Brazil's Rising Agricultural Productivity and World Competitiveness

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Abstract

Brazil now is the largest coffee, sugar, and fruit juice producer, second-largest soybean and beef producer, and third-largest corn and broiler producer (Production Supply and Distribution Database, 2008). It has overtaken the U.S. in poultry exports, nearly matches the U.S. in soybean exports, and dominates global trade in frozen orange juice. To test and better understand these advances, we draw on decennial farm censuses to examine technical change and efficiency in Brazilian agriculture. Our approach is to estimate a stochastic, multi-product, output distance frontier, using a translog functional form and data disaggregated to the micro-region (sub-state) level. Using two consecutive decennial farm censuses, we combine state-level Fisher productivity-change indexes with state-level translog distance function estimates of growth technical efficiency to impute state-level technical shifts. We find, leading up to the soon-to-be-released 2006 agricultural census, that Brazil's multi-factor productivity growth rate between 1985 and 1996 was 20.2%. Mean state-level growth efficiency was 91.2%, implying the production frontier expanded 22.2% over the reference time period.

Keywords: Brazil, Shephard distance function, stochastic frontier, technical change, technical efficiency

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Brazilian agriculture historically has been export-oriented, supplying the world market with raw agricultural commodities such as sugar, rubber, cocoa, cotton, and coffee. Cycles of boom-and-bust have occurred periodically in each of these commodities. For example, from 1950 to 1963, coffee constituted 90% of all Brazilian exports (Graham, Gauthier and Mendonca de Barros, 1987). Agricultural production traditionally has taken place on the extensive margin and employed labor-intensive methods of production. Agriculture maintained the highest share of GDP until the mid-1950s, when a government focus on intensive industrialization made manufacturing the economy's dominant sector (Baer, 2008).

From 1945 until the 1980s, Brazilian governments have enacted multiple cycles of free-trade and protectionist policies. Post World War II policies were free-trade oriented, with a focus on controlling inflation (Baer, 2008). A tidal wave of protectionism evolved from the United Nations Economic Commission for Latin America (ECLA), which promoted import-substitution-industrialization (ISI) strategies for Latin American countries. ISI strategies assume balanced growth (imports to equal exports) in their model of development, in which an industrialized center and an agricultural periphery equate differential incomes through an increase in the proportion of capital goods supplied by the agricultural periphery (Prebisch, 1959). Governmental policies that support ISI strategies protect infant domestic industries through high protective barriers, including tariffs, quotas, and licenses (Dornbusch, 1998). During the 1950s and 1960s, Brazil looked to the ISI model to realize an economic growth other industrialized countries had achieved by way of an independent domestic industrial base. In particular, it focused its industrialization towards transportation equipment, machinery, electric machinery & appliances, and chemicals. The ISI strategy intensified under President Juscelino Kubitschek (1956-1961). Kubitschek set a goal of rapid technical change in the industrial sector, which internationalized the Brazilian economy in part by relying on multi-national companies to supply foreign technologies (embodied technical changes) and improve organizational efficiencies (disembodied technical changes) (Baer, 2008).

The Brazilian ISI policies, created to establish capital formation industries while reducing the use of foreign exchange and curbing foreign debt, laid the foundation for modernizing the agricultural sector (Schnepf, Dohlman and Bolling, 2001). Initially, the ISI era was known for dampening agricultural producer incentives through social policies favoring cheap food for an increasingly urban consumer. Such policies disfavored export-oriented agricultural production through export and price controls, import licenses and restrictions, and currency controls (Schnepf, Dohlman and Bolling, 2001).[1] By the 1960s fears of industrial stagnation, attributed to a lack of export revenues and a heavy reliance on imported capital, led the Government to re-embrace free trade opportunities with a focus on exportable agricultural commodities such as soybeans. To this end, governmental policies directly promoted the soybean industry through publicly funded agricultural research, guaranteed minimum price supports, agricultural input subsidies, and public infrastructure programs (Schnepf, Dohlman and Bolling, 2001).[2]

A military *coups d'état* in 1964 altered economic planning toward a more balanced approach between internationalization and protectionism. The approach focused on a rapid increase in international trade via export diversification while concurrently pursuing ISI

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[1] By the mid-1960s, 84% of agricultural exports were unprocessed raw commodities, whereas by the early 1990s these primary commodities declined to be only 20% of agricultural exports (Baer, 2008)

[2] Schnepf, Dohlman, and Bolling (2001) report that only in 2 of the last 30 years has the national average soybean price fallen below the governmental minimum price support price.

ideologies focused on boosting domestic capital production. To improve foreign trade, state export taxes were abolished, administrative procedures for exporters were simplified, and export tax incentives and subsidized credit were provided for exporters (Baer, 2008). By the late 1960s, the domestically-focused ISI policies established an industrial foundation for the production of agricultural machinery, fertilizer, and chemical inputs.

In 1965, The National System of Rural Credit was established to quicken new technology adoption, prompt capital formation, and increase foreign exchange through growth in exportable agricultural commodities (Schnepf, Dohlman and Bolling, 2001). Adding an inflationary policy of cheap rural credit to the domestic industrial foundation created the first of two agricultural transformation phases: that of mechanized agricultural production, increased land concentration, and rural-to-urban labor migration (Graham, Gauthier and Mendonca de Barros, 1987). This first phase of agricultural transformation created a high demand for food production (Baer, 2008). A pre-existing food shortage problem was aggravated by the displacement of food-crop production to frontier areas. Increasing in the distance between urban consumers and food-crop production lifted food prices and strained the country's poor transportation infrastructure.[3]

The second phase of agricultural transformation came in the 1970s and early 1980s. Three factors of this phase have played critical roles in the growth Brazilian agriculture is presently experiencing. The first factor was a continued opening of the economy, in which soybeans drove an expansion of processed and semi-processed agricultural exports. Graham, Gauthier, and Mendonca de Barros (1987) estimate that metric tonnage of soybeans grew 17.88% from 1961 to 1970, and 18.61% from 1971 to 1980. A second study shows soybean

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[3] As of 2001, only an estimated 10% of Brazil's highways were paved (Schnepf, Dohlman and Bolling, 2001). In the state of Mato Grasso, the least-cost mode of transportation was by river, with costs increasing if producers chose to transport by rail or road. (Matthey, Fabiosa and Fuller, 2004).

production between 1966 and 1977 grew at a rate of 37.6% per annum, making Brazil the third largest soybean producer and second largest soybean exporter by the mid-1970s (Baer, 2008). Export subsidies to promote processed agricultural exports, specifically soybeans, coincided with trade controls and quotas to discriminate against agricultural producers of other primary commodities in favor of agro-industrial processors (Graham, Gauthier and Mendonca de Barros, 1987). One such example was a 50% export-tax imposed on coffee producers in the late 1970s (Helfand and Rezende, 2001). With growth in selected agricultural commodities for export, food-crop production was continually marginalized to frontier areas. In keeping with the previous era's mechanized production transformation, land holdings were increasingly consolidated, land prices rose, and labor was altered from tenancy and shareholding arrangements to seasonal, temporary opportunities (Graham, Gauthier and Mendonca de Barros, 1987). Subsidized rural credit became the primary policy instrument for initiating agricultural growth, with total agricultural credit as a proportion of agricultural GDP peaking at 94.1% in 1976 (Graham, Gauthier and Mendonca de Barros, 1987). Unfortunately the dispersion of rural credit was highly skewed to the larger, more technically advanced farms, and the success of rural credit programs became questionable as the demand for automobile credit rose (Baer, 2008).

A continuation of import-substitution strategies in the 1970s and early 1980s was an additional factor in the second phase of Brazil's agricultural transformation. One such ISI strategy was energy independence, denoted by the establishment of PROALCOOL in 1977. PROALCOOL is a government program designed to substitute sugarcane ethanol for imported petroleum (Baer, 2008). This initiative further pushed agricultural production to the frontier, this time driving livestock and soybean production toward the center-west region (Graham, Gauthier and Mendonca de Barros, 1987, Schnepf, Dohlman and Bolling, 2001).

