Assessing Brazil’s Cerrado agricultural miracle

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1 AUTHOR:

Nicholas Rada
United States Department of Agriculture

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Nicholas Rada*


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ABSTRACT

Brazil’s emergence as a primary global agricultural producer is often credited to production expansion into soils of the Brazilian savannah or Cerrado. These soils are, however, deficient in important nutrients and prone to degradation, requiring input-intensive processes that suggest a low level of productive efficiency. Employing a sequence of agricultural censuses and a biome approach for characterizing agricultural zones, the present study evaluates the Cerrado’s total factor productivity growth and productive potential. The analysis highlights the resource cost of Brazil’s “Cerrado Miracle,” the role of paved road infrastructure in expanding production opportunities, and the significant production gains that the Cerrado may yet achieve. Results suggest a substantial productivity gap between the Cerrado’s most efficient and average producers, implying that Cerrado production might well be further boosted if average producers succeed in adopting the technologies and management practices of the more efficient operators.

More generally, and to the extent the Cerrado model is generalizable elsewhere, agricultural development of the world’s savannahs, such as Sub-Saharan Africa’s Guinea regions, into breadbaskets will be expensive in terms of material inputs such as fertilizers and pesticides, depending for their success therefore on the real prices of these inputs.

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Introduction

Shortly after the 2007–2008 food price crisis, the Food and Agricultural Organization (FAO) estimated global food production would, by mid-century, need to rise 70% to feed an additional 2.3 billion people (FAO, 2009). FAO expressed cautious optimism when saying that such a boost likely would require 120 million more hectares of arable land, pointing to Sub-Saharan Africa and Latin America as potential sources of farmland expansion. That optimism may in part be driven by Brazil’s successful agricultural transformation of its broad savannah, the Cerrado. Some analysts now consider some of the world’s other savannah regions, including Sub-Saharan Africa’s vast Guinea Savannah, to have the potential to become new breadbaskets, in part because of the agro-climatic characteristics they share with the Brazilian Cerrado (Morris et al., 2012).

Brazil’s agricultural ascendance into the global market is often credited to production expansion into the Brazilian Cerrado (Economist, 2010; New York Times, 2007). Yet these soils are made up primarily of oxisols (46%) and ultisols (15%), weathered soils deficient in important nutrients such as nitrogen, phosphorus, and potassium (Lopes, 1996). Indeed, these tropical soils are characterized by good physical structure but low fertility, high acidity, and a proneness to degradation (Thomas and Ayarza, 1999). Overcoming such obstacles, Brazilian farmers have employed improved management practices and Embrapa- and university-developed modified crops and grasses (for pasture) to improve the Cerrado biome’s productive capacity. For example, Brazil was in 2006 the second-largest global producer of soybeans (FAO, 2011), 48.7% of that coming from the Cerrado.

Farms in this biome, often considered the frontier of Brazilian agriculture, rely on material inputs to ensure that farm technologies thrive in the biome’s acidic soils. But as new policy assessments look to the Cerrado as a potential model for transforming other savannahs (Morris et al., 2012; World Bank, 2009), it is imperative that we understand the true resource cost of such transformations. The Guinea Savannah in particular stretches across 400 million hectares of arable land in Sub-Saharan Africa; yet less than 10% of it is cropped (World Bank, 2009). Successfully adapting Brazilian agricultural technologies may provide one key to expanding and improving its output, especially in Mozambique, Nigeria, and Zambia, where for each the Guinea Savannah accounts for a minimum of 63% of total land area (World Bank, 2009). Morris et al. (2012) and the World Bank (2009) have examined the success of the Cerrado transformation and the policy challenges facing the Guinea Savannah. The present study instead focuses on providing an economic evaluation of the Cerrado’s agriculture, indicating...
how the productivity gap between the Cerrado’s most-efficient and average producers provides an opportunity for expanding the Cerrado’s agricultural potential.

Our hypothesis is that the Cerrado’s soils require significant investments in the material inputs needed to, for example, improve nutrient composition enough to allow commercial exploitation. Taken on its own account, that fact is a drag on productive efficiency. The input-intensive nature of the biome’s production processes, the substantial distances most material inputs must travel, and the sparseness of paved highways, are reasons to suspect the Cerrado of low productivity growth. If Cerrado producers have indeed operated at low productive efficiency, any significant output-price drop or input-price spike likely would reduce farm profitability and threaten Brazil’s position as a globally competitive agricultural supplier. Employing Brazilian agricultural census data (1985, 1995/1996, 2006) and environmental rather than political boundaries, the present article explores the resource cost of agricultural production in a savannah of low nutrient quality, focusing on the role of infrastructure in expanding the technological frontier.

