise in cane price relative to unchanging prices of the rest of the goods motivates producers to increase sugarcane production (gross output is 5.2 percent above base values for all t, table 6.k). The indirect effect is to dissuade the employment of cane as an intermediate factor of production in ethanol and sugar. However, these effects are greater for sugar than ethanol since cane accounts for 29% of the gross value added for sugar compared to 25 % for ethanol (Table 6.l, column 5 and 6). The 1.4 percent rise in sugar price is insufficient to cover the rise in costs of production, resulting in a decrease in sugar production by 2 percent with respect to the base, while the ethanol sector's price increase overcomes these costs and raises production by 12.2 percent. Hence, relative to the base, intermediate demand for cane in the production of ethanol rises and it falls for sugar, in spite of the increase in the price of sugar (Table 6.k, column 6 and 7).

The last major factor contributing to the economy-wide effects of these price changes is the relative factor intensities of the various sectors as factor markets re-equilibrate. In order for ethanol's gross output to increase relative to the base, the sector must pull resources from the rest of the economy. Given that ethanol is capital intensive, the sector increases the quantity of capital employed relative to the base for all t, and consequently the quantity of both skilled and unskilled labor increase (see Table 6.k).

Industry's unit cost of production rise primary due to the raise on energy prices, which account for 5 percent of total cost of production. Therefore, its gross output declines relative to the base by 0.6 percent for all t. Industry and sugar thus release capital and labor resources to the other sectors relative to the base solution.

The services and agriculture sectors are barely affected by the change in prices, the service sector price is the same as in the base solution, and rises as capital deepening occurs. Agriculture's gross output rises by 0.1 percent with respect to the base for all t. This result obtains because the rise in energy prices and countervailed by the decline in labor and capital costs.

Last, the energy prices change also has an effect on the value of land for agriculture and cane. The results in table 6.m are expressed relative to the base values; in this case, the price of agricultural land and its returns to land barely change, increasing both by a 0.1 percent relative to the base. On the other hand, the competitiveness of the cane land increases but the rate effects remain mostly unchanged. Cane firms have more command over the economy's resources, so the returns to cane land rises by 6.2 percent with respect to the base. The price of cane land also rises by 6.2 percent with respect to the base, which reflects that, all else constant, there is an increased incentive to convert other lands to cane.

Table 6.m: Evolution of prices and returns to land for agriculture and sugarcane relative to the base.

Land prices

Year	Ag. value of land/Ha	Cane value of land/Ha	Growth rate	Growth rate
2004	1.001	1.062		
2014	1.001	1.062	0.01%	0.01%
2024	1.001	1.062	0.01%	0.01%
2034	1.001	1.062	0.00%	0.00%
2044	1.001	1.063	0.00%	0.00%
2054	1.001	1.063	0.00%	0.00%

Returns to land

Year	πa/Ha	πc/Ha	Growth rate	Growth rate
2004	1.001	1.062		
2014	1.001	1.062	0.02%	0.01%
2024	1.001	1.062	0.01%	0.01%
2034	1.001	1.063	0.00%	0.00%
2044	1.001	1.063	0.00%	0.00%
2054	1.001	1.063	0.00%	0.00%

7 Conclusion

Approximately 90% of the world's commercially produced energy is obtained from non-renewable fossil fuels such as crude oil, coal, and gas (Birur et al. 2008). In order to enhance energy security and independence, many countries, such as Brazil, have supported the production and use of renewable energy sources such as biofuels. According to Martines et al. 2006, Brazil is the only country in the world able to produce ethanol from sugarcane at sufficiently low costs to be competitive. As ethanol in Brazil is made from sugarcane, sugar industry developments are now increasingly linked to policy initiatives in ethanol markets. Sugar represents a particularly important component of Brazil's economy, with the sugar/ethanol industry contributing 2% to national gross domestic product (Valdes, C. 2007) which places Brazil as the world's largest exporter of sugar and ethanol (ANFAVEA, 2006). A complex linkage between the production of sugarcane, sugar and ethanol has evolved as per capita income has grown and capital deepening has occurred.