The third factor contributing to Brazil's second phase of agricultural transformation was the establishment of Embrapa (Empresa Brasileira de Pesquisa Agrpecuaria) in 1973, under the Ministry of Agriculture and Food Supply. Embrapa is a national agricultural research agency, organized along federal lines and involving cooperation between federal and state experiment stations, created to increase human capital investments, provide regionalized research and development to improve small land-holder productivity, and increase yields in the acidic soils of the frontier regions of the southeast and center-west (Graham, Gauthier and Mendonca de Barros, 1987). Embrapa employs a decentralized model of agricultural research that allows localized research into crops and ecosystems and cooperation on product development with private seed producers and farm organizations (Matthey, Fabiosa and Fuller, 2004). Prior to the re-organization of the national agricultural research system creating Embrapa, agricultural development focused on exportable crops, agricultural research was underfinanced and poorly managed, and investment in human capital formation and rural extension services was lacking (Graham, Gauthier and Mendonca de Barros, 1987).[4]

Embrapa has enjoyed significant success in adapting tropical soybeans, corn, and cotton varieties to the acidic soils and climate of the center-west, along with some areas in the north and northeastern regions (Schnepf, Dohlman and Bolling, 2001). Moreover, from 1983 to 2007, Baer (2008) cites Embrapa's agricultural research and development as an important determinant of the observed increase in land productivity (measured in kilograms per hectare) of cotton, rice, sugarcane, corn, wheat, and soybeans.

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[4] Graham, Gautheir, and Mendonca de Barros (1987) do note the exception of Sao Paulo's research efforts on exportable commodities coffee and cotton.

Brazil has largely transformed its agricultural sector into a world agricultural powerhouse. As the U.S. share of world soybean exports declined from 79% to 32% from the 1970s through 1990s, Brazil's share rose from 9% to 28% (Schnepf, Dohlman and Bolling, 2001). Brazil now is the largest coffee, sugar, and fruit juice producer, second-largest soybean and beef producer, and third-largest corn and broiler producer (Production Supply and Distribution Database, 2008). It has overtaken the U.S. in poultry exports, nearly matches the U.S. in soybean exports, and dominates global trade in frozen orange juice. The Brazilian agricultural transformation, founded in the ISI era, developed a traditional agricultural system into an agro-industrial complex. The transformation was sustained through large-scale production of exportable agricultural commodities, favorable international prices and governmental policies, and rapid technical change in the agro-industrial sector (Baer, 2008). With the removal of discriminatory policies against food producers in the mid-1980s, sufficient incentives allowed the agro-industrial complex to modernize food production. One example is rice production in Rio Grande do Sul and Santa Catarina.[5] These states employ modern irrigation technologies that allow a higher quality and quantity of rice to be produced (Helfand and Rezende, 2001). By the late 1980s, policies that liberalized international trade, stabilized domestic prices, and attempted to eliminate state agricultural monopolies in sugar, alcohol, coffee, and wheat allowed agribusinesses to become increasingly influential in the agricultural sector (Baer, 2008). Agriculture's share of GDP from 1985 to 2005 is provided in table 1 of Appendix B. These shares provide insight into the stability of the agricultural sector, its share of the economy averaging 8.25% from 1985 to 1995, and 8.34% from 1985 to 2005.

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[5] Rio Grande do Sul accounted for 40% of Brazilian rice production in 1991 (Baer, 2008).

The interest of the present analysis is to examine agricultural productivity growth from 1985 to 2006. Unfortunately the 2006 agricultural census, scheduled to be publicly available in July of 2008, has yet to be entirely published. We therefore focus on the Post-Green revolution timeframe of 1985 to 1995/1996. We estimate state and national total factor productivity (TFP) growth via Fisher index number theory. The analysis employs 19 output commodities and 9 conventional inputs. To complement the productivity analysis, we use a stochastic multi-product output distance frontier to estimate state and national mean growth technical efficiency from 1985 to 1995/1996. These state-level growth inefficiency estimates allow an examination of the proportion of productivity growth achieved by average farms. In the absence of adequate time-series of panel data for directly estimating state and national technical change rates from the stochastic output distance frontier, I impute technical change as the ratio of a Fisher TFP growth rate to a stochastically estimated growth efficiency measure. Such TFP decomposition assumes allocative efficiency on Brazilian farms and a constant-returns-to-scale technology. We find the national decennial total factor productivity growth from 1985 to 1995/1996 to have been 20.2%. In light of a Brazilian mean growth efficiency of 91.2%, the imputed national decennial Brazilian agricultural technical change rate was 22.2%.

The Theoretical Specification

For measuring multi-input and multi-product productivity growth, the Fisher productivity quantity index best satisfies index number theory's axiomatic approach (Diewert, 1992). The index, developed originally as a price index by Fisher (1922 & 1927 , p. 360), is the ratio of a Fisher ideal output quantity index to a Fisher ideal input quantity index. The Fisher ideal index is defined as the geometric mean of the Laspreyes and Paasche quantity indices. The Laspreyes quantity index is defined as, $Q_L(p^{t+1}, p^t, x^{t+1}, x^t) = \frac{p^t x^{t+1}}{p^t x^t}$, where $p^t, p^{t+1}, x^t, x^{t+1} \gg 0$, are strictly positive price and quantity vectors $\left(p, x \in \mathbb{R}_+^M\right)$, respectively, and t refers to the time period. Alternatively, the Paasche quantity index is defined as $Q_P(p^t, p^{t+1}, x^t, x^{t+1}) = \frac{p^{t+1} x^{t+1}}{p^{t+1} x^t}$, with the same definitions as in the Laspreyes quantity index. Thus, the Fisher ideal quantity index is defined as,

$$(1) \qquad Q_F(p^t, p^{t+1}, x^t, x^{t+1}) = \left[\frac{p^t x^{t+1}}{p^t x^t} \cdot \frac{p^{t+1} x^{t+1}}{p^{t+1} x^t}\right]^{1/2}.$$

The Fisher ideal quantity index is superlative, or a quantity index which corresponds to a functional form capable of providing a second-order approximation to an arbitrarily twice differentiable linear homogenous function (Diewert, 1976).

From Output Distance Function to Frontier

To develop our econometrically tractable multi-product output distance frontier, let $y_{ji} \in \mathbb{R}_+^M$, $j = 1...M$ be an output scalar; $x_{ki} \in \mathbb{R}_+^N$, $k = 1...N$ a conventional input scalar; and $i = 1...I$ indicate observations defining the technology $T = \{(x_{ki}, y_{ji}) : x_{ki} \text{ can produce } y_{ji}\} \in \mathbb{R}_+^{N+M}$. The producible output set, a subset of technology T, identifies the feasible output vectors (y_{ji}) constrained by fixed input vectors (x_{ki}^o) in an economy of $M + N$ commodities, indicated as

$P(x_{ki}^o) = \{y_{ji} \in \mathbb{R}_+^M : (x_{ki}^o, y_{ji}) \in T\}$. We define the output distance function from the producible output set as (Färe and Primont, 1995),

(2) $$D_O(x_{ki}, y_{ji}) = \inf_\theta \{\theta > 0 : {}^{y_{ji}}\!/\!_{\theta} \in P(x_{ki}^o)\} \ \forall \ x_{ki} \in \mathbb{R}_+^N .$$

Distance functions are credited to Shephard (1953), (1970). From (2), $D_O(x_{ki}, y_{ji}) \le 1$ if and only if $(x_{ki}^o, y_{ji}) \in T$, assuming weak disposability of outputs (Färe and Primont, 1995). If outputs are located on the outer boundary of $P(x_{ki}^\circ)$, then $D_O(x_{ki}, y_{ji}) = 1$ and technical efficiency is maximized.