Results indicate that annual factor productivity growth among the Cerrado’s most efficient producers has been slightly more rapid in the livestock than in the crop sub-sectors of the agricultural economy. Paved-road infrastructure investments have significantly affected crop and livestock productivity growth of the Cerrado’s most efficient farms; a 1% improvement in paved-road density raises both livestock and crop production by more than 1%. However, the high resource cost of savannah production is clear. The average farm was, between 1985 and 2006, unable to keep pace with the most-efficient producers, achieving a total factor productivity (TFP) growth rate of only 0.4% per annum. Such high resource cost translates into a sizeable TFP gap between most-efficient and average farmer which, if closed, would substantially boost Brazil’s international position as a globally competitive supplier of agricultural commodities.

A biome assessment of Brazil’s productive efficiency

Evaluations of Brazil’s agricultural performance have focused predominately on measuring total factor productivity (TFP) growth and on comparing growth rates across such political boundaries as states or regions (Rada and Buccola, 2012; Gasques et al., 2010; Pereira et al., 2002; and Avila and Evenson, 1995). Of these studies, only Avila and Evenson (1995) have reported TFP growth rates beyond political boundaries, namely by agro-ecological zone. The latter provides an opportunity to evaluate production’s performance on the basis of climate, soil, and terrain characterizations. Brazil has 92 agro-ecological zones, too many for concise result reporting. Indeed, Avila and Evenson (1995) reported TFP growth estimates for only 22 of them.

The Brazilian savannah extends across every Brazilian region and 11 of the 27 states (Fig. 1). Hence, any analysis focusing on political boundaries obscures the agricultural performance and productive potential of the Cerrado itself. In evaluating the Cerrado, the present article evaluates, for the first time, agricultural TFP by Brazilian biome, providing an improved understanding of the productive efficiency of Brazil’s most important macro-ecosystem. A biome approach is not uncommon in the environmental literature (Klink and Machado, 2005; Ratter et al., 1997) but apparently has not yet been used for productivity estimation in the economics literature. Castro de Rezende (2003) and Barros et al. (2007) provide the only other known economic analyses focusing strictly on the Cerrado. The former is a land market analysis, the latter an assessment of the Cerrado’s competitive agricultural potential. Both define the Cerrado by political boundaries.

Moreover, Barros et al. (2007) define the Cerrado differently in the same report, alternating between using the Center-West states and the states of Goiás, Minas Gerais, and Mato Grosso. Unfortunately also, all these states contain biomes other than the Cerrado’s, and the Cerrado biome itself extends into seven other Brazilian states.

Brazilian biomes

Brazil may be divided into six biomes: Amazônia, Cerrado, Pantanal, Caatinga, Mata Atlântica, and Pampa (Fig. 1) (IBGE, 2006). Biome classifications are unique in that they express the environmental conditions which enable flora and fauna to inhabit the given area. The primary objective of the present analysis is to isolate and evaluate farm productivity in the Cerrado biome. For comparison, the Pantanal and Amazônia biomes are grouped together to form a Western biome, and the Cerrado, Caatinga, and Mata Atlântica biomes to form an Eastern biome.

The Amazônia biome is the largest in Brazil, accounting for 49.3% of the nation’s total area (Portal Brasil, 2011). Covering five states, it may be generally classified as a tropical rainforest with a hot and humid climate, heavy rainfall, and highly acidic soils of low fertility and drainage. The Pantanal biome borders the Amazônia on one side, spans two states, and is characterized as temperate grasslands with long-term flooding. These two biomes together cover 51.1% of Brazil’s land area yet, over the 1985–2006 period, generated only 6% of its mean total production value.

The Cerrado biome is Brazil’s second largest, accounting for 23.9% of the nation’s area (Portal Brasil, 2011). Crossing 11 states, it contains the source of three major river basins, has a hot sub-humid tropical climate, distinct wet and dry seasons, and consists of tropical grasslands and savannah whose acidic soils are relatively infertile. As farm expansion into this biome accelerated, so did its share of total farm revenue, rising from 19.2% in 1985, to 28.7% in 1995/1996, and peaking at 33.2% in the 2006 census period. As shown in Fig. 2, 1985–2006 mean production shares in the Cerrado are greatest for cotton (48.8%), oranges (41.7%), soybeans (39.6%), cattle (37.0%), and sugar (32.0%).

