The Yield Dynamics of Perennial Crops: An Application to Sugarcane in Brazil

Daniel Tregeagle¹, David Zilberman¹

¹Department of Agricultural and Resource Economics
University of California, Berkeley

Address Correspondence: Daniel Tregeagle
Department of Agricultural and Resource Economics
207 Giannini Hall
University of California
Berkeley, CA 94720-3310

Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2

Copyright 2016 by Daniel Tregeagle and David Zilberman. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.
The Yield Dynamics of Perennial Crops: 
An Application to Sugarcane in Brazil

Daniel Tregeagle
David Zilberman
May 25, 2016

Abstract

In 2011-2012 sugarcane yields in the Brazilian south-central region fell 15 percent lower than the average of the previous decade. This corresponded to the end of a decade of uninterrupted growth in sugarcane ethanol production in Brazil. Several explanations for this fall have been proposed including inclement weather, and a low field renewal rate due to the 2008-2009 financial crisis. We gather academic and journalistic evidence to demonstrate the possibility of the crisis-renewal pathway. We develop a theoretical model of perennial crop yields as a function of the renewal rate. We theoretically derive the number of lags of the renewal rate that should be used in a reduced form specification of perennial crop yields. Using a balanced panel of yields and renewal rates in the South-Central region of Brazil from 2005-2013 we investigate the relevance of these pathways. We find that the yield effects from a renewal rate change in Brazil are consistent with the yield effects predicted by our model. We also find that both pathways are significant, but that the weather pathway is driven by temperature, not rainfall.

Keywords: Brazil, Biofuel, Credit Crisis, Perennial Crop, Sugarcane Rotation, Sugarcane Yield
1 Introduction

We are motivated by explaining the decline in Brazil’s sugarcane yields in 2010-2011. Sugarcane is the key feedstock in Brazil’s ethanol industry. Brazilian sugarcane ethanol has particularly low carbon emissions, with Crago et al. (2010) estimating that its life-cycle carbon emissions are about half those of corn ethanol. In addition to its carbon benefits, sugarcane ethanol is an important component of Brazil’s economy, accounting for around 2.3 percent of its GDP in 2010 (Valdes, 2011).

We have collected evidence from journalistic and industry reports that the low yield may be a consequence of the 2008-2009 global financial crisis. In this story, access to credit became more scarce for farmers, who, lacking access to the necessary funds, chose to delay replanting their sugarcane fields. Lacking data on credit access for farmers, we theoretically and empirically analyze the second step in this chain — that lower renewal rates led to lower yields. Despite not being able to verify it, the credit constraint story suggests an important issue in the analysis of perennial crop yields, namely that they can be adversely affected for several years after a shock to anything that affects the renewal rate.

This has general relevance to the study of perennial crop supply chains, not just the Brazilian sugarcane ethanol industry. This mechanism is possible for any perennial crop, but those that have a tight integration between production and processing are particularly vulnerable.

We develop a theoretical model of the effect of a change in the renewal rate on perennial crop yields, and then use the results of this model to inform the specification of an econometric model that includes renewal rate, weather, input and output prices, and other covariates.

Our model is an adaptation of the framework for perennial crop analysis developed
by [Mitra et al. (1991)]. The model is completely general for all perennial crops, with an arbitrary number of age-classes, and an arbitrary yield in each age-class. We strip out the optimizing behavior, keep the perennial crop dynamics, and impose a new behavioral assumption that farmers renew a fixed percentage of their crop each year. Thus the choice of renewal rate is exogenous to the model. Choosing to keep the renewal rate exogenous to the model allows us to avoid specifying the mechanism by which credit constraints affect the renewal rate, which is clearly important but beyond the scope of this paper.

We analyze the yield trajectory between steady states of the system that results from both a marginal and a discrete change in the renewal rate. We are able to determine, in general, the precise number of lags of the renewal rate that should affect current yield. We determine whether the equilibrium yield after a renewal rate shock will be higher or lower than the old equilibrium; the relationship can be non-monotonic. We also demonstrate why, in general, using the intuitive metric of average perennial crop age can be misleading.

Using the specification suggested by the theoretical model we estimate an autoregressive panel data model. We use state level sugarcane yield and field renewal data in the South-Central growing region from the Brazilian Sugarcane Industry Association (UNICA), weather data from version 4.01 the climate data of Matsuura and Willmott, ethanol prices from the Center for Advanced Studies on Applied Economics (CEPEA), the No. 11 sugar price from the NY Board of Trade, the Brazilian nominal effective exchange rate and diesel prices from the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP).

Our results show that the main determinants of sugarcane yield in Brazil are renewal rate, temperature, ethanol price, and the exchange rate. Furthermore, the coefficients on the lags of renewal rate are equal in sign and relative magnitude to the
predictions of our theoretical model.

2 The Brazilian Sugarcane Industry during the Credit Crisis

We are thinking about a four-step process here. There is the economic context, then the farmers’ decisions, then the physical state of the sugarcane fields (yield and area), then production. The economic context contains all the economic factors that affect the farmers’ rotation decisions (e.g. price of input and output, credit availability etc.). The farmers’ decisions are divided into four categories: the rotation decision; the expansion decision; the harvest decision; and other decisions. The rotation decision is self-explanatory. The expansion decision is to decide whether to increase or decrease the total area of land allocated to sugarcane production. The harvest decision is to decide how much of the available sugarcane to actually harvest and hence move to ‘production’. The other decisions will include the quantity of labor to hire, the application of fertilizer, the sequencing of harvesting through the growing season, etc.

The model and econometric sections of this paper formalize and measure the link between the outcome of the rotation decision and the production, with the specification of the regression equation being governed by the structural relationship between rotation decision, sugarcane field state (age-structure — keeping within year decision effects constant), and the production outcomes. The remainder of this section and appendix A develop the link between the economic conditions and the farmers’ decisions.

A brief overview of what happened to Brazil and the sugarcane industry from
2.1 Stage 1 — Economic Context

- Rapid growth
- Increased indebtedness (debt-to-revenue increased from 30% to 130% in two years)
- Negative margins
- Financial crisis - no credit
- Brazilian banking sector increased preference for liquidity and tightened the lending requirements on borrowers
- Farmers, already highly leveraged and facing negative margins, were unable/less able to borrow.
- Unable to continue financing growth and expansion

2.2 Stage 2 — Economic Decisions

- Lack of financing and negative margins affected farmers’ decisions
Greatly reduced rate of expansion

Lower renewal (level and percentage of planted area)

Possible reduced input use (evidence for soy; true for sugarcane too?)