Stochastic frontier estimation was first proposed by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) and prescribes output variation to be explained by input variation, an idiosyncratic error term, and a technical inefficiency error term. Consider a stochastic expression of the Shephard multi-product distance function

(3) $$D_O(x_{ki}, y_{ji}, \beta) = e^{\varepsilon_i},$$

where β is a vector of parameters to be estimated and ε_i is an observation-specific error specified in exponential form. In (3) the stochastic distance frontier decomposes error term ε_i into the difference of two errors, $v_i - u_i$, so that with manipulation, the stochastic output distance frontier is

(4) $$e^{-u_i} = \frac{D_O(x_{ki}, y_{ji}, \beta)}{e^{v_i}}.$$

The idiosyncratic error term in (4), v_i, is assumed independently and identically distributed (iid), symmetric, with mean zero and variance σ_v^2 $\left(v_i \sim iid\ N(0, \sigma_v^2)\right)$. The inefficiency error u_i is a nonnegative random error term accounting for each observation's distance to the stochastically estimated frontier. u_i is assumed independently and half-normally distributed $\left(u_i \sim N^+(0,\sigma_u^2)\right)$. The two error terms, v_i and u_i, are assumed distributed independently of each other: $\sigma_{vu} = 0$. Error distributional assumptions follow from Battese and Coelli (1988).

Technical efficiency of the output distance frontier is obtained by dividing by e^{-u_i}, such that (4) becomes

$$D_O(x_{ki}, y_{ji}, \beta)e^{(u_i - v_i)} = 1. \tag{5}$$

Moreover, to evaluate the data at its mean implies the stochastic output distance frontier is no greater than unity:

$$D_O(x_{ki}, y_{ji}, \beta)e^{-u_i} \leq 1. \tag{6}$$

To guarantee positive numbers for the Shephard output distance frontier, we parameterize input-output relation $D_O(x_{ki}, y_{ji}, \beta)$ as $e^{h(\ln x_{ki}, \ln y_{ji}, \beta)}$. If we substitute the exponential form of $D_O(x_{ki}, y_{ji}, \beta)$ into (5), we have

$$e^{h(\ln x_{ki}, \ln y_{ji}, \beta)}e^{(u_i - v_i)} = 1. \tag{7}$$

We obtain an estimable stochastic distance frontier by rearranging terms:

$$e^{h(\ln x_{ki}, \ln y_{ji}, \beta)} = e^{(v_i - u_i)}. \tag{8}$$

A required property of any output distance function is that of linear homogeneity of degree +1in outputs. Therefore to ensure $e^{h(\ln x_{ki}, \ln y_{ji}, \beta)}$ is a distance function, we impose linear homogeneity on (8) by normalizing each of the outputs with a numeraire output.[6] Imposing output linear homogeneity through normalization is an elegant approach to estimation as it provides a dependent variable naturally lacking in distance functions. Output linear

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[6] In the production frontier framework, output linear homogeneity of degree +1 means scaling the output vector in given positive proportion scales output distance, or technical efficiency, in the same proportion.

homogeneity of degree +1 is maintained by requiring that

$D_O(x_{ki}, \omega y_{ji}, \beta) = \omega D_O(x_{ki}, y_{ji}, \beta)$, for any ω>0 (Shephard, 1970). Let $y^*_{ji} = {}^{y_{ji}}\!\!/\!_{y_{mi}} \neq +\infty$,

$y_{ji} \neq 0$, and $j = 1...m-1$, in which the m^{th} output is chosen as numeraire (Lovell, et al., 1994).

Substituting $\frac{1}{y_m}$ for ω, we then have from (8)

(9)
$$e^{h(\ln x_{ki}, \ln y^*_{ji}, \beta)} = \frac{1}{y_{mi}} e^{h(\ln x_{ki}, \ln y_{ji}, \beta)},$$

and by substituting (8) into (9) provides

(10)
$$e^{h(\ln x_{ki}, \ln y^*_{ji}, \beta)} = \frac{e^{(\nu_i - u_i)}}{y_{mi}}.$$

Taking logs of (10) and rearranging terms brings

(11)
$$-\ln y_{mi} = h(\ln x_{ki}, \ln y^*_{ji}, \beta) + u_i - \nu_i.$$

From (11), technical efficiency estimation employs the predicted logs of the i^{th} observation's output distance:

(12)
$$e^{-u_i} = D_O(x_{ki}, y_{ji}, \beta).$$

These predicted values are unobservable and must be derived from the composed error term, ε_i.

In the present analysis, observation-specific predicted values are expressed as (Battese and Coelli, 1988)

(13)
$$\widehat{TE_i} = E\left[\exp(-u_i) \mid \varepsilon_i\right].$$

Explaining Productive Efficiency

To estimate productive efficiency in a manner that allows inefficiency to be explained by policy variables, the variance of technical inefficiency error u_i is allowed to be heteroscedastic. Heteroscedasticity is theoretically prevalent for multiple reasons, but especially when resource size is a significant component of production. In the present study, rather than the homoscedastic u_i employed in the equations above, the model permits inefficiency error u_i to be heteroscedastic by way of a one-sided error term

(14) $$u_i \sim N^{+}(0, \sigma^2_{u,i}),$$

in which N^{+} indicates the half-normal distribution and $\sigma^2_{u,i}$ is a heteroscedastic variance dependent upon micro-region *i*.

To estimate mean impacts of state-level policy variables on inefficiency error variance $\sigma^2_{u,i}$, and thus on mean technical efficiency, we associate u_i with a vector of exogenous policy variables $\ln z_{ai}$ and a vector of parameters Ω in multiplicative form

(15) $$u_i = g(\ln z_{ai}; \Omega)\eta_i, \; a = 1 \ldots A.$$

g in equation (15) is a scaling function, a represents the a^{th} policy variable, and η_i is an iid random variable such that $\eta_i \geq 0$, $E(\eta_i) = 1$, and $V(\eta_i) = \sigma^2_{\eta}$. Scaling-factor g integrates observable characteristics that affect observation-specific inefficiency. η_i establishes the basic inefficiency level while policy variables $\ln z_{ai}$ capture differing features of the environment in which micro-regions operate. Including such observable characteristics alters equation (8) to become

(16) $$e^{h(\ln x_{ki}, \ln y_{ji}, \beta)} = e^{(\nu_i - g(\ln z_{ai}; \Omega)\eta_i)}.$$

A parametric specification of $g(\ln z_{ait};\Omega)\eta_{it}$ is required to estimate equation (11) in a manner incorporating (15) and (16). Following (Simar, Lovell and Vanden Eeckaut, 1994), we specify g in exponential form, so that (15) becomes

$$u_i = g(\ln z_{ai};\Omega)\eta_i = \exp(\ln z_{ai}{}^{'}\Omega)\eta_i. \tag{17}$$

The mean and variance of inefficiency error u_i then are

$$E(u_i) = \exp\left\{\ln z_{ai}{}^{'}\Omega\right\} > 0\text{, and} \tag{18}$$

$$V(u_i) = \sigma_{u,i}^2 = g(\ln z_{ai},\Omega)^2\sigma_\eta^2 = \exp\left\{2\ln z_{ai}{}^{'}\Omega\right\}\sigma_\eta^2. \tag{19}$$

Substituting (16)'s parametric specification into (11), we obtain

$$\begin{aligned} -\ln y_{mi} &= h(\ln x_{ki}, \ln y_{ji}^*, \beta) + g(\ln z_{ai};\Omega)\eta_i - v_i, \\ &= h(\ln x_{ki}, \ln y_{ji}^*, \beta) + \exp\left\{\ln z_{ai}{}^{'}\Omega\right\} + \varepsilon_i, \end{aligned} \tag{20}$$

where,

$$\varepsilon_i = -v_i + \exp\left\{\ln z_{ai}{}^{'}\Omega\right\}(\eta_i - 1). \tag{21}$$