The Eastern biome – Caatinga, Mata Atlântica, and Pampa – is slightly larger than the Cerrado, accounting for 25% of Brazil’s land (Fig. 1). The Caatinga extends over 10 states and is a tropical scrub forest of deciduous vegetation and two distinct dry seasons prone to drought. The Mata Atlântica, or Atlantic Forest, biome stretches over 15 states comprised of hot, humid, tropical deciduous forest. The Pampa biome, present only in the state of Rio Grande do Sul, is classified as a steppe and extends into Uruguay and Argentina. It has rainy weather and no dry season; grasses and shrubs are the primary vegetation. Although the Eastern biome covers only one-quarter of Brazil, it accounts for a mean 65.45% of total crop revenue and 34.55% of total livestock revenue over the sample time period. As shown in Fig. 2, the Eastern biome has produced, on average, a minimum 48% of all commodities reported over the three census periods (see Fig. 3).

Transportation infrastructure investments

Concern about Brazil’s transportation infrastructure and its impact on farm production and profitability, especially in the Cerrado, have been widespread (Vera-Diaz et al., 2009; Costa and Rosson, 2007; Matthey et al., 2004; Schnepf et al., 2001). The most vital form of Brazilian farm transportation is the road system. Matthey et al. (2004) found farm transportation costs in the state of Mato Grosso highest if commodities traveled by truck; yet 62% of farm products are shipped in this manner. Caixeta-Filho and Gameiro (2001) note that greater than 95% of the Cerrado biome’s export destined cotton production is transported by truck to Brazil’s
southern ports. And an estimated 60% of soybeans and 81% of total farm production are road-transported from this biome (ANUT, 2008).

Because careful farm management techniques and material input use are required in order for the Cerrado’s soils to be productive, farms there must thus rely on roads to not only send outputs to market but to obtain the large volume of necessary inputs. And the importance of material inputs to the Cerrado has been great, its share of national material expenditures rising from 23% in 1985 to 25.8% in 1995/1996, then leaping to 43.7% in 2006.\(^1\) Indeed, by 2006 the Cerrado biome accounted for 49.2% of Brazil’s

1 All material expenditures are normalized to 2006 Reais.
fertilizer expenditures and 48% of its pesticide expenditures. And Brazil that year was globally the seventh-largest user of nitrogen fertilizer, fourth-largest user of phosphate fertilizer, and third-largest user of potash fertilizer (FAO, 2011).

Measuring TFP growth

Total factor productivity is generally defined in accounting terms, namely the ratio of an aggregate of total outputs to an aggregate of total conventional inputs and hence the efficiency with which inputs are transformed into outputs. As such, agricultural total factor productivity reflects the total conventional resource cost of farm production. For this purpose, TFP is preferable to other partial-productivity measures, such as yield per hectare (land productivity) or output per worker (labor productivity), because such partial measures account for only a single production factor, whereas TFP accounts for the contributions of all measurable inputs, principally land, labor, capital, and materials. While growth in labor or land productivity may be attributed to rising use of other – less easily observed – inputs, TFP growth reflects improvements in the efficiency of the aggregate conventional input bundle.

While TFP accounting measures have the benefit of providing statistical significance: p < 0.10.
** p < 0.05.
*** p < 0.01.

Re-specifying the left hand side of (1) in exponential form

\[ D(\cdot) = \exp(\ln x_{it}, \ln y_{it}^{M}, \ln R_t; \delta) \]

in which inputs \( x_{it} \in \mathbb{R}, k = 1, \ldots, K \), and outputs \( y_{it}^{M} \in \mathbb{R}, j = 1, \ldots, M \), are in scalar form; \( t = 1, \ldots, T \) is a time trend proxying for technical change; \( i = 1, \ldots, N \) defines each observation; are Brazil’s road densities; \( \delta \) is an estimable parameter; \( u_{it} \sim N(\mu, \sigma^2) \) is a nonnegative, half-normally distributed error representing an observation’s departure from its technical frontier; and \( v_{it} \) is an independently and identically distributed (iid) random noise with mean zero and variance \( \sigma_v^2 \) (Aigner et al., 1977). Error terms \( v_{it} \) and \( u_{it} \) are assumed distributed independently of one another: \( \sigma_v = 0 \).