Two major factors are felt to contribute to the growth of biofuels, one of which is due to the fundamental forces of capital deepening and the other to the improvement in the external terms of trade, induced indirectly by the rise in fossil fuel prices and the complex inter-linkages with the sugar sector.

Though there is a plethora of literature modeling the economics of biofuels, one major problem of these studies is that they do not provide a validating exercise of their models' forecasts. In addition, they fail to depict the economic forces of structural transformation in which sectors of the economy compete for economy-wide resources in the process of economic growth, and hence these models poorly capture, if at all, the effects of possible impediments to growth on the biofuel sector or the dynamic effects of changes in a countries terms of trade over time.

The unique contribution of this study is to analytically and empirically examine the interaction between Brazil's economic growth and the evolution of the bio-fuel sector and its links to sugar cane, sugar and fossil fuel production as the economy transitions toward long-run equilibrium. The study fits to Brazilian data to a Ramsey-like model with seven sectors, depicting interconnections of the economy through various channels. The study also provides insights into what extent the structure of the economy changes over time, and whether such transition forces differ from the base solution given different initial conditions.

The baseline model result shows Gross Domestic Product per capita increases marginally over the fifty year period 2004-2055, 2,972 to 3,217 in constant 2004 USD. This increase suggests the country's potential to increase household's real income per capita from transition growth is somewhat limited requiring 79 years to double income, thus suggesting that impediments to growth are embodied in the data and hence in the model's parameters.

Brazilian agriculture seems not typical of other countries, as it is capital intensive. The basic underlying economic forces of transition growth are such that increase the agricultural and ethanol sectors' share in GDP, while the rest of the sectors' share decrease or remain unchanged. Accompanying this transition is capital deepening in all sectors of the economy, rising wages and sector specific rents. More specifically, for the case of agriculture and cane, the sector specific is mainly land, the evolution of land price is evaluated for each sector, and both are expected to rise as capital deepening occurs. Land prices also suggest how much a household is willing to pay for an incremental increase in the stock of land, all else constant. To convert other lands to agricultural or to cane land almost surely requires resources to carry out. So it is unknown whether the results suggest incentives for "harvesting" of other otherwise unused lands. If so, one might expect incentives exist to expand land areas in cane and agriculture.

The rise in the price of the service sector (a non-traded good) contributes to a decline in the internal terms of trade for the internationally traded goods. In the case of sugarcane, the other non-traded good, its price declines over time, while its production rises. Only a general equilibrium model is able to see that due to the fact that cane is a relatively capital intensive sector, cane production expands as capital deepening occurs to such an extent that the growth in derived demand for cane from ethanol and sugar cause the market clearing price of cane to fall, as the capital deepening effect outweighs the demand effect.

A the same time, the decline in cane prices lowers the cost of sugarcane as an input into the processing of ethanol and sugar. Therefore, for ethanol, the positive effect of capital deepening and decline of cane prices dominate the negative effect of service sector rise in price. In the case of sugar, the net effect of price changes in the nontrade goods is positive as cane accounts for a higher percent of sugar's production than the service sector, but given that sugar is relatively unskilled labor intensive, its share in GDP declines over time.

Two simulations are performed: decreasing the domestic cost of financial intermediation and increasing the price of ethanol, sugar and fossil fuels. Decreasing the domestic cost of financial intermediation increases the incentive for households to save which in turn increases the country's rate of capital deepening. While capital deepening induces all sectors to increase output, the most capital intensive sectors tend to increase output over base line values to the largest degree. Competition for resources causes the share of the agricultural and ethanol sectors in GDP to increase (since they are relatively capital intensive), while sugar cannot compete for resources and decreases its production relative to the base. Higher factor income stimulates both intermediate and final demand for service goods, and the stronger effects of capital deepening dominate the more negative terms of trade for Industry and fossil fuels, for which growth exceeds the base solution. The case of cane is special, because even though it is capital intensive, its production increases at a decreasing rate of growth with respect to the base over time; this is due to its price declining at a higher rate than the base. Last, land competitiveness for agriculture and cane increases as well as the rate effects in order to hold the no arbitrage condition.