To estimate policy impacts on technical inefficiency variance $\sigma_{u,i}^2$, we constrain u_i such that from (19) we have

$$\ln\sigma_{u,i}^2 = \ln\sigma_\eta^2 + 2\ln z_{ai}{}^{'}\Omega, \tag{22}$$

where $\ln\sigma_\eta^2$ is an intercept, and estimates $\widehat{\Omega}$ provide the elasticities of technical inefficiency variance with respect to the exogenous policy variables. To obtain mean technical efficiency estimates, we apply equation (23):

$$\widehat{TE}_i = E\left[\exp(-u_i \mid \varepsilon_i)\right] = E\left[e^{-\exp\{\ln z_{ai}{}^{'}\Omega\}} \mid \varepsilon_i\right]. \tag{23}$$

While equation (22) allows exogenous policy variables to explain variations in technical inefficiency variance $\sigma_{u,i}^2$, our interest is drawn to how these exogenous policy variables impact, or shift, national mean technical efficiency. To this end, we differentiate the national-level mean predicted technical efficiency with respect to the exogenous policy variables, shown as

$$(24) \qquad \frac{\partial \ln \widehat{TE}_i}{\partial \ln z_{ai}} = \frac{\partial \ln E\left[e^{-\exp\{\ln z_{ai}'\Omega\}} \mid \varepsilon_{it} \right]}{\partial \ln z_{ai}} = -\exp\{\ln z_{ai}'\Omega\}\left(\frac{\partial \exp\{\ln z_{ai}'\Omega\}}{\partial \ln z_{ai}} \right).$$

Brazilian Application

Brazil's land mass encompasses 27 states in 5 regions and covers over half of the South American continent (Baer, 2008). Details of the respective states and regions are presented in table 3 of Appendix B, while figure 1 (in Appendix B) geographically presents Brazil's political boundaries. As United States' global share of major field crops increasingly erodes, understanding Brazil's agriculture productivity, and more generally their agricultural competitiveness, is imperative in allowing U.S. policy makers to assess and act upon these changes.

Structural changes in the agricultural sector provide insight into factor share changes. The number of farm establishments, land area, labor counts, and tractor counts are detailed in table 2 of Appendix B for agricultural census years 1975, 1985, 1995/1996, and 2006. Column 7 of table 2 suggests surprising changes in the number of establishments (-17.7%), total agricultural area (-5.9%), cropland (-22.1%), labor (-26.6%), and tractor inventories (18.9%). Land consolidation may be a major reason for the decrease in the number of farm establishments between 1985 and 1995/1996. Furthermore, mean increases in agricultural productivity may have induced inefficient farms to exit the sector. A decrease in total agricultural cropland suggests a shift from producing on the extensive margin to increasing yields. A decline in labor, with an increase in the number of tractors, suggests a labor-saving and capital-using bias in technical change.

But Helfand and Brunstein (2000) argue that these structural change indicators overestimate actual change. Helfand and Brunstein emphasize two problems with the 1995/1996 census: weak comparability with previous censuses, and weak representation of mid-1990s agricultural production (Helfand and Brunstein, 2000). Weak comparability of the 1995/1996 census to previous census studies is particularly owing to the reference-period which, between census years 1985 and 1995/1996, changed from January 1 – December 31 to August 1 – July 31. Thus the planting and harvesting periods differ between the pre-1995/1996 censuses and the 1995/1996 census, altering data continuity. Compounding the problems associated with the 1995/1996 census, 1994 was the start of an increasingly rationed agricultural credit regime which, in turn, influenced plantings in 1995 (Baer, 2008). Helfand and Rezende (2001) add that with implementation of the Real Plan and the introduction of the new Real in 1994, high interest rates created an incentive for producers to buy capital assets.[7] That in turn pushed land, cattle, and agricultural commodity prices downward in early 1995. With an increase in agricultural investment and credit, the price declines resulted in the most severe agricultural financial crisis in Brazilian history (Helfand and Rezende, 2001).

Brazilian agricultural productivity analyses generally have followed non-stochastic methods of estimation. Avila and Evenson (1995) employ a Törnqvist-Thiel index number approach from 1970 to 1985 to obtain regional TFP growth rates per annum of: north (1.31%), northeast (1.60%), southeast (3.06%), south (1.46%), and the center-west (3.80%). Helfand and Rezende (2001) cite Barros (1999), whose Brazilian agricultural productivity dissertation

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[7] For a comprehensive analysis of the Real Plan, please see Chapter 7 of Baer (2008).

employed a growth accounting approach. Barros (1999) concluded that Brazil's agricultural TFP grew by 20% between 1975 and 1995, most of the growth coming in the 1990s (Helfand and Rezende, 2001). da Silva Dias and Amaral (2000) estimated agricultural productivity levels by index number theory from 1987 to 1998. The percentage change estimated from their crop- and livestock-composed 1987 – 1996 agricultural productivity index was 22.8%. Pereira, da Silveira, Lanzer, and Samohyl (2002) employ a Malmquist productivity index to estimate state, regional, and national agricultural TFP. Their analysis accounts only for states existing in 1970, thus excluding two important states in frontier agricultural production: Mato Grosso do Sul and Tocantins (Pereira, et al., 2002). They estimate annual TFP growth rates from 1970 to 1996 of: north (-0.71%), northeast (-0.62%), southeast (5.00%), south (4.63%), center-west (7.30%), and Brazil (4.81%). Lastly, Vicente (2004) estimated mean state, regional, and national technical efficiency levels for agricultural crop production in 1995. Fisher quantity output indices were employed in Data Envelopment Analysis (DEA) estimation to obtain regional and national technical efficiencies of: northeast (0.51%), north (0.84%), southeast (0.89%), south (0.69%), center-west (0.92%), and Brazil (0.72%).

Applied Methodology

The present analysis estimates, from 1985 to 1995/1996, state and national Fisher quantity TFP growth rates, along with output- and input-growth from each of the three Fisher output and input indices. To obtain growth technical efficiency estimates, three output and input Fisher quantity-growth indices are used to econometrically estimate output distance frontier (20). Such estimates have implications for government agricultural research and extension policy. We highlight those states which exhibit high technical changes and low growth efficiencies. Enhancing agricultural extension services and local adaptive-research capacity allows farmers to make better use of existing technology and hence move closer to their own technological possibilities. The marginal cost of these improvements likely will be low because the technology for realizing them is already in place.

To apply our theoretical model, let $y_{ji} \in \mathbb{R}_+^3$ be an output scalar, with $j = 1,...,3$ representing the Fisher output growth indices for perennial crops, annual crops, and livestock. Let $x_{ki} \in \mathbb{R}_+^3$ be a conventional input scalar, with $k = 1,...,3$ representing the Fisher input growth indices for labor, capital, and material inputs. Lastly, let $i = 1,...,557$ indicate the Brazilian micro-regions. Our growth efficiency analysis uses the livestock Fisher output quantity growth index as the numeraire output because the livestock growth index recorded the largest increase between 1985 and 1995/1996.