Re-specifying the left hand side of (1) in exponential form

\[ D(\cdot) = \exp(\ln x_{it}, \ln y_{it}^{M}, \ln R_t; \delta) \]

where \( g(\cdot) \) is a function gives an expression of a given observation’s stochastic distance to the technically efficient frontier. Converting that expression into the distance frontier employed in the present analysis requires imposing linear homogeneity in inputs (Shephard, 1970). This may be done by allowing \( x_{it} = x_{it}/x_{it}^{\#} + \infty \), in which the \( \# \)th input is employed as numeraire (Lovell et al., 1994). Rearranging terms, taking logs,
and modeling inefficiency error after Battese and Coelli's (1992) time-effect parameterization − u(t) = u0 + η(t − S0) + u1H, where η is an iid random variable to be estimated − brings

\[ -\ln x_{it} = g(\ln x'_{it}; \ln y_{jit}, \ln R_{it}, t; \delta) - y_{it} + u_{it}. \]  

(2)

\[ g(\ln x_{it}, \ln y_{jit}, \ln R_{it}, t; \delta) = \delta_0 + \sum_{k=1}^{K} \delta_k \ln x_{it} + \sum_{j=1}^{M} \delta_j \ln y_{jit} + \delta_g \times \ln R_{it} + \delta_t t \]  

(3)

where subscript k indexes family labor, hired labor, capital, and materials, respectively; j indexes crop or livestock; i indexes 558 Brazilian micro-regions; and t is the time trend spanning three consecutive censuses (1985, 1995/1996, and 2006). The \( t^\text{th} \) input, used as numeraire to impose linear homogeneity, is land, allowing for a per-hectare interpretation of each normalized input.

One of the many advantages of Brazil's agricultural census data is its rich cross-section, information exploited here to allocate each micro-region to its respective biome. Using Geographic Information Systems (GIS), the centroid of each micro-region is located in relation to Brazil's GIS-mapped biomes (Fig. 1). Biomes, however, are not defined by political boundaries. When a micro-region straddles several biomes, a biome's input and output allocations are here computed on the basis of the biome in which the majority of the micro-region's municipalities or counties reside. Five micro-regions, constituting 0.9% of the sample total, are equally split between biomes. These were allocated by determining in which biome the micro-region had the greatest land area.

Because the focus of the present analysis is on biome-specific TFP growth rates, it is important to control for state-wise, time-invariant, unobserved heterogeneity. Stochastic frontier methods often incorporate fixed effects through inefficiency error \( u_{it} \). That approach, as noted by Greene (2005), may confound state-wise and time-wise inefficiency with all other unobserved heterogeneity across states. Alternatively, dummy variable \( P_h, h = 1, \ldots, H \) may account for state-wise, time-invariant heterogeneity, leaving error \( u_{it} \) to account for any agricultural inefficiency. Incorporating dummy variable \( P_h \) into Eq. (3), rewriting its right-hand side as \( g(P_h, \ln x'_{it}; \ln y_{jit}, \ln R_{it}, t; \delta) \), and substituting that into into Eq. (2) gives

\[ -\ln x_{it} = g(P_h, \ln x'_{it}; \ln y_{jit}, \ln R_{it}, t; \delta) - y_{it} + u_{it}. \]  

(4)

Technical change in (4) is measured by the model's time trend, allowing one to statistically distinguish among the technical change rates in the various crop and livestock subsectors of the Brazilian agricultural economy. Technical change statistics are

\[ E(TE_h) = E[e^{u_{it}/u_{it}}]. \]  

(5)

Data

Three Brazilian agricultural censuses (1985, 1995/1996, 2006) are chosen for the present analysis, providing panel data for 558 micro-regions and covering 20 outputs and 11 inputs. The farm-level survey data are employed at two aggregation levels: micro-region and state (Table 1). Descriptive statistics for both output and input data are provided in Table 2.

Production data

The 20 commodities included in this analysis are from the micro-region data, recorded in metric tons and aggregated into two revenue-share-weighted quantity indexes: crops and livestock. Crops accounted for 72% of total revenue in 1985, livestock making up the other 28%. By 2006, the livestock sub-sector had gained 6 percentage points, shifting those shares to 66% and 34% respectively.

The majority of recorded production inputs are available in the censuses at the micro-region level. They are hectares of agricultural land and fertilizer, feed, seed, pesticides, livestock vaccines, and electricity expenditures. Although some labor, livestock, and farm machinery data are available at the micro-region level, the remaining are state aggregations. The infrastructure data, recorded in the annual statistical yearbooks, are available at the state level. All data not available at the micro-region level are imputed to the micro-region and described in Appendix A. Each of Brazil's 27 states, themselves comprised of the 558 micro-regions, is shown in Fig. 1. Because the Brazilian currency changed five times between 1984 and 1994, 1985 output and input prices are converted to Reais. All 1985 and 1995/1996 prices are then normalized to a 2006 basis using the Internal Availability General Price Index (IGP-DI), which captures wholesale, consumer, and construction price changes (IBRE, 2010).