The direct effect of increasing ethanol, sugar and fossil fuel prices are the expansion of the economy's production of ethanol and fossil fuel while sugar production declines due to counter veiling forces (own price rise versus cane price rising). Therefore, the indirect effect of these price changes is the increase in derived demand for cane causing its price to rise. Last, land competitiveness for cane increases while the rate effects are unchanged.

8 Appendix A

To derive the inter-temporal system of equations, it is useful to reduce the dimensionality of the intra-temporal system by replacing the supply variables $\hat{y}_j$ with their functional forms.

From zero profit we obtain

$$\hat{w}_u = \tilde{w}^u (p_s, p_c) \equiv W^u(p_{vm}, p_{vs}, p_{vz})$$

$$\hat{w}_s = \tilde{w}^s (p_s, p_c) \equiv W^s(p_{vm}, p_{vs}, p_{vz})$$

$$r^k = \tilde{r}(p_s, p_c) \equiv R(p_{vm}, p_{vs}, p_{vz})$$

These equations are homogeneous of degree zero in prices; however, p_s and p_c are endogenous variables. Nevertheless, these equations can be substituted into the factor market clearing equations for $W^u (p_{vm}, p_{vs}, w_s), W^s (p_{vm}, p_{vs}, w_s)$ and $R(p_{vm}, p_{vs}, w_s)$. Since the resulting equations are linear in output, we easily obtain the supply functions

$$\hat{y}_j = \tilde{y}^j \left(p_s, p_c, \hat{k}\right), \ j = m, s, z$$

The supply function for agriculture, sugarcane, ethanol and fossil fuels can be expressed in output price alone by substituting the rental rate equations into the partial equilibrium supply function for $j = a, c, \varepsilon, g$ to obtain

$$\hat{y}_a = \tilde{y}^a (p_s, p_c) \equiv y^a \left(p^{va}, \hat{w}_u, \hat{w}_s, r^k\right) H_a \equiv \frac{\partial \pi^a (p^{va} (p_t, p_s), \hat{w}_u, \hat{w}_s, r^k) H_a}{p_{va}}$$

$$\hat{y}_c = \tilde{y}^c (p_s, p_c) \equiv y^c \left(p^{vc}, \hat{w}_u, \hat{w}_s, r^k\right) H_c \equiv \frac{\partial \pi^c (p^{vc} (p_t, p_s), \hat{w}_u, \hat{w}_s, r^k) H_c}{p_{vc}}$$

$$\hat{y}_\varepsilon = \tilde{y}^\varepsilon (p_s, p_c) \equiv y^\varepsilon \left(p^{v\varepsilon}, \hat{w}_u, \hat{w}_s, r^k\right) H_\varepsilon \equiv \frac{\partial \pi^\varepsilon (p^{v\varepsilon} (p_t, p_s), \hat{w}_u, \hat{w}_s, r^k) H_\varepsilon}{p_{v\varepsilon}}$$

$$\hat{y}_g = \tilde{y}^g (p_s, p_c) \equiv y^g \left(p^{vg}, \hat{w}_u, \hat{w}_s, r^k\right) H_g \equiv \frac{\partial \pi^g (p^{vg} (p_t, p_s), \hat{w}_u, \hat{w}_s, r^k) H_g}{p_{vg}}$$

Thus, the home good market clearing condition can be expressed as

$$\hat{\epsilon} \;=\; \tilde{\epsilon}(p_s, p_c, \hat{k}) \equiv \frac{p_s}{\lambda_s}(\tilde{y}^s(p_s, p_c, \hat{k}) - \sum_{j\epsilon m,s,z} \sigma_{sj}\tilde{y}^s_j(p_s, p_c, \hat{k}) -$$

$$\sum_{j\epsilon a,c,\varepsilon,g} \sigma_{sj}\tilde{y}^s_j(p_s, p_c) - \lambda_{sk}\hat{y}^{sk}\left(p_m, p_a, p_s\right)\left[\dot{\hat{k}} + \hat{k}\left(x + n + \delta\right)\right]$$