2.3 Stage 3 — The Growing Process

• Reduced expansion and renewal changes the age structure, which changes the yield

• Reduced expansion changes the yield

• Changes to ‘all other decisions’ also change yield (e.g. reduced fertilizer applications)

• Changes to expansion and renewal have multi-year impacts on yield through the persistent changes to the age-structure

2.4 Stage 4 — The Outcome: Production

• Production declines in 2011/2012

• Production shows an inflection point in 2008/2009

• First differences are increasing then decreasing with a peak at 2008/2009

• Refinery openings and closings show a similar pattern

3 Model

Perennial crops can be grown and harvested for multiple years before they need to be replanted. Over their lifespan, the yield of the crop changes with time. We call this
pattern the *age-yield relationship*. Following Mitra et al. (1991) we can characterize this relationship into three phases: the establishment phase (increasing yield), the peak phase (constant, maximal yield), and the senescence phase (decreasing yield).

The particular age-yield relationship will vary depending on the crop, the growing location, the farm management practices, pest load, water availability, among other factors.

To illustrate the idea of an age-yield relationship, consider the age-yield relationship presented by Margarido and Santos (2012) for the Alta Mogiana region of São Paulo state. This relationship is shown in figure 2. The establishment phase occurs in the first year. The peak occurs in the second year and lasts for only one year. The senescence phase begins in the third year and continues until the 7th year. Since Brazilian sugarcane tends to be renewed by or before its 7th year, we have not found data on the age-yield relationship for Brazilian sugarcane for higher years.

![Sugarcane Age-Yield Relationship](image)

Figure 2: Age yield relationship taken from Margarido and Santos (2012)

Margarido and Santos (2012) identify the key features of sugarcane yield dynamics, that the yield trajectory will be non-monotonic in response to a change in the renewal rate. We quote:

> It is important to point out that after large decreases in planting or in
renovation, there is a significant increase in total production in the next year, but drastic reduction in the second year, because of two factors: i) part of the first cut cane (1/7), which is used for seedlings, is not used for sowing, and therefore, it is added to the next growing season; ii) because of renovation itself, which if it is not carried out, increases the cutting area in the following year. (Margarido and Santos, 2012, p. 12)

Although they identify this key feature, they leave several questions unanswered. What happens after the third year? What will be the new equilibrium level of production? In order to create an econometric model of the effect of renewal rates on sugarcane yield we must have answers to these questions — both to correctly specify the model, and also to provide testable hypotheses. In the remainder of this section we develop a general model of yield trajectories as a function of changes in the renewal rate. This model uses an exogenous renewal rate — it is not determined by an optimization model. The model is applicable for any perennial crop, and we apply it to a stylized representation of Brazilian sugarcane to generate testable hypotheses for this specific case.

3.1 The Dynamics of Age Structure

Before considering the dynamics of the yield of a perennial crop we must first consider the dynamics of its age structure. Begin with the simplest model of age structure dynamics, where we have a fixed plot of land (normalize its size to 1) that is divided into sub-plots of different ages, e.g. 20% of the land may be 1-year-old trees, 10% of the land is 2-year-old trees, and so on. Let $x_{st}$ be the quantity of land allocated to age-class $s$ in year $t$.

---

1Margarido and Santos analyze a production system where 1 ha of sugarcane can produce seedlings for 7 ha — which makes a balanced system very attractive
Under the natural dynamics of this system (i.e. without human intervention) the trees will enter the next oldest age class next year\footnote{I am assuming away any loss between years, e.g. due to weather damage, or pest damage etc}. Mathematically, this is to say $x_{s+1,t+1} = x_{st}$. Following Mitra et al. (1991) and Salo and Tahvonen (2004) we assume the existance of some oldest age class, $S$. This makes the analysis tractable by making the age-class state space finite. It is also reasonable — the oldest age class could simply be a zero yield class for plants that are dead or non-yielding from old age.

Now introduce the possibility of plant renewal, which is a human choice. Renewing a plant means to replace an old plant with a fresh seed, seedling or cutting. When renewing $s$-year-old plants, land is moved from age class $s$ to age class 1. Theoretically land from any age class could be renewed. This implies two linked dynamic equations: $x_{0,t+1} = r_{st}$ and $x_{s+1,t+1} = x_{st} - r_{st}$. Note that not all land allocated to a single age class needs to be replanted at once. The replant choice variable is constrained to be between 0 and $x_{st}$ by the physical nature of land.

Combining the natural and artificial dynamics of the system and summing up across all age categories gives us the following system of dynamic equations, which is illustrated in figure 3:

\begin{align*}
x_{1,t+1} &= \sum_{s=1}^{S} r_{st} \\
x_{s,t+1} &= x_{s-1,t} - r_{st} \text{ for } 1 < s < S \\
x_{S,t+1} &= x_{S-1,t} + x_{St} - r_{St}
\end{align*}

Mitra et al. (1991) section 3) demonstrate that old plants will be renewed before
Figure 3: Each age class is populated only from the previous age class, except for the youngest age class which collects all the renewed land in a particular year. Land in the oldest age class stays in the oldest age class unless renewed.

young plants if they follow a three-phase age-yield relation (described above). Since plants will be renewed in decreasing order of age, we can identify the youngest age class not renewed in a single year. If this age class is the oldest class year after year in an unchanging system, then we can denote the index of this age class as the rotation length. For example if we observe that if plants are renewed as soon as they reach their 6th birthday, then we can describe the system as having a rotation length of 5 years, and the land will be divided into 5 age classes. Let $L$ denote rotation length.

Let $x_{st}$ be an *active age-class* if $x_{st} > 0$. If $L$ is the rotation length then age-classes 1, \ldots, $L$ will be active.

### 3.2 The relationship between rotation length and percent replanted

There is not an inherent connection between the rotation length and percent planted. This is because an arbitrary amount of land of rotation age could be available in any given year. However, when we consider only balanced perennial systems, then there is a clear relationship between rotation age and percent replanted.

In a stationary system the state of the system remains unchanged from period to period.
period (Mitra et al., 1991). Let $\mathbf{x}_t$ be the vector of land allocations across all age classes in period $t$. Then in a stationary system $\mathbf{x}_t = \mathbf{x}_{t+1}$. To achieve this state, a constant fraction of the land must be renewed each year.

**Quick Proof:** Since $\mathbf{x}_t = \mathbf{x}_{t+1}$, it follows that $x_{1t} = x_{1,t+1}$. Using the equation of motion for land in the first age class to write this in terms of renewal decisions we get $\sum_{s=1}^{S} r_{s,t-1} = \sum_{s=1}^{S} r_{st} \forall t$. Hence the aggregate quantity of land rotated in each period must be constant in a stationary system.

In a stationary planting there will be equal quantities of land are allocated to all but the oldest active age class, i.e. $\mathbf{x}_t = \mathbf{x}_{t+1}$ AND $x_{st} = x_{rt} \forall s, r \in \{1, \ldots, L - 1\}, x_{Lt} \leq x_{st}$.

Given the result in section ?? that age classes will be selected for renewal as a declining function of their age, the fraction of land renewed in a balanced rotation must be $\frac{1}{L}$ of the total land area.