Evaluating the production data by biome

Each variable's description, unit of measurement, number of microregions, and mean values by biome, are provided in Table 2. Unsurprisingly, mean crop and livestock production in the Cerrado exceeds that in the Eastern biomes by a factor of 1.6 and 1.4, respectively, indicating the Cerrado's larger scale of operations. Indeed, not only does an average farm (representative of that average microregion) produce more than its counterparts in the East, it also employs substantially more resources. For instance, an average

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2 Attempts to include various policy variables, such as stocks of Embrapa's agricultural research expenditures, into the technology function were met with heavy collinearity with the time trend.

3 Such an approach is recommended by Greene (2005) for efficiency measurement provided dummy variable \( P_h \) accounts for unobserved heterogeneity that is not efficiency related.

4 The reader is referred to Rada and Buccola (2012) for a review of the currency changes in Brazil.
farm in the Cerrado spends 2.6 times as much on material applications (fertilizer, pesticides, animal vaccines, seed, feed, and electricity) and twice as much on capital services (machinery and livestock) as a farm in the Eastern biome. Moreover, the farm in the Cerrado employs 2.8 times as much quality-adjusted land. These descriptive statistics underline the disproportionately resource-intensive nature of producing agricultural commodities in the Brazilian savannah.

Road densities

Lengths of road, in kilometers, are available in various Brazilian statistical yearbooks at the state-level and account for roads under municipal, state, and federal jurisdictions. State-level paved road densities employed in this analysis are then measured as the sum of the length of asphalted road, divided by the state’s geographic area. Brazilian statistical yearbooks show that 1.58 million kilometers of road were built in 2006, 11.4% of them paved. That was an improvement over the 1.38 million kilometers of road in 1985, of which only 5% were paved (AEB, 2008, 1986). Paved roads are particularly important to Brazilian producers because the cost of traversing paved roads is one-third that of unpaved roads (Vera-Diaz et al., 2009).

Results

Models (4)–(5) were estimated by STATA 12 with full information maximum likelihood. Coefficient estimates of distance frontier (4) are provided in Appendix Table A1 for each biome grouping. Technical change estimates are provided in Table 3, and mean technical efficiency changes and total factor productivity growth rates in Table 4.5

The highest pair-wise correlation, across all biome applications of Eq. (4), is the 0.81 between hired and family labor in the Eastern biome. But because that same pair-wise correlation is 0.65 in the Cerrado biome, both labor variables are retained in every biome-specific regression to maintain model consistency.6 Such consistency is especially important for generating a national biome-reve-

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5 Because the Brazilian census data are decennial, linear annual growth across a given decade is assumed to allow for result comparability with other analyses. For instance, the Cerrado’s annual 4.33% rate of technical change in Table 4 reflects a 43.12% per-decade rate of change over the 1985–2006 period.

6 Omitting hired labor from each model does not alter the nationally biome-aggregated total factor productivity growth rate by more than 0.08%.

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Note: IBGE is the Brazilian Institute of Geography and Statistics.


6 Omitting hired labor from each model does not alter the nationally biome-aggregated total factor productivity growth rate by more than 0.08%.
### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Unit of obs.</th>
<th>Western</th>
<th>Cerrado</th>
<th>Eastern</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of microregions (obs.)</td>
<td>Mean values</td>
<td>Number of microregions (obs.)</td>
<td>Mean values</td>
<td>Number of microregions (obs.)</td>
</tr>
<tr>
<td><strong>Crops</strong></td>
<td>Beans, cotton, maize, manioc, onion, groundnuts, rice, soybeans, wheat, tomato, bananas, cocoa, coffee, oranges, and sugarcane</td>
<td>Metric tons</td>
<td>219</td>
<td>9744</td>
<td>318</td>
</tr>
<tr>
<td><strong>Livestock</strong></td>
<td>Cattle meat, eggs, cow milk, poultry meat, and pig meat</td>
<td>Metric tons</td>
<td>219</td>
<td>5579</td>
<td>318</td>
</tr>
<tr>
<td><strong>Family labor</strong></td>
<td>Male-labor equivalents</td>
<td>Count</td>
<td>219</td>
<td>28,694</td>
<td>318</td>
</tr>
<tr>
<td><strong>Hired labor</strong></td>
<td>Male-labor equivalents</td>
<td>Count</td>
<td>219</td>
<td>3946</td>
<td>318</td>
</tr>
<tr>
<td><strong>Land</strong></td>
<td>Temporary-cropland-equivalents</td>
<td>Hectares</td>
<td>219</td>
<td>96,956</td>
<td>318</td>
</tr>
<tr>
<td><strong>Capital</strong></td>
<td>Machinery and livestock capital service expenditures</td>
<td>Thousands of constant 2006 Reais</td>
<td>219</td>
<td>37,387</td>
<td>318</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>Fertilizer, seed, pesticide, animal vaccine, feed, and electricity expenditures</td>
<td>Thousands of constant 2006 Reais</td>
<td>219</td>
<td>24,873</td>
<td>318</td>
</tr>
<tr>
<td><strong>Paved roads</strong></td>
<td>Kilometers of paved roads per square kilometers of area</td>
<td>Density</td>
<td>219</td>
<td>0.005</td>
<td>318</td>
</tr>
</tbody>
</table>

Note: Mean estimates are for observations with positive values only.