The translog quadratic input-output distance relation $D_O(\ln x_{ki}, \ln y_{ji}^*, \beta)$ is expressed as

$$\begin{aligned} D_O(\ln x_{ki}, \ln y_{ji}^*, \beta) &= \beta_0 + \sum_{k=1}^{N} \beta_k \ln x_{ki} + \sum_{j=1}^{M-1} \beta_j \ln y_{ji}^* + \frac{1}{2}\sum_{k=1}^{N}\sum_{h=1}^{N} \beta_{kh} \ln x_{ki} \ln x_{hi} \\ &+ \frac{1}{2}\sum_{j=1}^{M-1}\sum_{l=1}^{M-1} \beta_{jl} \ln y_{ji}^* \ln y_{li}^* + \sum_{k=1}^{N}\sum_{j=1}^{M-1} \beta_{kj} \ln x_{ki} \ln y_{ji}^*, \end{aligned} \tag{25}$$

or more simply as

$$D_O(\ln x_{ki}, \ln y_{ji}^*, \beta) = \beta_0 + TL(\ln x_{ki}, \ln y_{ji}^*, \beta)\,. \tag{26}$$

To incorporate fixed-effects into the multi-output distance frontier, dummy variables are included for each of the 27 states. Fixed-effects capture unobserved cross-state heterogeneity present in the data, yet not accounted for in the quality-adjusted conventional inputs. Including dummy variables to account for fixed-effects in stochastic frontier models is recommended provided the time-invariant unobserved heterogeneity modeled is not efficiency-related (Greene, 2005). Specifying (26) to include fixed-effects allows us to write

(27) $$D_O(\ln x_{ki}, \ln y^*_{ji}, \beta) = \beta P_s + TL(\ln x_{ki}, \ln y^*_{ji}, \beta),$$

where subscript $s = 1,....,27$ represents the state dummy variables. To obtain an estimable model, substitute (27) into (20):

(28) $$-\ln y_{mi} = \beta P_s + TL(\ln x_{ki}, \ln y^*_{ji}, \beta) + \exp\left\{\ln z_{ai}{'}\Omega\right\} + \varepsilon_i.$$

To estimate the factors impacting state-level mean growth inefficiencies, we apply the variance characterization of u_{it}, equation (22), and employ the policy variables in log-linear form, so that (22) becomes

(29) $$\ln \sigma^2_{u,i} = \alpha_0 + \alpha_1 \ln PublicEducation_i + \alpha_2 \ln RuralEduction_i + \omega_i;\ \omega_i \sim N(0, \sigma^2).$$

Model (29) explains agriculture's growth inefficiency variance in Brazil by a constant, real per-capita state-level expenditure on public education, and the average number of schooling years of the rural population over the age of 10. For estimation purposes, we assume per-capita state-level expenditures in each state are equally divided amongst all micro-regions in that state. Equations (28) and (29), employing functional form (27) are estimated jointly with Full Information Maximum Likelihood (Stata Version 2008).

Data: Outputs, Inputs, and Exogenous Policy variables

The data employed in the present analysis come from the 1985 and 1995/1996 Brazilian agricultural censuses. Census data are obtained from the Instituto Brasileiro de Geografia e Estatística (IBGE, 2009), while supplementary data is also obtained from the Food and Agricultural Organization of the United Nations (FAO, 2009), and the World Bank. The farm-level survey data collected in the agricultural censuses are recorded at two levels: the micro-region and the state. The 557 micro-regions vary in number within each of the 27 states. The strength of the Brazilian agricultural census data lies in its structure; with 28 outputs, 9 inputs, and 557 observations in the 1995/1996 census year and 554 observations in the 1985 census year, it provides a very rich cross-section of 554 observations.

Outputs

The 19 outputs cover three categories: annual crops, perennial crops, and livestock. Annual crops in the data are green beans, cotton, maize, manioc, onion, peanuts, rice, soybeans, and tomatoes. The perennial crops are bananas, cocoa, coffee, oranges, and sugarcane. Livestock data is comprised of cattle meat, pig meat, poultry meat, cow milk, and hen's eggs. Each commodity's quantity and output revenue is available at the micro-region level. All output commodities are measured in metric tons. The Brazilian currency changed five times between 1984 and 1994 and is detailed in table 4 of Appendix B. To create the Fisher output quantity index, 1985 prices were converted to *Reais*. Both 1985 and 1995/1996 prices then were deflated by the World Bank's Brazilian GDP deflator to constant 1989 prices. Poultry quantities were unavailable at the micro-region level in the 1985 census, but were available at the national level. To obtain data at the micro-region level in 1985, each micro-region's share of national production in the 1995/1996 census is employed assuming a constant growth rate.

Inputs

Labor, land, fertilizers, pesticides, feed, vaccines, seed, tractors, and animal power are the conventional inputs employed in the present analysis. Input expenditure data are recorded at the micro-region level. To obtain quantities, we assume each micro-region in a given state faces the same input price, as only state-level input prices are available. To create the Fisher input quantity index, 1985 prices are converted to *Reais*. Both 1985 and 1995/1996 prices then were deflated by the World Bank's Brazilian GDP deflator to constant 1989 prices.

Fertilizers, Pesticides, Feed, Vaccines, & Seed

Fertilizers, chemicals, feed, vaccines, and seed expenditures are recorded at the micro-region level, with prices recorded at the state level. The state-level price of each input is the price of its most commonly used form in that state (Avila and Evenson, 1995). For example, the fertilizer price is the price of the most commonly used compound in that state. We assume each micro-region in each state faces the same input price. Using micro-region input expenditures and state-level prices, we interpolate input quantities for each micro-region.

Agricultural Equipment

In the present analysis, tractors and horses employed in agriculture comprise the agricultural equipment input. The count of horses in agriculture is recorded at the state level. To obtain the agricultural work horse rental rate, we divide the total agricultural work animal value by the total horse count, and apply a 2.5% discount rate. We then deflate the rental rate by the World Bank's GDP deflator specific to Brazil to obtain constant 1989 prices. We assume that every micro-region in a given state utilizes the same share of horses and faces the same service rental rate.

Tractor usage in the Brazilian data is recorded at the micro-region level. Tractor counts are recorded within specific ranges of horsepower (hp) into five classifications: <10 hp, 10-20 hp, 20-50 hp, 50-100 hp, and >110 hp. The tractor counts are converted to 75-horsepower-equivalent tractors within each micro-region. To obtain the tractor service rental price, the imported tractor wholesale unit price, obtained from the FAO, is marked up by 50%, converted to *Reais*, amortized over 10 years at a 10% discount rate, and deflated by the World Bank's Brazilian GDP deflator to constant 1989 prices. The 50% markup adjusts the wholesale price to be consistent with farm-level prices observed with other inputs.

Land

Cropland and pasture-land are recorded at the micro-region level in hectares. Each micro-region's expenditures on, and hectare-quantity of, rented lands are also reported in the census. We assume rented lands have equivalent quality as owned land. To obtain the land rental rate, rented land expenditures are divided by total hectares of rented land. The land rental rates are then deflated by the World Bank's Brazilian GDP deflator to constant 1989 prices.

Labor

Labor quantity is recorded at the state level by labor sector and labor class. Three sectors (crop labor, livestock labor, and forestry labor) and three classes (family labor, permanent labor, and temporary labor) are recorded in the census. To estimate the contribution of labor to agricultural productivity, a single labor count – quality-adjusting all labor classes into permanent-labor equivalents and accounting only for crop- and livestock-sector labor – projected from the state to the micro-region is required. Let our characterization of total agricultural labor count in a given state be

$$\sum_{r=f,p,t} L_{rs} = C_{rs} + A_{rs} + F_{rs}, \quad s = 1, \ldots, 27 . \tag{30}$$

Subscripts $r = f, p, t$ represent family labor $\left(f = 1, \ldots, F\right)$, permanent labor $\left(p = 1, \ldots, P\right)$, and temporary labor $\left(t = 1, \ldots, T\right)$, respectively. As before, subscript $s = 1, \ldots, 27$ refers to the Brazilian states. C_{rs} represents the labor count in crops, A_{rs} the labor count in livestock, and F_{rs} the labor count in forestry.