**Proposition:** For each renewal rate $R_t \in [0, 1]$ there exists a corresponding stationary system, denoted $\mathbf{x}(R_t)$, defined as:

$$
\mathbf{x}(R_t) = \begin{cases} 
\begin{align*}
    x_{st} &= R & \text{for } s < \left\lfloor \frac{1}{R} \right\rfloor \\
    x_{st} &= 1 - R(\left\lfloor \frac{1}{R} \right\rfloor - 1) & \text{for } s = \left\lfloor \frac{1}{R} \right\rfloor \\
    x_{st} &= 0 & \text{otherwise}
\end{align*}
\end{cases}
$$

for $\left\lfloor \frac{1}{R} \right\rfloor < S$

$$
\mathbf{x}(R_t) = \begin{cases} 
\begin{align*}
    x_{st} &= R & \text{for } s < S \\
    x_{st} &= 1 - R(S - 1) & \text{for } s = S
\end{align*}
\end{cases}
$$

for $\left\lfloor \frac{1}{R} \right\rfloor \geq S$

Where $\left\lfloor \cdot \right\rfloor$ is the ceiling function. This characterization assumes a constant, unit area of land.
**Proposition:** If the renewal rate is held constant at \( \bar{R} \), then an arbitrary plantation will reach the equilibrium described by equation 1 in at most \( \min(\lceil \frac{1}{\bar{R}} \rceil, S) - 1 \) periods.

**Proof:** Start with a system in an arbitrary state at time \( t = 0 \). Let the renewal rate be set to \( \bar{R} \) at time \( t = 0 \). Thus \( x_{1,t} = \bar{R} \). In each subsequent period \( x_{1,t} \) will be set to \( \bar{R} \). Hence after \( \min(\lceil \frac{1}{\bar{R}} \rceil, S) - 1 \) periods the fraction of land in each of the age-classes 1 to \( \min(\lceil \frac{1}{\bar{R}} \rceil, S) - 1 \) will be equal to \( \bar{R} \), and since we are assuming a constant quantity of land, age-class \( \min(\lceil \frac{1}{\bar{R}} \rceil, S) \) must contain \( 1 - \bar{R}(\min(\lceil \frac{1}{\bar{R}} \rceil, S) - 1) \) units of land. This corresponds to the equilibrium in equation 1.

### 3.3 Simulations of a change in the rotation length

What happens to the yield of a system when there has been a change in the rotation length? Say that the system has been in a stationary state and then at time 1 there is a change in the rotation length, that is, there has been \( \frac{1}{L} \) rotation in a \( L \) length system, which changes suddenly to \( \frac{1}{L+1} \) in an \( L + 1 \) length system?

For example, a stationary system with \( x_{3t} = \frac{1}{3}, x_{4t} = 0 \) and \( r_{3t} = \frac{1}{3} \), to a system where now \( r_{3t} = 0 \) and \( r_{4t} = \frac{1}{4} \)? Illustrated in figure 4.

**Proposition:** The sign of the change in yield one year after a marginal change in the renewal rate is equal to the sign of \( f_1 - (\Delta \hat{r}_{1t} f_1 + \Delta \hat{r}_{2t} f_2 + \ldots + \Delta \hat{r}_{St} f_S) \)

**Proof:** Let \( \bar{R}_t = \sum_{s=1}^{S} r_{st} \). Let \( R_t = \frac{\bar{R}_t}{\sum_{s=1}^{S} x_{st}} \) be the renewal rate. We want to know the sign of \( \frac{\partial Y_{t+1}}{\partial \bar{R}_t} \). For a system with a constant quantity of land, a change in the renewal rate can only occur through a change in \( \bar{R}_t \) through a monotonic relationship. Hence \( \text{sign}(\frac{\partial Y_{t+1}}{\partial \bar{R}_t}) = \text{sign}(\frac{\partial Y_{t+1}}{\partial R_t}) \).

A change in total renewal \( \bar{R}_t \) will be the sum of the changes in the age-class specific renewal, i.e. \( \Delta \bar{R}_t = \sum_{s=1}^{S} \Delta r_{st} \). There are many sets of individual changes that can
result in an increase in total renewal. Any vector of changes such that the sum of the changes is positive is admissable. Let \( \Delta \hat{r}_t \) be the unit vector pointing in the direction of the vector of changes individual renewal.

We can now write \( \frac{\partial Y_{t+1}}{\partial R_t} \) as the directional derivative \( \nabla Y_{t+1} \cdot \Delta \hat{r}_t \), where \( \nabla Y_{t+1} = \begin{bmatrix} \frac{\partial Y_{t+1}}{\partial r_{1t}} & \frac{\partial Y_{t+1}}{\partial r_{2t}} & \cdots & \frac{\partial Y_{t+1}}{\partial r_{St}} \end{bmatrix} \).

\[
\nabla Y_{t+1} \cdot \Delta \hat{r}_t = \frac{\partial Y_{t+1}}{\partial \hat{r}_{1t}} \Delta \hat{r}_{1t} + \frac{\partial Y_{t+1}}{\partial \hat{r}_{2t}} \Delta \hat{r}_{2t} + \cdots + \frac{\partial Y_{t+1}}{\partial \hat{r}_{St}} \Delta \hat{r}_{St}
\]
\[
= (f_1 - f_1)\Delta \hat{r}_{1t} + (f_1 - f_2)\Delta \hat{r}_{2t} + \cdots + (f_1 - f_S)\Delta \hat{r}_{St}
\]
\[
= (\Delta \hat{r}_{1t} + \Delta \hat{r}_{2t} + \cdots + \Delta \hat{r}_{St}) f_1 - (\Delta \hat{r}_{1t} f_1 + \Delta \hat{r}_{2t} f_2 + \cdots + \Delta \hat{r}_{St} f_S)
\]
\[
= f_1 - (\Delta \hat{r}_{1t} f_1 + \Delta \hat{r}_{2t} f_2 + \cdots + \Delta \hat{r}_{St} f_S) \quad \text{since } \Delta \hat{r}_t \text{ is a unit vector}
\]

Thus \( \text{sign}(\frac{\partial Y_{t+1}}{\partial R_t}) = \text{sign}(f_1 - (\Delta \hat{r}_{1t} f_1 + \Delta \hat{r}_{2t} f_2 + \cdots + \Delta \hat{r}_{St} f_S)) \).

**Corollary:** If \( \Delta \hat{r}_{1t} f_1 + \Delta \hat{r}_{2t} f_2 + \cdots + \Delta \hat{r}_{St} f_S > f_1 \), then \( \frac{\partial Y_{t+1}}{\partial R_t} < 0. \)
There are two observations we can make about sugarcane production that will guarantee that this corollary holds. First, for Brazilian sugarcane the first age-class is non-yielding since the plant is still establishing itself (see figure 2). “On average, the first cut is carried out one year and a half after planting” (Margarido and Santos, 2012). This implies that $f_1 = 0$, so the condition from the corollary simplifies to $\Delta \hat{r}_2 f_2 + \ldots + \Delta \hat{r}_S f_S > 0$. Second, since renewal will proceed in declining order of age, i.e. all plants of age-class $s + 1$ must be renewed before any plants of age class $s$ will be renewed, an increase in the total renewal rate will imply an increase in the renewal of the youngest, or next-youngest age-classes currently being renewed. We have eliminated the possibility of $\Delta \hat{r}_{st}$ being negative. The left hand side becomes the inner product of two non-negative vectors (both with at least one strictly positive element), and so the inequality is satisfied.