The clearing condition for the ethanol sector becomes,

$$\varepsilon mk\left(p_s, p_c, \hat{k}\right) \equiv \sigma_{cz}\tilde{y}^z\left(p_s, p_c, \hat{k}\right) - \frac{\partial\pi^{\varepsilon}\left(p^{v\varepsilon}\left(p_t, p_s\right), \hat{w}_u, \hat{w}_s, r^k\right)H_{\varepsilon}}{\partial p_{v\varepsilon}} \frac{\overbrace{\partial p_{v\varepsilon}}^{=\sigma_{c\varepsilon}}}{\partial p_c} -$$

$$\pi^c_{p_c}\left(p_c, \hat{w}_u, \hat{w}_s, r^k\right)H_c$$

9 Appendix B

9.1 Confronting model forecasts to the data

Numerical measures of the model's forecast accuracy are reported in table 15. Pearson's correlation coefficient provides a linear measure of the correlation between the data and the forecast without accounting for differences in the level of the variables in the two series. As can be seen in table 15, the correlation in each sector and GDP is extremely high. Lin's (1989) concordance correlation measure is bounded between zero and unity, and accounts for discrepancies between the means of the two series. The result of this measure tells us that the Economy's agricultural sector has the lowest correlation. The mean absolute error is relatively lower for the GDP's forecast and pretty high for Agriculture. Theil's U statistic is unbounded from above with smaller values indicating a closer fit to the data. This measure also tends to show the predicted values for GDP to be lower than in the case of the other sectors, agriculture is again relatively high. But overall, these measures show that the model's forecast accuracy is pretty high.

Table 15: Measures of the model's forecast accuracy, 1995-2005.

Measure	Economy GDP	Agriculture GDP	Industry GDP	Service GDP
Correlation Coefficient	0.9868	0.9858	0.9315	0.9891
Concordance Correlation Coefficient	0.0102	0.1036	0.0136	0.0816
Theil's U Statistic	0.0451	0.6457	0.4823	0.4001
Mean Absolute Error (%)	4.26	64.95	48.19	39.67

9.2 Validation results

The reluctance to validate structural models has been one of the main critiques leading to some skepticism as to their value in explaining and predicting economic events. Many early practitioners of applied general equilibrium models dismissed the need for validation. Kehoe (2003) suggests ex-post performance evaluations of applied general equilibrium models are essential if policy makers are to have confidence in the results produced by them.

Typically, the model provides the trajectory for a larger set of variables than are available in the form of time series data. We limit our comparison of model predictions to economy and sectoral GDP which we contrast with data taken from the WDI. Model predictions are indicated by the dashed line in Figure 4. The model is fit to the data such that the initial year is 2001 and then solved to provide predictions backward to 1995 and forward. The upper left-hand chart shows the model's forecast of GDP value added in terms of GDP's value in the base year 2001. The three remaining charts express sector value added in terms of the respective sector value in the base year 2001. The reason for this normalization is because of differences in GDP and sector's definitions.

Briefly, the problem is that the International Standard Industrial Classification (ISIC) defining the sectors in the WDI data are not the ideal classification needed for the model. For example, agriculture corresponds to ISIC divisions 1-5 in the WDI data. This division includes crop and animal agriculture, hunting and related service activities, forestry, fishing and mining of coal. Food products are included in manufacturing. Thus, the ISIC 1-5 aggregation for agriculture is not an appropriate characterization of the sector's output, if in the modeled economy; the sector's output is treated as a final good. The additional subsectors in agriculture cause the model's agriculture GDP to exceed that of the WDI by about 23 percent in the initial year 2001. Similar adjustments are made to the GDP, industrial and service sectors, which cause industrial sector GDP to exceed that of the WDI by 17 percent, while the service sector and GDP are underestimated by the model by 35 percent and 17 percent respectively.

In spite of the differences between the WDI and model's definition of sectoral GDP, the predicted values should show a similar trend to the data if the model captures some of the fundamental structural features of the economy. In this case, validation was done one two of the working models against data, and as it can be seen in Figures 4 to 7, the model predicts extremely well the trends in the data.