To differentiate the labor count in (30) among its micro-regions in a given state, each sector must be share-weighted. To estimate each micro-region's share of cropland (measured as hectares, and defined as permanently and temporarily cultivated land) in a state's crop sector, we define ρ_i, $i = 1, \ldots, 557$ as a micro-region's cropland share. To obtain the micro-region's labor count in the livestock sector, the value of nonworking livestock in a given state is share-weighted by the number of micro-regions in that state. The nonworking livestock value, θ_i, is defined as the value of swine and cattle. Reliable data on the forestry sector are unavailable for accurately projecting state-level data to the micro-region. Therefore, each state's total forestry labor count is estimated by share-weighting the state-level data by the number of micro-regions in that state (Avila and Evenson, 1995). To project labor in the s^{th} micro-region, by class and sector, we have

$$\sum_{r=f,p,t} L_{rs} = \rho_i C_{rs} + \theta_i A_{rs} + \delta_i F_{rs} \tag{31}$$

In equation (31), $\rho_i C_{rs}$ represents the s^{th} micro-region's labor share (family, permanent, and temporary) accounted for in the crop sector, $\theta_i A_{rs}$ represents the s^{th} micro-region's labor share in the livestock sector, and $\delta_i F_{rs}$ represents the s^{th} micro-region's labor share in the forestry sector.

To obtain permanent-labor equivalents in (31), each labor class is quality-adjusted. We assume two-thirds of family labor is permanent labor. Family labor consists of women and children who do not work full-time. Permanent labor is considered full-time labor. Temporary labor is assumed to work less regularly than permanent labor, as in much of Brazil they are a seasonal labor force. To quality-adjust temporary labor to permanent-labor equivalents in each micro-region, we follow Avila and Evenson (1995) and weight the temporary labor count by the ratio of average temporary-labor expenditure to average permanent-labor expenditure. This ratio provides a measure of temporary labor quantity relative to permanent labor and is defined as

$$\frac{Exp_{ti} \big/ labor_{ti}}{Exp_{pi} \big/ labor_{pi}}, \tag{32}$$

where Exp_{ri} represents labor expenditure in a r^{th} class and i^{th} observation, and $labor_{ri}$ represents the r^{th} and i^{th} labor count. Because labor expenditure is identical to per hour wage rate multiplied by the average number of labor hours worked times the labor count, and because we assume temporary and permanent labor receive equal wage rates, we have

$$Exp = (wage/hr.)*(Avg.\ hrs.\ worked/labor)*(labor)\,. \tag{33}$$

Substituting (32) into (31), we have

$$\frac{(wage/hr.)*(Avg.\ hrs.\ worked/labor_t)*(labor_t) \big/ labor_t}{(wage/hr.)*(Avg.\ hrs.\ worked/labor_p)*(labor_p) \big/ labor_p}\,. \tag{34}$$

Canceling terms obtains

$$\frac{(Avg.\ hrs.\ worked/labor_t)}{(Avg.\ hrs.\ worked/labor_p)}\,. \tag{35}$$

Equation (35) is then multiplied by the temporary labor count to obtain temporary labor in permanent-labor equivalents:

(36) $$\frac{(Avg.\ hrs.\ worked\ /\ labor_t)}{(Avg.\ hrs.\ worked\ /\ labor_p)} * labor_t = labor_p \, .$$

Exogenous Policy Variables

The exogenous policy variables used in this analysis to explain the variance of growth inefficiency are rural education and state-level per-capita public education expenditures. Rural education data are available by state and consist of the average number of years of schooling of the rural population over 10 years of age (Avila and Evenson, 1995). Expenditure data are available from 1996 to 2002. 1995 state-level expenditures are estimated by using 1996-2002 data to regress state-specific expenditures against time, then extrapolating the results to each state in 1995. Public expenditures on education entail funding for administration and support, special education, primary, secondary, and higher education, research, and student aid. Due to wide variations in state populations, gross state expenditures are expressed in a per-capita basis.[8] State population data from the IBGE are employed to generate per-capita public education expenditures. To distribute public expenditures among micro-regions, we assumed every micro-region in a given state receives an equal share of education payments. All expenditures are converted to *Reais* and deflated by the World Bank's Brazilian GDP deflator to obtain constant 1989 state-level per-capita education expenditures.

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[8] Baer (2008) reports the 1980 and 1996 regional distributions of population: North (4.9% in 1980, 7.1% in 1996), Northeast (29.3% in 1980, 28.5% in 1996), Southeast (43.4% in 1980, 42.7% in 1996), South (16% in 1980, 15% in 1996), and Center-West (6.4% in 1980, 6.7% in 1996).

Empirical Evidence

In light of insufficient panel data to directly estimate Brazilian agricultural technical changes from the stochastic output distance frontier, the present analysis employs Brazilian state and national Fisher TFP estimates, in conjunction with state and national growth efficiency estimates, to impute state and national technical changes. To this end, we assume Brazilian farms operate under constant-returns-to-scale technology and allocative efficiency such that TFP is equal to the product of technical change (TC) and growth efficiency (GE). Technical changes may therefore be imputed as

$$TC = \frac{TFP}{GE}. \tag{37}$$

Equation (1) is used to obtain state and national TFP estimates, while state and national mean growth efficiencies are estimated, given a sample of 550 micro-regions, from the stochastic multi-output distance frontier in (28). We then obtain the impact of each policy variable on the average farm's growth efficiency. Finally, a focus is kept on those states which have experienced relatively high technical changes and relatively low growth efficiencies. Farmers in these states have the potential to rapidly improve productivity through enhanced agricultural extension services and local adaptive-research because the marginal cost of implementing existing technologies likely is low given that they are already in place.

Some may question the consistency of employing a Fisher index approach with a translog functional form in (28) to impute technical changes. In the aggregate (country-level) there was virtually no difference between Fisher TFP growth estimates and those obtained from the Törnqvist-Thiel approach.[9] A random sample taken at a more disaggregated level (state-level)

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[9] Relative to base 1.00, the aggregate Tornqüist-Thiel approach obtained a 1.19 measure of agricultural productivity, while the aggregate Fisher approach obtained a 1.20 measure.

shows no significant difference (exact to the hundredths decimal place) between the two index approaches. Furthermore, Acquaye, Alston, and Pardey (2002) find no difference in productivity levels when employing the same data set to each approach; they obtained a 0.9999 simple correlation between the Törnqvist-Thiel and Fisher TFP estimates.

Output Growth

To better understand the state and national Fisher TFP estimates, it is necessary to review the growth in each of the three output (annual crops, perennial crops, and livestock) and input (labor, materials, and capital) categories. Table 5 in Appendix B presents the Fisher output growth indices from 1985 to 1995/1996 for each output category and state in Brazil. The northern state of Rondônia experienced exceptional output growth in its livestock sector, with a seven-fold increase in production. Rondônia's livestock growth was led by cattle and milk production, followed closely by that of poultry and swine. Roraima, a second northern state to experience considerable output growth, observed a three-fold increase in perennial crops, led by banana production.

The state of most interest in table 5 is Mato Grosso, located in the center-west region. Unlike most states in Brazil, Mato Grosso experienced production growth in all three output categories. Annual crop production doubled, led by cotton, corn, and soybeans. Perennial crop production observed the most growth, with contributions mainly from sugarcane and orange/citrus products. Livestock production, especially in swine and poultry, grew nearly as much as in perennial crops.

Input Growth

Table 6 in Appendix B presents the Fisher input growth indices for each state and input category. The states immediately standing out are once again the northern ones of Rondônia and Roraima, and the center-west state of Mato Grosso. Rondônia experienced an over four-fold increase in material inputs, largely attributed to an increase in the application of animal vaccines, although pesticide and fertilizer use also grew. Roraima showed a nearly-four-fold increase in material inputs, with fertilizer use leading the way but seed, pesticides, and animal vaccines contributing. Mato Grosso likewise experienced an increase in material input application, with seed, fertilizer, and pesticide use growing the most. Only four states did not exhibit labor declines: Acre, Roraima, Espírito Santo, and Mato Grosso do Sul. Only in eight states did capital inputs grow: Rondônia, Acre, Amazonas, Roraima, Pará, Paraná, Mato Grosso do Sul, and Mato Grosso. Overall, the Brazilian input Fisher growth indices show very small declines in inputs, largely attributed to capital and labor reductions.