3.4 What is the equilibrium yield after a change in the renewal rate?

Assume that renewal rate increases. What stationary age-structure does this imply? How long will it take for the plants to reach this age-structure?

If the oldest age-class is older than the age with the highest average yield, then a decrease in the renewal rate will lead to relatively more older plants and a decline in the equilibrium average yield.

When considering an increase in the renewal rate we can either have a marginal or a discrete increase. In the case of a marginal increase is is not possible for the number of active age-classes to decrease, since for any $R \in [0, 1]$ there exists an $\varepsilon > 0$ such that $\lceil \frac{1}{R + \varepsilon} \rceil = \lceil \frac{1}{R} \rceil$.

If some $\Delta \hat{r}_{st}$ are negative, the inequality may not be satisfied, particularly if there are large negative weights on high-yielding age-classes.
From equation 1 we know that all but the oldest age classes will necessarily have $R$ units of land allocated to them, and the oldest age-class will contain $1 - R(\min(\lceil \frac{1}{R} \rceil, S) - 1)$.

This allows us to rewrite the yield equation as a function of the renewal rate.

$$\text{yield}_t = f_1 x_1 + f_2 x_2 + \ldots + f_s x_s$$  Where $s$ is the oldest active age class

$$\text{yield}_t = f_1 R + f_2 R + \ldots + f_{s-1} R + f_s (1 - R(s - 1))$$

Taking the derivative with respect to $R$ gives us the change in equilibrium yield with respect to a change in the renewal rate.

$$\frac{d \text{yield}_t}{dR} = f_1 + f_2 + \ldots + f_{s-1} - f_s(s - 1)$$

Equilibrium yield increases after an increase in the renewal rate if

$$\frac{f_1 + f_2 + \ldots + f_{s-1}}{s - 1} - f_s > 0$$

That is, if the average productivity of all but the oldest age-classes is greater than the productivity of the oldest age class, or, alternatively, if having more land allocated to the oldest age class reduces the average yield.

### 3.5 Does yield increase or decrease 2+ years after the increase in renewal rate?

Only need to consider at most the $\min(\lceil \frac{1}{R} \rceil, S) - 1$ periods after the change in the renewal rate.
3.5.1 The yield trajectory from a marginal change in $R$

It is not enough to know the change in equilibrium yield from a change in the renewal rate. We would also like to know the trajectory that yield takes to reach the new equilibrium (is this a comparative dynamic and the comparison of equilibrium yield a comparative static?).

From section 3.4 we know that a marginal increase in the renewal rate will not change the number of active age-classes.

We know that the new equilibrium will be reached after at most $s - 1$ periods. Hence, for each of those periods ($0 \leq t \leq s - 1$) we would like to know whether the yield increases or decreases from the previous year, that is, is $y_{t+1}$ greater or less than $y_t$?

$t$ years after the renewal rate has changed from $R$ to $R'$ (let $\Delta R = R' - R$), the yield will be given by:

$$\text{yield}_t = f_1 R' + \ldots + f_t R' + f_{t+1} R + \ldots + f_{s-1} R + f_s (1 - R (s - t - 1) - R' (t)) \quad (3)$$

Similarly, after $t + 1$ years, the yield will be given by:

$$\text{yield}_{t+1} = f_1 R' + \ldots + f_t R' + f_{t+1} R' + \ldots + f_{s-1} R + f_s (1 - R (s - (t+1) - 1) - R' (t+1)) \quad (4)$$

The change in yield from $t$ to $t + 1$ ($\text{yield}_{t+1} - \text{yield}_t = \Delta \text{yield}_t$) is given by:

$$\Delta \text{yield}_t = f_{t+1} R' - f_{t+1} R + f_s (1 - R (s - (t+1) - 1) - R' (t+1)) - f_s (1 - R (s - t - 1) - R' (t)) \quad (5)$$
Simplifying and collecting like terms gives us:

\[
\Delta \text{yield}_t = f_{t+1}(R' - R) - f_s(R' - R) = \Delta R(f_{t+1} - f_s) \tag{6}
\]

Hence, \( \frac{d(\Delta \text{yield}_t)}{dR} = f_{t+1} - f_s \)

### 3.5.2 As applied to the Brazilian case

In the Brazilian case, \( f_1 = 0 \) and \( f_2 > f_3 > \ldots > f_s > \ldots > f_S > f_1 \). Thus

\[
\frac{d(\Delta \text{yield}_1)}{dR} = f_1 - f_s < 0 \text{ i.e. } \text{yield}_1 < \text{yield}_0,
\]

\[
\frac{d(\Delta \text{yield}_2)}{dR} = f_2 - f_s > 0 \text{ i.e. } \text{yield}_2 > \text{yield}_1,
\]

and

\[
\frac{d(\Delta \text{yield}_3)}{dR} = f_3 - f_s > 0 \text{ i.e. } \text{yield}_3 > \text{yield}_2 \text{ etc.}
\]

After an increase in the renewal rate, the yield will initially decrease for a single period, then monotonically increase to reach the new equilibrium yield. This confirms the quote from Margarido and Santos (2012) at the beginning of this section, and answers the question of what happens after the second period.

### 3.5.3 The effect of a discrete renewal rate increase that reduces the number of active age classes by one

Unlike the marginal change case, a discrete change in the renewal rate from \( R \) to \( R' \) can change the number of active age classes.

Here we show the effect of an *increase* in the renewal rate on the yield transition
trajectory.

Say that at time $t$ there are $s$ active age classes (where $s = \lceil \frac{1}{R} \rceil$), and that at time $t + 1$ the number of active age classes declines to $s - 1$. What is the change in yield?

The yield at time $t$ is

$$\text{yield}_t = f_1 R' + \ldots + f_t R' + f_{t+1} R + \ldots + f_{s-1} R + f_s (1 - R(s - t - 1) - R'(t))$$

and the yield at time $t + 1$ is

$$\text{yield}_{t+1} = f_1 R' + \ldots + f_t R' + f_{t+1} R' + \ldots + f_{s-1} (1 - R((s - 1) - (t + 1) - 1) - R'(t + 1))$$

Notice how the oldest active age-class at $t + 1$ is now $s - 1$, and that in the $s - 1$ land allocation equation the $R$ term is multiplied by $(s - 1) - (t + 1) - 1$. This is because there are now $s - 2$ other active age-classes.