Figure 2: GDP

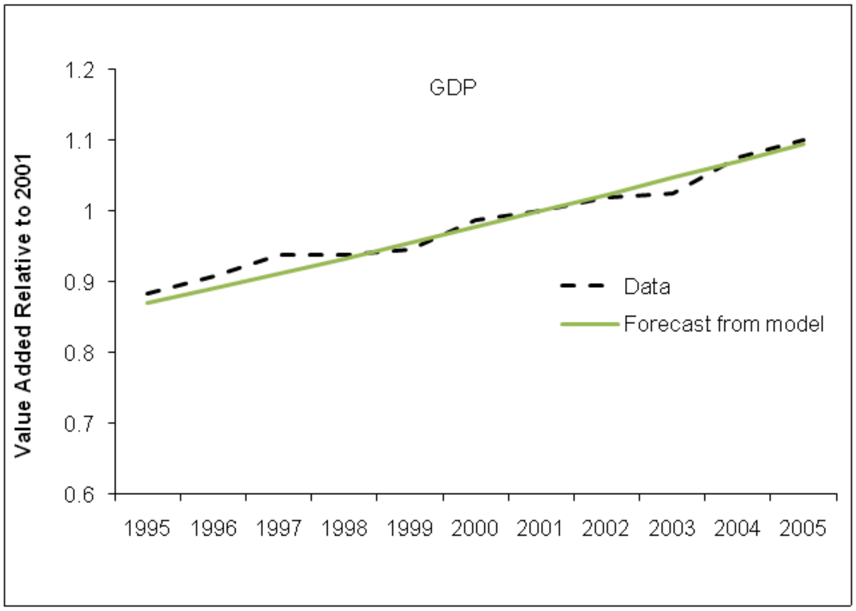


Figure 3: Industry Sector

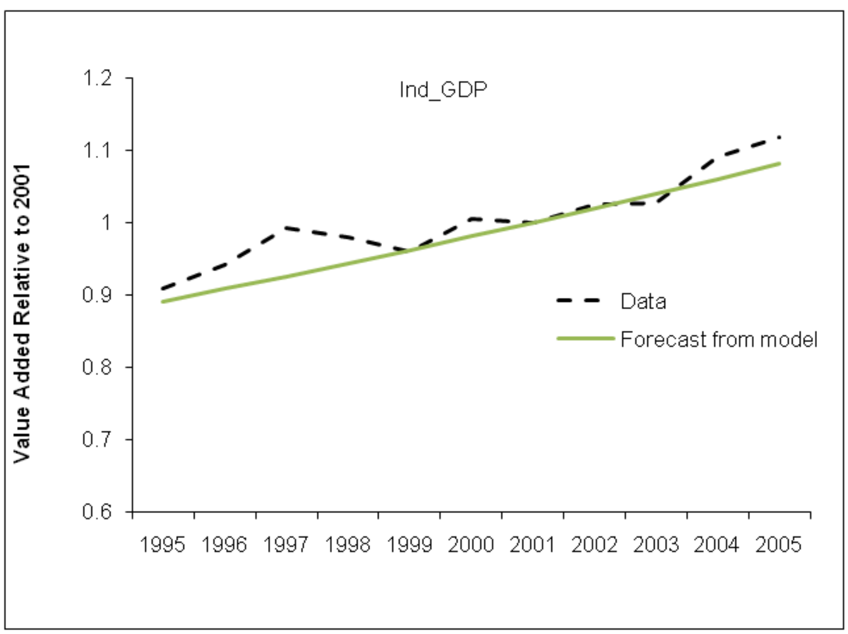


Figure 4: Agriculture

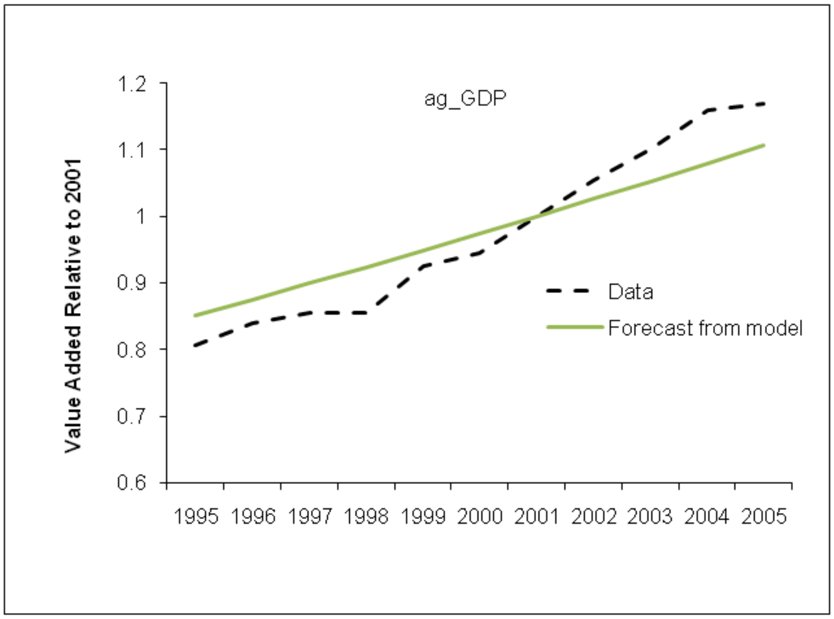


Figure 5: Services

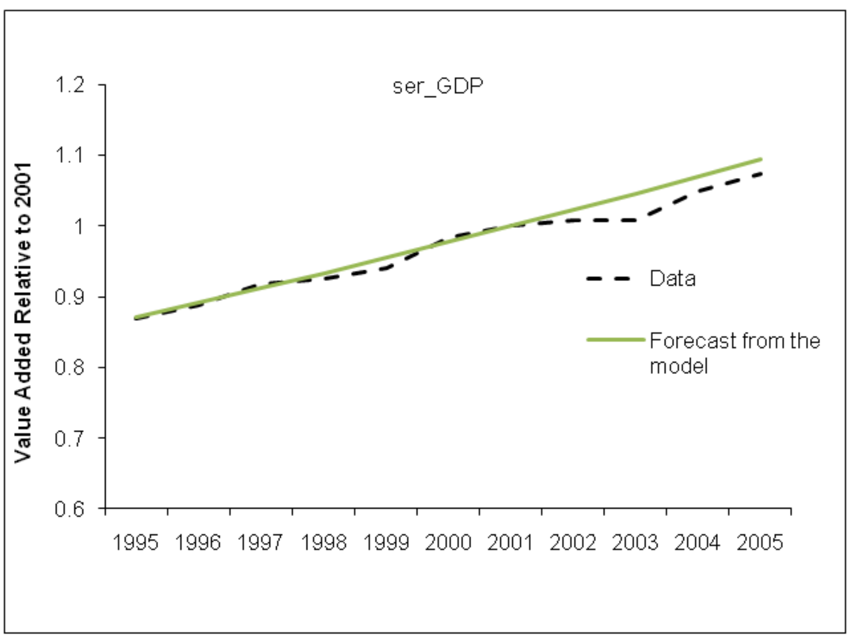