### Table 3

<table>
<thead>
<tr>
<th>Biome</th>
<th>Output</th>
<th>Informal Technical Change Rates (TCR) (%)</th>
<th>Output elasticity of roads (%)</th>
<th>Time rate of change in roads (%)</th>
<th>Roads impact (%)</th>
<th>Total TCR (%)</th>
<th>Output’s revenue share weights (%)</th>
<th>Biome’s aggregated TCR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western</td>
<td>Crops</td>
<td>6.99</td>
<td>−0.75</td>
<td>0.045</td>
<td>−0.03</td>
<td>6.96</td>
<td>48</td>
<td>5.38</td>
</tr>
<tr>
<td></td>
<td>Livestock</td>
<td>3.94</td>
<td>−0.43</td>
<td>0.02</td>
<td>3.92</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerrado</td>
<td>Crops</td>
<td>4.17</td>
<td>1.02</td>
<td>0.033</td>
<td>0.03</td>
<td>4.20</td>
<td>63</td>
<td>4.33</td>
</tr>
<tr>
<td></td>
<td>Livestock</td>
<td>4.51</td>
<td>1.11</td>
<td>0.04</td>
<td>4.55</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern</td>
<td>Crops</td>
<td>4.49</td>
<td>0.00</td>
<td>0.017</td>
<td>0.00</td>
<td>4.49</td>
<td>65</td>
<td>7.10</td>
</tr>
<tr>
<td></td>
<td>Livestock</td>
<td>12.02</td>
<td>0.00</td>
<td>0.00</td>
<td>12.02</td>
<td>35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a* The Western biome grouping consists of the Amazônia and Pantanal biomes.

*b* The Eastern biome grouping consists of the Mata Atlântica, Caatinga, and Pampa biomes.

*c* Time rates of change are rounded to the third decimal point.
mean 67% of total revenues during the three census periods; yet its most efficient producers also achieved the most rapid efficiency improvements, largely on the progress made in its livestock subsector. Indeed, the Eastern biome’s share of total livestock revenues averaged 63.8% between 1985 and 2006, further emphasizing the biome’s outstanding livestock technical progress.

Technical efficiency change and TFP growth

The technical efficiency changes provided in column 1 of Table 4 show that in each biome, average producers were unable to match the most efficient farms. For instance, while the most efficient farms in the Cerrado progressed at an impressive 4.3% annualized pace, average farm productivity rose by only 0.4% per annum, the gap between frontier and average farm expanding 3.9% each year. Surprisingly, the Eastern biome not only achieved Brazil’s most rapid technical progress but, at 4% per annum, the fastest average-farm total factor productivity growth. The Eastern biome’s average-farm TFP growth rate clearly lifts the entire nation’s TFP growth (Table 3).

In the Western biome, the rate of technical efficiency loss has exceeded the rate of technical progress (outward shift in the production possibility frontier), so that total annual factor productivity growth has been a negative 0.82%. This suggests that while efficiency on some farms (possibly those bordering the Cerrado) improved rapidly, average producers used inputs so inefficiently that input growth exceeded production gains. Yet Gasques et al.’s (2010) index-number-generated TFP growth rates in the 1985–2006 period do not include any Brazilian state with negative TFP growth. Methodological differences between the Gasques et al. analysis and the present one may partially explain this difference. But the likely more important factors include the greater number of outputs (367) that Gasques et al. account for and the different approach they use to measure inputs. For instance, while Gasques et al. account for a greater number of material inputs and assume that all land is of equal quality, the present analysis accounts for more capital and labor inputs and adjusts for each land type’s distinct productive capacity. In spite of these differences, weighting each biome’s TFP growth rate (column 2 of Table 4) by its respective mean revenue share over the 1985–2006 period generates a national biome-aggregated TFP growth rate of 2.73% per annum. This estimate is very close to the only other studies employing 1985–2006 Brazilian census data: Gasques et al.’s index number estimate of 2.87%, and Rada and Buccola’s (2012) input distance frontier estimate of 2.62%.

Discussion

In isolating and evaluating the productive performance of the Brazilian Cerrado, new information is presented that may help us understand the resource cost of producing in a savannah and how the targeting of infrastructural investments might be improved.