The change in yield between $t$ and $t + 1$ is given by the difference between these two expressions

$$\Delta \text{yield}_t = f_{t+1} R' - f_{t+1} R + f_{s-1} (1 - R((s - 1) - (t + 1) - 1) - R'(t + 1)) - f_{s-1} R - f_s (1 - R(s - t - 1) - R'(t))$$

which, after simplifying, becomes

$$\Delta \text{yield}_t = (f_{t+1} - f_{s-1}) \Delta R + (f_{s-1} - f_s) (1 - R(s - t - 1) - R'(t))$$

The first term in this expression is the ‘within age-class yield effect’ and the second term is the ‘between age-class yield effect’ which exists due to the change in the number of active age-classes. Notice that the ‘within yield effect’ is not exactly the same as the case when there was no change in the number of age classes. The
yield of the $t + 1^{th}$ age-class is now being compared to the $s - 1^{th}$ age class, not the $s^{th}$.

### 3.5.4 The effect of a discrete renewal rate increase that reduces the number of active age classes by $n$

The change in the renewal rate must be big enough to change the number of active age-classes by $n$ in one time step, otherwise the formula in section 3.5.3 is sufficient with a redefinition of $s$ each time step.

Say that at time $t$ there are $s$ active age classes, and that at time $t + 1$ the number of active age classes declines to $s - n$. What is the change in yield?

The yield at time $t$ is

$$ yield_t = f_1R' + \ldots + f_tR' + f_{t+1}R + \ldots + f_{s-1}R + f_s(1 - R(s - t - 1) - R'(t)) $$

and the yield at time $t + 1$ is

$$ yield_{t+1} = f_1R' + \ldots + f_tR' + f_{t+1}R' + \ldots + f_{s-n}(1 - R((s-n) - (t+1) - 1) - R'(t+1)) $$

The change in yield between $t$ and $t + 1$ is given by the difference between these two expressions

$$ \Delta yield_t = f_{t+1}R' - f_{t+1}R + f_{s-n}(1 - R((s-n) - (t+1) - 1) - R'(t+1)) - f_{s-n}R - f_{s-n+1}R - \ldots $$

$$ - f_{s-1}R - f_s(1 - R(s - t - 1) - R'(t)) $$
which, after simplifying, becomes

$$\Delta \text{yield}_t = (f_{t+1} - f_{s-n}) \Delta R + (f_{s-n}(n-1) - \sum_{i=1}^{n-1} f_{s-n+i}) R + (f_{s-n} - f_s)(1 - R(t - 1) - R'(t))$$

4 Data

4.1 Yield

Yield data are constructed from production and area planted data available from the Brazilian Sugarcane Industry Association (UNICA). Annual production (tons) and area planted (ha) data are available for each state in Brazil. We include only the states in the south-central region, by far the largest sugarcane growing region in Brazil.

Although area harvested data is also available, but we use area planted as the more appropriate measure. For sugarcane, a significant fraction of the land each year is devoted to young cane, which is not harvested while it is being established \( \text{Bakker} \ 1999 \). In a balanced \( T \) year rotation, \( \frac{1}{T} \) of the land will be in this phase of the production cycle \( \text{Margarido and Santos} \ 2012 \). Focusing on area harvested will ignore this integral part of the sugarcane production cycle and overestimate the yield.

4.2 Percent Replanted

Percent replanted data was downloaded from the UNICA website. The UNICA database includes data from the CanaSat project which used satellite observations to measure how much sugarcane growing land is replanted with new canes each year. For the state of São Paulo we used data from 2003 to 2013. For the other sugarcane
growing states in the south-central region (Goias, Mato Grosso, Mato Grosso do Sul, Minas Gerais, and Parana) this data was only available starting from 2005, so we used data from 2005-2013. For each year, the percentage replanted was generated by taking this area under replanting data and dividing it by the total planted area.

4.3 Weather

Weather data were downloaded from the Willmott and Matsuura dataset, hosted by the University of Delaware. Version 4.01 of the Terrestrial Air Temperature Time Series was used for the temperature data and version 4.01 of the Terrestrial Precipitation Time Series was used for the precipitation data \cite{Matsuura2015}. We used MATLAB to extract the average temperature and rainfall for each state using state shapefiles obtained from the GADM Global Administrative Areas database \url{gadm.org}.

4.4 Ethanol Price

Ethanol prices were obtained from the Center for Advanced Studies on Applied Economics (CEPEA). Monthly prices were available for São Paulo, Pernambuco and Alagoas. Only São Paulo is in the South-Central region, so only this price was used. We aggregated these data to create an average price for each harvest year (Apr-Mar).

4.5 Sugar Price

We used the No. 11 Sugar Price quoted by the New York Board of Trade, and supplied by the Global Financial Database. We used the yearly close price as our proxy for the sugar price received by Brazilian growers.
4.6 Exchange Rate

We used the Brazilian Nominal Effective Exchange Rate to represent the exchange rate faced by exporters of Brazilian sugarcane products. The effective exchange rate is an index calculated by the Bank for International Settlements (BIS). It is a geometric weighted average of bilateral exchange rates where the weight is determined by the volume of trade over a recent period\footnote{For more details regarding the calculation of this index, see the BIS website \url{www.bis.org}}.

4.7 Diesel Price

Diesel is a significant input into the production of sugarcane; mechanical harvesters and all transportation to and from a mill relies on diesel engines \cite{Ewing2013}. Diesel has become increasingly important since the introduction of mechanical harvesting techniques in the early 2000’s \cite{AzanhaFerraz2014}. We obtained monthly price data for each state in the South-Central region from the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP), which collects a sales-weighted average price for each state from 555 sales locations across Brazil. We aggregated these data to obtain the average Diesel price in each state for each harvest year (Apr-Mar).

5 Econometric Model

We develop an econometric model to test the predictions from section 3.5.2. The specification of the model is

\[ y_{it} = \sum_{l=0}^{L} \beta_{l\text{pctReplant}} i_{t-l} + \alpha X_{it} + \gamma Z_{t} + v_{i} + u_{it} \]
where

\[ \alpha X_{it} = \alpha_1 \text{meanTemp}_{it} + \alpha_2 \text{meanRain}_{it} + \alpha_3 \text{dieselPrice}_{it} \]

\[ \gamma Z_t = \gamma_1 \text{sugarPrice}_{t} + \gamma_2 \text{ethanolPrice}_{t} + \gamma_3 \text{FXRate} \]

Where \( i \) indexes the major sugarcane growing states in the south central region of Brazil (Goias, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Parana, and São Paulo). And \( t \) indexes the sugarcane growing year (Apr-Mar). Observations for São Paulo for 2003 and 2004 to create a balanced panel from 2005-2013.

Using Wooldridge’s test for serial correlation in panel data (Drukker, 2003) we reject the null hypothesis of no serial correlation for all specifications varying the number of lags. To correct for this we used a fixed effects estimator that assumes that the idiosyncratic component of the error term follows an AR(1) process.