TFP Growth

The Brazilian agricultural Fisher TFP growth index, presented in table 7 of Appendix B, grew by 20.2% over the decennial reference period of 1985 to 1995/1996. With an 11.3% increase, Roraima experienced the lowest decennial productivity growth of all northern states, while at 66.7% Amazonas achieved the highest decennial productivity growth. The northeastern states varied widely in productivity growth. Piauí observed a robust decennial growth of 73.4%, while on the other end of the spectrum Pernambuco achieved the poorest decennial growth: -10.6%. In the southeastern region, no state had a decennial productivity growth greater than 17%. The southern region contained only one state (Santa Catarina) with exceptional decennial productivity growth (49.4%). Santa Catarina's TFP growth may be a product of the new irrigation technologies employed to boost food crop production. The center-west region, the epicenter of recent agricultural interest in Brazil (Hecht and Mann, 2008, Helfand and Levine, 2004, Matthey, Fabiosa and Fuller, 2004), observed decennial growth of 51% in Mato Grosso do Sul, 71.8% in Mato Grosso, 22.6% in Goiás, and 52.2% in the Federal Distracit (Brasilia).

Other studies of Brazil's agricultural technical change include Helfand and Rezende (2001) who cite Barros (1999). Barros employs a Törnqvist-Thiel approach from 1985/1986 to 1994/1995 to obtain 15% TFP growth. Gasquez, Bastos, and Bacchi (2008) also employ a Törnqvist-Thiel index using national-level data, with base 1.00 in 1985, to obtain a 1.24 index measure in 1995, or 24.2% decennial productivity growth. Baer (2008) cites Guilherme Leite da Silva Dias and Cicely Moitinho Amaral (2000), who estimate 22.8% decennial growth in agricultural TFP from 1987 to 1998.

da Silva Dias and Amaral (2000) attribute Brazil's agricultural productivity growth to weak infrastructure investments in the 1980s, forcing production to occur on the intensive margin in the 1990s; Embrapa's contribution to embodied and disembodied technical changes; migration transferring human capital from the southern and center-west states to northern ones; and trade liberalization's effect on improving the availability of material inputs at lower prices. While each of these determinants have undoubtedly played a part in the substantial increase Brazil experienced in agricultural productivity growth, the state-wide agricultural TFP growth disparities displayed in table 7, Appendix B, should be a warning to both Brazilian policy makers and Brazilian agriculture's competitors. Negative agricultural productivity growth affects local and regional development by reducing, or even eliminating, a significant revenue source from the rural population. Improvements in states with low or negative productivity growth would further boost Brazil’s agricultural supply to both domestic and international markets. Such improvements would either have the direct welfare impact of cheaper domestic food, or the indirect impact of improving Brazil’s macro-economic stability by way of the rising currency reserves from exporting to international markets.

Technology Regularity Conditions

Linear homogeneity, monotonicity, and convexity are important regularity conditions required of multi-output distance functions to ensure rational behavior. Linear homogeneity was imposed on the output distance frontier through the normalization of outputs given a numeraire output, shown by equations (9) and (10). To test for monotonicity and convexity, it is first necessary to rewrite (28) in a way which reveals the underlying transformation function (TF):

$$\begin{aligned} 0 &= \mu' P_s + TL(\ln x_{ki}, \ln y^*_{ji}, \beta) + \ln y_{mi} + \exp\left\{\ln z_{ai}{}'\Omega\right\} + \varepsilon_i, \\ &= TF. \end{aligned} \tag{38}$$

Transformation function (38) must be an increasing function of each output quantity and a decreasing function of each input quantity to be monotonic. Table 8 in Appendix B confirms the transformation function is monotonic, as the derivative of (38) with respect to each of the two normalized Fisher output quantity indices (annual crops and perennial crops) is positive, while the derivative of (38) with respect to each of the three Fisher input quantity indices (labor, materials, and capital) is negative.

Technological convexity requires a positive semi-definite Hessian matrix, in turn requiring that each principal minor be nonnegative (Simon and Blume, 1994). Table 9 in Appendix B presents the case that the technology is nearly convex, as the fourth principal minor is negative. Non-convexity of the Brazilian agricultural technology is to be expected, as convexity requires farm agents to maximize profits, have perfect information, and be able to divide outputs and inputs without limit. While profit-maximizing behavior is questionable for any developing country's agricultural sector, weather fluctuations and natural disasters such as fire and flood make perfect information a generally unrealistic assertion for agricultural production.

Growth Efficiency

As production technologies evolve, the dissemination of technical information and farm organization strategies determine the proportion of the productivity growth achieved by average farms. Thus, to assume a heteroscedastic inefficiency error is to assume the dissemination of technical information and farm organization strategies vary across observations. Our assumption of a heterscedastic inefficiency error is confirmed by the Chi-squared likelihood ratio (LR) test, which at the 1% level with two degrees of freedom.[10] This result confirms that scale function $g(\ln z_{ai};\Omega)\eta_i$ from equation (20) is not constant and growth efficiency in Brazilian agriculture is heterogeneous across micro-regions.

Mean growth efficiencies provide evidence of how well observations internalize the productivity growth. Table 10 of Appendix B presents state and national mean growth efficiency estimates. The national mean growth efficiency is 91.2%.[11] Therefore, from 1985 to 1995/1996, average Brazilian farmers internalized (or achieved) 91.2% of the productivity growth that occured. An interesting result from table 10 involves the northeast region. Of the nine states in the northeast, seven have observed nearly 100% growth efficiency: Piauí (99.4%), Ceará (99.9%), Paraiba (99.7%), Pernambuco (99.4%), Alagoas (99.1%), Sergipe (99.0%), and Bahia

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[10] LR chi2(2) = 13.47; Prob > chi2 = 0.0012

[11] The 95% confidence interval for national mean technical efficiency is (0.904, 0.921).

(99.8%). In fact, only two other states – Rondônia (99.3%) and Amazonas (99.9%), each located in the north region – also achieved nearly 100% mean growth efficiency. Brazil's lowest mean growth efficiency estimates are from the Federal District (63.7%) and Amapá (68.4%). Apart from Amapá, table 10 raises the question of why the highest mean growth efficiencies are observed in the northern regions. One possible explanation comes from differing complexity in the relative technologies employed. Generally, simple technologies need lower understanding and education levels to obtain optimal utilization. It is thus possible that the technologies employed in the northern regions agricultural sectors are of less complex nature than those employed in the southern and center-west regions. Another more feasible explanation could be the significant public expenditures, relative to the rest of the country, funneling into the northern regions to improve agricultural productivity (Baer, 2008).

To explain growth inefficiency error variance $\sigma_{u,i}^2$, education data representing human capital are employed. Those micro-regions with higher rural education and state-level per-capita public education expenditures are expected to experience lower growth inefficiency variances because education improves human capital, a primary determinant of agricultural productivity growth (Schultz, 1998). The results of equation (29) are presented in table 11 of Appendix B. The significant positive coefficients on both state-level per-capita public education expenditures (significant at the 5% level) and rural education (significant at the 3% level) suggest that micro-regions with higher human capital tend to have higher growth inefficiency variances. While these results are not expected, a possible explanation may be that farmers with more education leave the agricultural sector in search of higher wages, or profits, in non-farm activities. Agricultural production is then left to the remaining farmers who have lower human capital.

Because inefficiency error u_i is specified in a half-normal distribution, to increase the variance of technical inefficiency is to increase mean technical inefficiency, and to increase mean technical inefficiency is to decrease mean technical efficiency. Our results from table 11 of Appendix B indicate that, indeed, micro-regions with more human capital have higher growth inefficiency variances. To determine the associated shift in national-level mean growth efficiency, we employ equation (24). We find that a marginal increase in real state-level per-capita public education expenditures implies a 0.00003% decrease in mean growth efficiency, while a marginal increase in the average number of years of schooling in the rural population implies a 0.0025% decrease. So while the education variables significantly impact technical inefficiency's variance, their impact on mean growth efficiency is very small.