Paved-road density’s uneven impact

Paved-road density’s impact varied widely by biome, but in the Cerrado was significant. It is thus reasonable to ask what information might best assist policy makers in targeting infrastructural investments to boost farm productivity. The present results suggest road systems’ productivity performance (Table 3) may depend on the level of Brazil’s infrastructural development, which is quite uneven. The failure of farms in such highly developed regions as the Brazilian South and Southeast to benefit from additional road density is likely because roads there already are heavily paved. Eighty-three percent of the South and Southeast micro-regions are in the Mata Atlântica biome and account for an average 65% of all paved roads in the 1985–2006 period. In contrast, the failure of farms in such infrastructure-poor regions as the Western biome to benefit from new road construction might well be because farm production there is adequately commercial to exploit it. Brazil’s northern states dominate the Amazônia biome and account for only a 7.7% mean share of 1985–2006 paved roads. Indeed, a negative coefficient may represent the substantial set-up cost of developing a commercial farm in that region.

Assessing the productive performance of the Cerrado

Producers at the Cerrado’s technical frontier, that is who managed their resources most efficiently, have enjoyed an average TFP growth rate of 4.3%. But the great majority of enterprises were unable to match that efficiency, so that overall average TFP growth rate was only 0.4%. This 3.9% TFP gap suggests considerable room for efficiency improvement and thus for production levels well above those in 2006.

Central to our objectives is to estimate the resource cost of producing in the Brazilian Cerrado. To answer that question we computed, between 1985 and 2006 and for all 318 microregions, the Cerrado’s average revenue-share-weighted production growth. Between those years, the Cerrado’s logged mean growth rose 192%, from 146,088 to 995,563 tons. But the Cerrado’s logged TFP growth implies the average farm produced only 7.9% more in 2006 than in 1985 without applying more inputs. Because the log of TFP growth is the difference between logged output growth and logged input growth, these estimates suggest that only 7.9% of the 192% production rise can be accounted for by improved efficiency or technology. Stated differently, given that TFP growth accounted for 15% of production growth, the use of additional inputs must have accounted for the remaining 177%, confirming the high resource cost of Cerrado farming. Production growth on the average Cerrado farm thus is based predominantly on bringing more labor, land, materials, and capital into production rather than on improving the efficiency of existing resources.

Further evaluations of the substantial gains in Brazil’s agricultural development might well focus on the impact of scale economies to the Cerrado biome’s productivity growth. The sources of any such scale economies would be captured in our TFP measures presented above. But given the large TFP gap between the Cerra-
do's average and most efficient producers, it would be interesting to ask whether these most-efficient farms are large commercial ones or smallholders. Helfand and Levine (2004) find a nonlinear relationship between farm size and technical efficiency, the efficiency first declining and then rising with farm size. But they do so in a two-stage approach rather than by decomposing TFP growth into its technical progress, efficiency change, and scale economy components, and they focus on the entire Center-West region rather than Cerrado biome. Isolating the contribution of scale economies to the Cerrado's TFP growth would improve our understanding of the forces behind the Cerrado's 'agricultural miracle' and more generally help target the policies designed to promote savannah agricultural growth.

Conclusion

This paper finds that agricultural production in the Brazilian savannah has been highly resource-intensive. While the Cerrado's most efficient farms have accelerated production in part through substantial efficiency improvements, the majority of farms have boosted production largely through greater resource use. This suggests that any agricultural transformation of native savannah, in the Brazilian Cerrado, Guinea Savannah, or elsewhere, will have high resource cost. Paved road investments have played a significant role in boosting the productivity growth of the Cerrado's most efficient producers. Because road-paving impacts have varied widely across biomes, such infrastructural investments appear to bring a particularly high return when targeted toward areas in which paved roads are a major limitation to agricultural growth.

Brazil could substantially improve its global competitive position in the supply of important farm commodities by improving average efficiency in the Cerrado itself, such as by pushing average-performing farmers toward the technologies and management practices of those on the technical frontier. That would provide a significant contribution toward the 70% global food supply rise that some spokesmen have called for by mid-century. Optimal growth policy in the world's other savannah regions such as the Guinea Savannah is less clear. Whether, as in the Cerrado, a large-scale commercial agricultural approach is taken, or as recommended by Morris et al. (2012) smallholder-led commercialization instead is adopted, success will depend on the real prices of the substantial material input quantities shown in the Cerrado to be required for maintaining adequate plant growth under savannah conditions. Costs of material inputs like fertilizers, pesticides, feed, seed, and power appear indeed to be a great constraint to raising farm production when expanding onto new arable lands of low nutrient composition.