6 Results

The average renewal rate in the south-central region varies between 9 and 24 percent over the sample period. The formula in section 3.2 tells us the maximum number of relevant lags given the renewal rate. Assuming that the fields in Brazil are younger than the maximum allowable age \( S \) (a reasonable assumption) then the number of relevant lags will be between 4 and 11.

This presents a tradeoff. Since we only have 9 years of data we cannot include all 11 possible lags, and with each additional lag we lose a year of data, e.g. the first year with 4 years available is 2009, so with 4 lags we can only use 2009-2013. Since the solution to this tradeoff is not obvious \textit{a priori} we present results for specifications for 0 to 5 lags. These results are presented in table [1]

An interesting pattern emerges from the results. For 0 to 3 lags we see roughly
<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Lag</td>
<td>1 Lag</td>
<td>2 Lags</td>
<td>3 Lags</td>
<td>4 Lags</td>
<td>5 Lags</td>
</tr>
<tr>
<td>% Replanted</td>
<td>-0.0733</td>
<td>-0.4605</td>
<td>-0.8022</td>
<td>-1.1952</td>
<td>-0.7769*</td>
</tr>
<tr>
<td>% Replanted - Lagged one year</td>
<td>0.2604</td>
<td>0.0641</td>
<td>0.1714</td>
<td>2.3677***</td>
<td>2.6335*</td>
</tr>
<tr>
<td>% Replanted - Lagged two years</td>
<td>-0.1973</td>
<td>-0.7385</td>
<td>1.3687**</td>
<td>0.0700</td>
<td></td>
</tr>
<tr>
<td>% Replanted - Lagged three years</td>
<td>-1.1168</td>
<td>0.7728</td>
<td>-0.2106</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Replanted - Lagged four years</td>
<td>0.2115</td>
<td>-0.2432</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Replanted - Lagged five years</td>
<td>-0.5259</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Price (BRL)</td>
<td>-8.2499</td>
<td>13.2564</td>
<td>20.0088</td>
<td>38.0345*</td>
<td>-12.1339</td>
</tr>
<tr>
<td>No.11 Sugar Price (USD)</td>
<td>0.0968</td>
<td>0.1773</td>
<td>0.5087</td>
<td>-0.0615</td>
<td>-1.0479*</td>
</tr>
<tr>
<td>Ethanol Price (USD)</td>
<td>-29.1472***</td>
<td>-42.8236***</td>
<td>-46.3557***</td>
<td>-47.0294**</td>
<td>-47.9802***</td>
</tr>
<tr>
<td>Nominal Effective Exchange Rate</td>
<td>0.0531</td>
<td>0.5094*</td>
<td>0.3603</td>
<td>0.9681</td>
<td>1.0451***</td>
</tr>
<tr>
<td>Yearly Average Temp (C)</td>
<td>-4.6228*</td>
<td>-5.6132**</td>
<td>-6.4790**</td>
<td>-5.1336</td>
<td>-7.4277***</td>
</tr>
<tr>
<td>Yearly Average Rainfall (mm)</td>
<td>0.0125</td>
<td>-0.0649</td>
<td>-0.0866</td>
<td>-0.1124</td>
<td>-0.0855</td>
</tr>
<tr>
<td>Mean of Dep Variable</td>
<td>63.83</td>
<td>63.63</td>
<td>63.09</td>
<td>62.18</td>
<td>61.56</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>48</td>
<td>43</td>
<td>38</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>Autocorrelation†</td>
<td>0.001</td>
<td>0.002</td>
<td>0.032</td>
<td>0.042</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 1: Comparison of standard and AR(1) fixed effects panel estimators where standard estimates are bootstrapped. † p-values of serial correlation test for model without AR(1) errors using Wooldrige’s panel data serial correlation test with $H_0$: No serial correlation (see Drukker (2003)).

The pattern we would expect from an increase in the renewal rate: an immediate drop in yield, then an increase in yield in subsequent years. The higher lags are the wrong sign, but the lags on all these coefficients are statistically indistinguishable from zero.

Things change dramatically once the fourth lag is added. The signs are exactly what we expect; they are significant; and the relative magnitudes correspond to description in the quote from Margarido and Santos (2012) in section [3](#) (reverse the signs for the effect of a decrease in the renewal rate).

Once the 5th lag is added, the signs of the coefficients remain as expected, but the power seems inadequate.
References


Ewing, R. (2014). Brazil’s big cane mills cut costs, capex against losses.


Forero, J. (2014). Brazil’s ethanol sector, once thriving, is being buffeted by forces both man-made, natural.


The Economist (2008). The credit crunch reaches Brazil Inc.


A Notes and references for the history of Brazil and the Sugarcane industry from 2000-2012

A.1 Before the Crisis: Increasing production and increasing vulnerability

- From 2001 to mid-2008 the oil price rose from 50 BRL to 215 BRL per barrel [From graphs]

27
• In the early 2000s the Real was steadily appreciating against the dollar [From graphs]

• The renewal rate was particularly low in 1999 [From graphs]

• The renewal rate was low-ish in the mid-2000s, but not nearly as low as the troughs in 1999 and 2009-2010 [From graphs]

• Sugarcane yields declined in 1999-2000 and immediately recovered [From graphs]

• Between 2005-2007 the value of ‘loan liabilities’ held by Other Depository Corporations increased 5-fold [From graphs]

• “Taking advantage of the increase in the value of the Brazilian Real (R$), many sugar-cane plants took out cheap loans in US dollars and used the funds to speculate in foreign exchange derivatives. When the dollar’s value rose again in relation to the Real, many factories went bankrupt and the sector accumulated more than R$4 billion in losses.” (Mendonça et al., 2013)

A.1.1 Sugarcane firms were heavily indebted and hence vulnerable


• Mills became heavily indebted during expansion and were vulnerable to the credit crisis (Ewing, 2013a)

• “Liquidity problems, stemming largely from the global financial crisis that caught the industry over-leveraged from its expansion, forced more than 40 mills to shut down over the past few years. This took more than 30 million metric tons of Brazil’s 690 million metric ton crushing capacity.” (Ewing, 2013a)
A.1.2 Expectations that Brazil would be resilient to the crisis

- Pre-Lehman Brothers collapse analysts thought that the developing world would prove immune to the financial crisis (Filho, 2011)

- Brazil had a low debt/GDP ratio before the crisis (The Economist, 2008)

- “Although credit has been growing fast, it still amounts to only about 40% of GDP — a much lower figure than in developed economies” (The Economist, 2008)

- Observers believed Brazil was ‘decoupled’ and would fare well during the financial crisis, but became more pessimistic after the Lehman Brothers collapse (Sobreira and de Paula, 2010)

A.1.3 Credit is increasingly important in Brazil

- Credit expanded substantially from 2003-2011. “Credit operations”/GDP was 21.9% in 2003 and 40% in 2011 (de Mendonça and Deos, 2013)

A.2 Crisis: Tight margins

The gasoline (and hence ethanol) price was being kept low as a matter of government policy