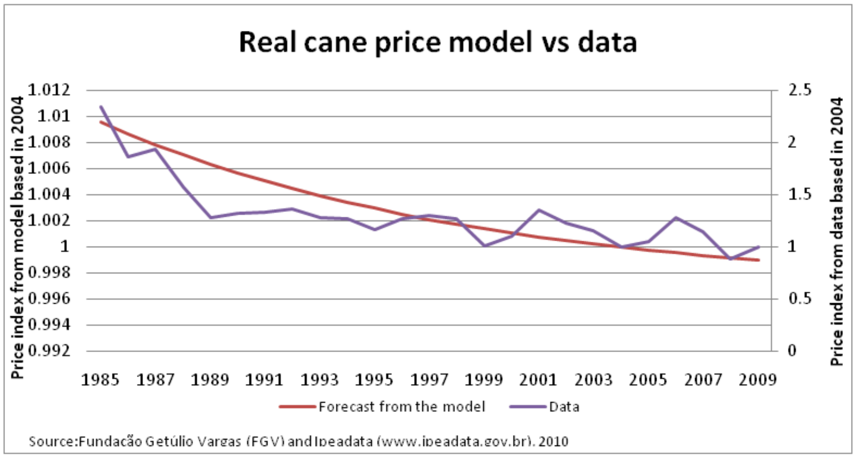


Figure 6: Cane price validation



10 References

Agénor, P. (2005). *Shooling and public Capital in a Model of Endogenous Growth.* Centre for Growth and Business Cycle Research, Economic Studies, University of Manchester, Manchester, M13 9PL, UK.