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Appendix A. Data

As described below, some of the inputs are quantity indexes and others expenditure indexes. Upon converting all output and input prices to Brazilian reais, 1985 and 1995/1996 prices are converted to a 2006 basis via Brazil's General Price Index-Domestic Availability (IGP-DI), which captures wholesale, consumer, and construction price changes (IBRE, 2010).

Labor

Labor's contribution to production is represented by two male-equivalent labor quantity indexes: hired and family labor. 1985 and 1995/1996 state-level labor counts are obtained from Avila and Evenson (1995) and 2006 micro-region-level labor counts from the Brazilian Institute of Geography and Statistics (IBGE, 2010). Female labor is quality-adjusted to male-labor equivalents, using the mean ratio of 1998–2002 female to male agricultural wage rates specific to Brazil (International Labor Organization, 2010). Over that time period, female agricultural labor wages were on average 92% of male wages.

The 1985 and 1995/1996 state labor counts require interpolation to the micro-region. Those labor counts are available by type (i.e., family, permanent-hired, and temporary-hired) and agricultural sub-sector (crop, livestock, and forestry). Following Avila and Evenson (1995), each labor type engaged in the livestock sub-sector is weighted by the micro-region's state share of livestock sold. Labor engaged in crop agriculture is interpolated to the micro-region by weighting each labor type by the micro-region's share of total cropland. Every state's forestry labor is distributed equally to each micro-region in that state.

In constructing the male-equivalent hired labor index, permanent and temporary labor are summed and multiplied by each state's agricultural-labor gender share, then re-aggregated using the ILO wage data. A similar approach is taken for family labor to construct its male-equivalent labor index. Because the 2006 census labor data are available by gender and type at the micro-region level, no interpolation is required to obtain the family and hired-labor male-equivalent quantity indexes.

Land

Hectares of land are available at the micro-regional level in each census, quality differentiated into four groups: permanent cropland, temporary cropland, natural pasture, and planted pasture. The planting of perennials distinguishes permanent from temporary cropland, which is itself planted to annuals, forages, and flow- ers. Because reliable land rental rates are unavailable, Fuglie's (2010) method of estimating relative land weights for each land group and census period is followed to generate a temporary-cropland-equivalent land series. Those weights are available in Rada and Buccola (2012). Quality-adjusting land is important when measuring productivity growth because bias might arise in the land series if land changes occur unevenly among groups (Fuglie, 2008), as was the case in Brazil. The land weights indicate temporary cropland is assumed the most productive in 1985 and 2006, permanent cropland taking that mantle in 1995/1996.

Capital

Unlike the land and labor quantity indexes, the capital index is expressed as expenditures on farm machinery and livestock services. The farm machinery data is limited to tractors, 1985 census data shortage restricting the measure from a broader range of mechanical implements. Barros (1999) provides state-level 1985 and 1995/1996 tractor service prices. These prices are estimated by using new and used 1997–1998 prices of two Massey Ferguson tractor sizes, amortized over 21 years at a 7% depreciation rate, converted to Reis, and deflated by the FGV's IGP-DI to a 2006 basis. The 1985 and 1995/1996 capital service expenditures are thus the estimated service prices multiplied by 1985 and 1995/1996 census-provided counts of tractors-in-use. Year 2006 tractor ser-
vice prices are obtained by multiplying the 1995/1996 annual service price by the IGP-DI conversion to 2006, then multiplying that price against the 2006 census’ tractors-in-use.

State-level data in the 1985 and 1995/1996, and micro-region data in the 2006 census, of on-farm stools of bulls and steers, bovines, horses, asses, mules, pigs, goats, chickens, roosters, and hens are used to construct this study’s livestock capital. Each animal is aggregated to bovine equivalents using Hayami and Ruttan’s 1985, p. 450) cattle-normalized weights. State bovine-equivalent animal stocks are interpolated to each micro-region by multiplying the state stock by each micro-region’s state share of livestock sold. Bovine sale prices, available by state in 1985 and by micro-region in 1995/1996 and 2006, are amortized over 10 years at a 10% discount rate to obtain the bovine-equivalent capital service price. The bovine-equivalent animal stocks are then multiplied by the service price, obtaining the livestock capital service expenditures.

**Materials**

Much like the capital expenditure index, materials are also constructed into an expenditure index. Fertilizer, seed, pesticide, animal vaccine, feed, and electricity expenditures constitute that material service expenditure index. These farm expenditures are available from each census at the micro-region level. Year 1985 material expenditures are converted to Reais and then deflated to a 2006 basis using the IGP-DI price index.

**References**