- The ethanol price barely changed as oil prices fell off a cliff in 2008 [From graphs]

- The exchange rate dropped abruptly against the dollar in late-2008 [From graphs]

- The Diammonium Phosphate price increased 4-fold from early-2007 to mid-2008 [From graphs]
• In the second half of 2008, the oil price halved [From graphs]

• The sugar price stayed between 12-20 USD/bag from mid-2008 to mid-2009 [From graphs]

• Sugar prices declined from 18 to 13 in the second half of 2008 [From graphs]

A.2.1 Brazilian ethanol trade

• Global ethanol supply is dominated by US and Brazil (7)

• USA has been the major importer of Brazil’s exported ethanol (Neves et al 2011) (7)

• Recently Brazil has been importing ethanol from the US (Crooks and Meyer 2011) (7)

• The 2008 financial crisis decreased demand for ethanol in the USA and the EU, so Brazil’s total exports dropped by 35.6 percent in 2009 (Neves et al, 2011) (7)

A.3 Crisis: Tight credit

Credit was harder to obtain as banks tightened their lending requirements, while the industry’s balance sheets were in worse shape (highly leveraged and with low/negative margins)

• The value of private loans outstanding was constant from late-2008 to late-2009 [either because the value of the loans fell, or there were no new loans being issued] [From graphs]

• The Brazil average lending rate increased from 40 to 55 percentage points during 2008 [From graphs]
• In late-2008 ‘loan liabilities’ returned to their 2005 levels [From graphs]

• “The 2008-2009 crisis combined the impossibility of accessing resources for debt rollovers with losses from investments in exchange rate derivatives. Many plants went under, which intensified the process of acquisitions by and mergers with transnational corporations.” (Mendonça et al., 2013)

A.3.1 Renewal declined during the financial crisis

• Gross renewal did not change much during the 2005-2014, but the percentage renewal decreased because the large recent expansion (from 2006/2007 to 2009/2010) was not being renewed. Moreira (2015)

• “Investments have slowed in the expansion of cane production, one of the most capital intensive aspects of the business.” (Ewing, 2014)

• Investment in cane replanted diminished in response to credit market conditions (Ewing, 2013a)

A.3.2 Farmers had trouble accessing credit during the crisis

• “Farmers are finding it hard to find credit to buy fertilisers and pesticides” (The Economist 2008) (6)

• Loans specifically earmarked for replanting were not finding their way to farmers “Altogether, the government has provided R$13bn in extra farm finance this year but, like the loans for machinery, few farmers in Mato Grosso can use it. Ana Laura Menegatti of MB Agro, a farm consultancy in So Paulo, says that out of R$49bn made available to finance this year’s planting before the emergency funding, just R$18.5bn was actually lent to farmers nationwide. “Banks don’t
like the risk and there is too much bureaucracy, so very little finance gets to the farmers,” she says.” (Financial Times 2008) (6)

• “There are reports that farmers are finding it hard to find credit to buy fertilizer and pesticides, which could affect next year’s harvest” (The Economist 2008)

• The credit crisis had real impacts on the farming sector (Wheatley 2008)

• Many farmers could not use the government loans because they had no collateral (Wheatley 2008)

• Less than half of the emergency funding made it to farmers (Wheatley 2008)

• Big trading companies are lending less to farmers than usual (Wheatley 2008)

• Farmers fund their activities using their own funds, and loans from banks and agribusiness companies (Wheatley 2008)

• “Banks are repossessing farm machinery. Credit for fertiliser and other inputs has dried up.” (Wheatley 2008)

• “In Mato Grosso last week, the FT spoke to 26 farmers, just one of whom had made his 40 per cent payment this year, by selling land. The government has provided R$ 500m in credit to help pay loans on machinery, but most cannot use it because they have no collateral. Mr Spigosso’s situation is typical. He bought one combine harvester in 2001 for R$ 220 000 and another in 2003 for R$ 280 000. Because of accumulated interest, the debt on his two machines has grown to R$ 800 000, while the machines’ value has fallen to less than half that amount.” (Wheatley 2008)

• “out of R$49bn made available to finance this year’s planting before the emergency funding, just R$18.5bn was actually lent to farmers nationwide. “Banks
don’t like the risk and there is too much bureaucracy, so very little finance gets to the farmers,” she says.” (Wheatley, 2008)

• “Traders, such as Cargill Inc. and Bunge Ltd., cut credit to farmers to 25 percent this year compared with 52 percent for the previous crop, Agroconsult, a Rio de Janeiro-based consulting firm, has said.” (Cortes, 2009)

• “The amount of financing will determine the size of the crop,” Sperotto said in a telephone interview yesterday from Porto Alegre, Brazil. “Lower financing means smaller crops.”” (Cortes, 2009)

• “Companies stopped investing in, for example, the renewal of sugarcane plantations, crop handling and fertilization, which are needed to maintain high production levels. This is why in January 2012, the Brazilian government released R$4 billion in funds to be used specifically for plantation renewal.” (Mendonça et al., 2013)

• “The main argument ethanol plants used to justify the decline in productivity was their inability to invest in plantation renewal, fertilization and chemicals. One way of compensating the reduction in investments was through the territorial expansion of sugarcane monocropping. Despite the crisis, the BNDES continued to finance plants and, in early 2012, it made R$ 4 billion available to them through a line of subsidised credit to be used specifically for plantation renewal” (Mendonça et al., 2013)

A.3.3 Private and public lending during the crisis

• From 2008-2010 the private sector did not increase its credit outstanding as a percentage of GDP, and the public dsector stepped in to provide loans instead
• Public loans were provided to the agricultural sector by the Banco do Brazil (Barbosa 2011) (6)

• BNDES funds much of the sugarcane sector (Ewing 2013a)

• Public banks’ credit growth continued, while private banks’ credit growth stagnated (Canuto 2010)

A.3.4 Reasons the financial crisis affected Brazil

• Reasons the financial crisis affected brazil (Filho 2011)
  – withdrawal of portfolio capital and FDI
  – Interruption of credit, especially for foreign trade
  – Falling commodity prices
  – Declining exports to developed countries
  – Volatile exchange rates
  – Rising levels of profit repatriation by transnational corporations

A.3.5 Policy responses to the crisis

• In 2009 the BCB lowered the SELIC (interest) rate (Filho 2011)

• Public banks operated in credit markets to offset private banks’ preference for liquidity (Filho 2011)

• External credit was provided by BCB and (Brazilian) Federal Reserve Bank to finance exports (Filho 2011)
• There were exchange rate market interventions to mitigate the effect of the Real’s devaluation (Filho, 2011)

• The government pushed loan maturity in 2005 to 2010 [i.e. loans that would have matured in 2005 now matured in 2010] (Wheatley, 2008)

• “When farmers ran into trouble in 2005, the government ruled instalments due that year could be paid in 2010. Then it said instalments due in 2006 could be paid in 2011. In 2007, it said farmers must pay 15 per cent of what they owed, and the rest in 2012. This year, it said farmers must pay 40 per cent, and the rest in 2013.” (Wheatley, 2008)

• In resonding to the “severe liquidity problem” after the Lehman collapse, the Brazilian government: (Sobreira and de Paula 2010)
  – Raised the value to be deducted in the calculation of reserve requirements of the time deposits
  – Decreased the reserve ration of the demand deposits from 45 percent to 42 percent
  – Decreased the reserve ratio of time deposits from 100 percent to 30 percent
  – Decreased (to 40 percent) the reserve ration of time deposits of the biggest banks that acquired the credit operations of the smallest banks
  – These measures were designed to expand the quantity supplied of credit

• The government created direct lines of credit from BNDES, Banco do Brazil and Caica Econmica Federal. BNDES and BdB were to fund investment expenses and working capital. (Sobreira and de Paula, 2010)
• In mid-2009 the government reduced the long-term rate of interest from 6.25 percent to 6 percent [as measured by the TJLP] (Sobreira and de Paula 2010).