Al-Riffai, P., Dimaranan, B. and Laborde, D. (2010). *Global Trade and Environmental Impact Study of the EU biofuels Mandate.* IFPRI Contract No SI2.537.787.

Anderson, K. & Valdes, A. (2008). *Distortions to Agricultural Incentives in Latin America.* The World Bank.

ANFAVEA, Associação Nacional dos Fabricantes de Veículos Automotores (2006). http://www.afavea.com.br.

ANP, Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (2010). http://www.anp.gov.br/

Banse M., Van Meijl, H., Tabeau, A. and Woltjer, G. (2007). *Impact of EU Biofuel Policies on World Agricultural and Food Markets.* Paper presented at the Tenth Annual Conference on Global Economic Analysis, Purdue University, West Lafayette, IN. 7-9 June, 2007.

Beck, T. (2000). *Impediments to the Development and Efficiency of Financial Intermediation in Brazil.* Working paper. Financial Sector trategy and Policy, World Bank.

Birur, D., Hertel, T. and Tyner, W. (2008). *Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis.* GTAP Working Paper No. 53.

Blyde, J., Castelar, A., Daude, C. and Fernandez-Arias, E. (2008). *What is stopping growth in Brazil?.* Working paper

Bolling, C. & Suarez, N. (2001). *The Brazilian Sugar Industry: Recent Developments.* http://www.ers.usda.gov/briefing/Brazil/braziliansugar.pdf

Calderon, C. and Serven, L. (2003). *The Output Cost of Latin America's Infrastructure Gap.* InW. Easterly and Serven, Eds., *The Limits of Stabilization: Infrastructure, public Deficits and Growth in Latin America.*

Pp. 95-118. Stanford university Press, Palo Alto, CA and the World Bank, Washington D.C.

Calderon, C. and Serven, L. (2004). *The Effects of Infrastructure Development on Growth and Income Distribution. Policy Research Working Paper No. 3400.* World Bank, Washington D.C.

Caprio, B. and Levine, S. (2001). *The Regulation and Supervision of Banks Around the World: A New Database.* World Bank Paper Series #2588.

Caselli, F. and Ventura, J. (2000). *A Representative Consumer Theory of Distribution. American economic Review,* 90(4), 909-926.

Cass, D. (1965). *Optimum Growth in an Aggregative Model of Capital Accumilation.* Review of Economic Studies, 32, July, 233-240.

Center for Global Trade Analysis (2010). The GTAP 7 data base. Purdue University, West Lafayette,IN47907, USA.

Coyle, W. (2007). *The Future of Biofuels, a Global Perspective.* Economic Research Service/USDA. Amber Waves, 5 (5).

Demurger, S. (2001). *Infrastructure development and economic Growth: An Explanation for Regional Disparities in China?.* Journal of Comparative Economics, 29, 95-117.

Echevarria, C. 1995. *Agricultural Development vs. Industrialization: Effects of Trade.* Canadian Journal of Economics. Vol. XXVIII, no. 3. pp. 631–647.

Echevarria, C. 1997. *Changes in Sector Composition Associated with Economic Growth.* International Economic Review. Vol. 38, no. 2. pp. 431–452.

Echevarria, C. 2000. *Non-homothetic Preferences and Growth.* Journal of International Trade & Economic Development. Vol. 9. no.2. pp. 151–171.

Fajnzylber, P. & Lederman, D. (1999). *Economic Reforms and Total factor productivity Growth in Latin America and the Caribbean* (1950-95). Policy Research Working Paper 2114. The World Bank.

Food and Agriculture Organization of the United Nations FAO. (2008).

High-level Conference on World Food Security: the Challenges of Climate Change and Bioenergy. HLC/08/INF/3.

Feenstra, R. (2004). *Advanced International Trade: Theory and Evidence.* Princeton and Oxford: Princeton University Press.