• “Central bank eased reserve requirements, designed to liberate an amount of liquidity potentially superior to 5.7 percent of GDP” (Canuto 2008) (de Mendonça and Deos 2013).

• Two main policy responses to the crisis (de Mendonça and Deos 2013)
  – central bank providing liquidity to banks
  – Public banks increasing the supply of credit

• The BCB sold US$14.5b in the spot market to support the Real (de Mendonça and Deos 2013).

• The BCB was also active in the derivatives market, offering swaps in which assumed liability positions in dollars, aiming to ensure hedge operations (de Mendonça and Deos 2013).

• *The paper has a table of changes in the reserve requirement ratios* (de Mendonça and Deos 2013).

• The reduction of reserve requirements involved an injection of around US$116b into the economy (de Mendonça and Deos 2013).

• Increased time deposit guarantee to R$20m per depositor per bank (up from R$60 000) (de Mendonça and Deos 2013).

• The use of foreign reserves, and monetary and fiscal policy were made possible because of the policy space previously acquired (Canuto 2010).
A.3.6  How the crisis unfolded in Brazil

- Credit problems began with a sell-off of shares and currency (The Economist, 2008).

- Currency sell-off triggered losses on foreign exchange derivatives (The Economist, 2008).

- News of exchange rate vulnerability led to fears about toxic assets (Canuto, 2008).

- Corporations were accepting dollar put options from banks in exchange for lower funding costs (Canuto, 2008) (de Mendonça and Deos, 2013).

- Foreign funds became more scarce so the Brazilian market redirected towards domestic credit (de Mendonça and Deos, 2013).

- Foreigners sold assets in Brazil, which lowered their price (de Mendonça and Deos, 2013).

- Brazilian corporations were exposed to around US$37b worth of currency derivatives, whose value fell when the Real depreciates (de Mendonça and Deos, 2013).

- Interest rate and exchange rate markets experienced high volatility (de Mendonça and Deos, 2013).

- Following the outbreak of the financial crisis there was an intense increase in liquidity preferences of agents, particularly banks (de Mendonça and Deos, 2013).

- Industrial production and exports of manufactured goods were the channels of transmission from credit markets to the real economy (Canuto, 2010).
A.4 Aftermath of the credit-crisis in the sugarcane industry

- From the start of 2008 to early 2014, the oil price increased from 95 to 250
  Real/barrel [From graphs]

- The renewal rate was particularly low in 2009 and 2010 [From graphs]

- In late 2014 the oil price halved [From graphs]

- The Diammonium Phosphate price spike ended and returned to trend in 2009-
  2010 [From graphs]

- From 2009 onwards, ‘loan liabilities’ steadily increased [From graphs]

- In 2009 the Real recovered and beban steadily appreciating against the dollar
  [From graphs]

- Sugarcane yields declined 20 percent in 2010 and stayed low in 2011 [From
  graphs]

- Ethanol prices increased rapidly in 2009 from 0.25 to 0.65 USD/Liter [From
  graphs]

- The sugar price increased rapidly through 2009-2011 and then steadily returned
  to 2008 levels by 2014-2015 [From graphs]

- Global demand for Brazilian ethanol is increasing again because of improve-
  ments in the global economy, and US blending more under the RFS (Ewing
  2013) (7)
A.4.1 Mills closed during and after the crisis

- 27 new mills opened in 2008, but 2011 to present has 10 net closures each year (6)

- “Since the 2008 financial crisis some 50 mills have shut of the 430 total in Brazil, while around 60 have entered court-protected restructuring” (Brough and Ewing, 2014)

- 50 mills have closed since the financial crisis and another 60 are expected to close in the next 2 years. (Ewing, 2013b)

A.4.2 Industry began to recover in 2012

- Industry invested $4b in cane expansion and renewal in 2012 (Ewing, 2013b)

- Government-subsidized loans allowed more replanting (Ewing, 2013a)

A.4.3 Production declined

- Brazil’s sugarcane production declined by 22 percent from 2010 to 2012 (7)

- “We observed rapid growth in the sector’s production levels, mainly between the 2004-05 and 2010-11 harvest years. During this period, there was a 50.08% increase in the amount of sugarcane processed. Also in this period, the production of sugar and ethanol increased 45.2% and 79.6% respectively. However, there was a change in this trend during the 2011-12 harvest: while the volume of production began to decline, the territorial expansion of sugarcane monocropping continued.” (Mendonça et al., 2013)
A.4.4 **Brazil recovered quickly after the crisis**

- Brazil bounced back in 2010 (Filho 2011)
- Real GDP only fell in 2 quarters in early 2009 (Canuto 2010)

A.4.5 **Foreign companies have had their ability to purchase land restricted (closing a potential source of investment in the industry)**

- Foreign companies can no longer purchase unlimited land (Colitt and Ewing 2010)
- “The government has decided to close a legal loophole that had permitted foreign interests to circumvent existing restrictions by creating a Brazil-based company, the attorney-general’s office said.” (Colitt and Ewing 2010)

A.5 **Secular trends through the crisis**

- The Diammonium Phosphate price trended upward (roughly linearly) from 2001-2014 [From graphs]
- The Brazilian average lending rate had a downward trend from 1999 to 2014 [From graphs]
- The value of loans outstanding for public and private banks increased roughly logistically from 2003 to 2015 [From graphs]
- Sugarcane yields remained roughly stable from 2000-2010 [From graphs]
A.5.1 Mechanization has increased productivity

- The industry has invested $4.5b in mechanization of harvesting since 2006 (Ewing, 2013b)

- Mechanization has greatly augmented the productivity of labor (Forero, 2014)

- “Among the drivers was Hugo Dantas, who years ago did the cutting by hand, harvesting eight tons on a good day. “God set me free,” Dantas, 34, said as his machine cut through a sea of cane. “From here, I can cut up to 700 tons — one machine, 700 tons, every 24 hours.”” (Forero, 2014)