Gollin, D., S. L. Parente, and R. Roberson. 2004. *Farm Work, Home Work and International Productivity Differences.* Review of Economic Dynamics and Control. Vol. 9 pp. 827–850.

Hausmann, R., Rodrik, D. and Velasco, A. (2005). *Growth Diagnostics.* John F. Kennedy, School of Government, Harvard University.

Hirschman, A. O. (1958). *The Strategy of Economic Development.* New Haven, CT: Yale University Press.

Jones, C. I. (2007). *Input-Output Multipliers, General Purpose Technologies, and Economic Development,* Working Paper, Dept of Econ., U.C. Berkeley and NBER.

Kehoe, T. (2003). *An Evaluation of the Performance of Applied General Equilibrium models of the Impacts of NAFTA.* Federal Reserve Bank of Minneapolis, Research Department Staff Report 320.

Koopmans, T. (1965). *On the Concept of Optimal Economic Growth.* The Econometric Approach to Development Planning. Amsterdam: North Holland, 1965.

Lin, L. (1989). *A Concordance Correlation Coefficient to Evaluate Reproducibility.* Biometrics. Vol. 45. pp. 255–268.

Martines-Filho, J.; H.L. Burniquist, and C.E.F. Vian (2006) *Bioenergy and the Rise of Sugarcane-Based Ethanol in Brazil.* Choices, 2nd Quarter, 21(2): 91-96.

Mitchell, D. (2008). *A Note on Rising Food Prices.World Bank* Policy Research Working Paper No. 4682.

Nichols, D. A. 1970. *Land and Economic Growth.* The American Economic Review, Vol. 60. no. 3. pp. 332–340.

Outlaw, J., Burnquist, H. and Ribera, L. (2007). *Bioenergy: Agricultural*

Issues and Outlook. 4th Annual North American Agrifood Market Integration Consortium Workshop: Contemporary Drivers of Integration.

Portaria no. 64, (1996). Ministério da Agricultura, Abastecimento e Reforma Agrária

Ramsey, F. (1928). *A Mathematical Theory of Savings.*Economic journal, 38, December, 543-559.

Regaldo, A. and G. Fan (2007). *Ethanol Giants Struggle to Crack Brazil Market.* The Wall Street Journal, September 10, 2007.

Reilly, J. & Paltsev, S. (2007). *Biomass Energy and Competition for Land.* MIT, Science and Policy of Global Change. Report No. 145.

Rodrik, D. (2006). *Goodbye Washington Consensus, Hello Washington Confusion?* A Review of the World Bank's Economic Growth in the 1990s: Learning from a Decade of Reform. Journal of Economic Literature,Vol. XLIV, 973-987.

Roe, T. & Smith, R. (2008). *Disease Dynamics and Economic Growth.* Journal of Policy Modeling, 30(1), 145-168.

Roe, T., Smith, R. and Saracoglu, S. (2010). *Multisector Growth Models: Theory and Application.* Springer Publishers.

Schuh, E. (1970). *The Agricultural Development of Brazil.* Praeger Publishers.

See Agenor, Pierre Richard (2005) *Shooling and public Capital in a Model of Endogenous Growth.* Centre for Growth and Business Cycle Research, Economic Studies, University of Manchester, Manchester, M13 9PL, UK. (http://www.socialsciences.manchester.ac.uk/cgbcr/dpcgbcr/dpcgbcr61.pdf)

Trostle, D. (2008). *Global Agriculture Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices.* WRS-0801, Economic Research Service/USDA.

US energy information administration (2010).http://www.eia.doe.gov/

Valdes, C. (2007) *Ethanol Demand Driving the Expansion of Brazil's Sugar Industry.* Sugar and Sweeteners Outlook, Economic Research Service, United States, Department of Agriculture, SSS-249, June 4, 2007. pp: 31-38.

Woodland, A. D. 1982. *International Trade and Resource Allocation.* Amsterdam, New York: North-Holland.

World Bank. (2004). *Inequality and Economic Development in Brazil.*

Zuurbler, P. and Van de Vooren, J. (2009). *Sugarcane ethanol, contributions to climate chamge mitigation and the environment.* Wageningen Academic Publishers.