Conclusion

We have examined Brazil's agricultural sector employing micro-region and state-level data from the agricultural censuses conducted in 1985 and 1995/1996. In light of insufficient panel data to obtain technical change estimates directly from the stochastic output distance frontier, state and national technical changes are imputed as the ratio of agricultural Fisher TFP growth estimates to stochastically estimated growth efficiencies. The empirical evidence indicates, at the national level, agricultural total factor productivity to have grown 20.2% from 1985 to 1995/1996. The average Brazilian farmer was able to internalize – or experience – only 91.2% of the agricultural productivity growth, implying the production frontier expanded 22.2% over the reference time period.

Brazil could improve agricultural productivity, and thus international competitiveness, by focusing on states with low growth efficiency and high imputed technical growth. Such states are: Acre, Mato Grosso do Sul, Mato Grosso, and the Federal District. Acre's agricultural Fisher TFP decennial growth was nearly 42%, while the average farmer in Acre was only 81.1% efficient in that growth. Acre's imputed decennial technical change therefore was 51.7%, second-best among states in the northern region. In 1995, Acre's revenue shares were dominated by manioc (35.7%), cattle meat (23.0%), and milk production (10.4%). Mato Grosso do Sul experienced decennial Fisher TFP productivity growth of 51%, growth efficiency of 84.1%, and an imputed technical change of 60.6%. Mato Grosso do Sul's revenue shares were predominately comprised of cattle meat (60.8%) and soy production (16.2%). Mato Grosso's decennial TFP growth of 71.8% -- the national high -- and its growth efficiency of 88.4% imply an imputed decennial technical change of 81.2%. Mato Grosso's revenue shares in 1995 favored rice (38.6%), cattle meat (27.8%), and sugarcane production (10.7%). The Federal District's decennial TFP growth of 52.2% and national-low 63.7% growth efficiency generated an imputed decennial technical change of 82%. Eggs (32%), poultry (13.6%), and maize (13.1%) constituted the largest shares of the Federal District's revenues in 1995. Amazingly, the results show Mato Grosso's and the Federal District's frontier producers nearly doubled production from 1985 to 1995/1996.

Apart from Mato Grosso's sugarcane revenues, each of the four high-technical-change low-growth-efficiency states obtained significant shares of their revenues from annual crops and livestock production. These four states should be able to improve average-farm productivity at low marginal cost through improved dissemination of technical information, as the technologies to produce at higher growth rates are already available. In order to maximize agricultural production in these four states, that is to push the average farmer up to the technical frontier, Brazil should emphasize disseminating technical information about annual crop and livestock production. Technical information sources available to farmers include, but are not limited to, national extension services, input suppliers, consultants, farmer organizations, and non-governmental organizations (NGOs) (Morris and Byerlee, 1998).

Future research should focus on the role of extension services and their contribution to improving technical inefficiencies in Brazilian agriculture. Our results show that improving the education of the average Brazilian farmer most likely comes at a small cost to agricultural productivity. Thus any policy efforts to improve farmer knowledge of available production technologies may simultaneously need to provide incentives to hold farmers in the agricultural sector.

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Appendix A: Empirical Results

	DEP. VAR.: -LnLivestock	COEFFICIENTS	STANDARD ERROR	Z	P > |Z|
Singular Coefficients	LnAnnuals	0.38288	0.05574	6.870	0.000
	LnPerennials	0.07018	0.02374	2.960	0.003
	LnCapital	-0.10319	0.11113	-0.930	0.353
	LnMaterials	-0.12643	0.05988	-2.110	0.035
	LnLabor	-0.63013	0.08907	-7.070	0.000
Squared Coefficients	LnCapital_2	0.27740	0.16356	1.700	0.090
	LnMaterials_2	-0.11486	0.05498	-2.090	0.037
	LnLabor_2	-0.04735	0.08142	-0.580	0.561
	LnAnnuals_2	0.12611	0.03742	3.370	0.001
	LnPerennials_2	0.02188	0.00786	2.780	0.005
Cross-Product Coefficients	LnCapital_LnMaterials	0.01421	0.06832	0.210	0.835
	LnCapital_LnLabor	-0.07562	0.10685	-0.710	0.479
	LnMaterials_LnLabor	0.05136	0.06871	0.750	0.455
	LnAnnuals_LnPerennials	-0.04971	0.01282	-3.880	0.000
	LnAnnuals_LnCapital	0.26819	0.05759	4.660	0.000
	LnAnnuals_LnMaterials	-0.07085	0.03555	-1.990	0.046
	LnAnnuals_LnLabor	-0.04836	0.04820	-1.000	0.316
	LnPerennials_LnCapital	-0.09537	0.03241	-2.940	0.003
	LnPerennials_LnMaterials	0.00444	0.01633	0.270	0.786
	LnPerennials_LnLabor	0.04760	0.03091	1.540	0.124
State Fixed-Effects	Rondônia	-0.78591	0.11161	-7.040	0.000
	Acre	-0.10048	0.16629	-0.600	0.546
	Amazonas	-0.75576	0.07788	-9.700	0.000
	Roraima	-0.08833	0.14910	-0.590	0.554
	Pará	-0.50218	0.07406	-6.780	0.000
	Amapá	0.12394	0.25327	0.490	0.625
	Tocantins	-0.16774	0.11015	-1.520	0.128
	Maranhão	-0.50832	0.07786	-6.530	0.000
	Piauí	-0.46962	0.08489	-5.530	0.000
	Ceará	-0.34068	0.06180	-5.510	0.000
	Rio Grande Do Norte	-0.29859	0.08169	-3.660	0.000
	Paraiba	-0.27280	0.06572	-4.150	0.000
	Pernambuco	-0.24608	0.07286	-3.380	0.001
	Alagoas	-0.51936	0.07969	-6.520	0.000
	Sergipe	-0.14822	0.08352	-1.770	0.076
	Bahia	-0.00323	0.06516	-0.050	0.960
	Minas Gerais	-0.17550	0.06003	-2.920	0.003
	Espírito Santo	0.29464	0.09916	2.970	0.003
	Rio De Janeiro	-0.11443	0.09081	-1.260	0.208
	São Paulo	0.09602	0.08672	1.110	0.268

State Fixed-Effects Continued	Paraná	-0.48910	0.07577	-6.450	0.000
	Santa Catarina	-0.35338	0.09192	-3.840	0.000
	Rio Grande Do Sul	-0.20505	0.07932	-2.590	0.010
	Mato Grosso Do Sul	-0.36936	0.11377	-3.250	0.001
	Mato Grosso	-0.64233	0.09801	-6.550	0.000
	Goiás	-0.25969	0.07862	-3.300	0.001
	Federal District (Brasilia)	-0.36617	0.65943	-0.560	0.579
	LnSigma_2: v				
	constant	-2.893175	0.0793149	-36.48	0.00
Variance Function	LnSigma_2: u				
	constant	-18.389440	7.400423	-2.480	0.013
	LnEducationExpenditures	1.5880	0.7949212	2.000	0.046
	LnRuralEducation	10.2248	4.709389	2.170	0.030

Log Likelihood: -31.475; number of observations = 550

Appendix B: Tables

Table 1: Agriculture's share of GDP (current prices, US$)

Year	Agriculture's GDP share	Year	Agriculture's GDP share
1985	9.00%	1996	8.32%
1986	9.24%	1997	7.96%
1987	7.73%	1998	8.23%
1988	7.60%	1999	8.25%
1989	7.20%	2000	7.97%
1990	8.10%	2001	8.39%
1991	7.79%	2002	8.75%
1992	7.72%	2003	9.90%
1993	7.56%	2004	9.05%
1994	9.85%	2005	7.53%
1995	9.01%	2006	n/a
1985-1995 Avg.	8.25%	1985-2005 Avg.	8.34%

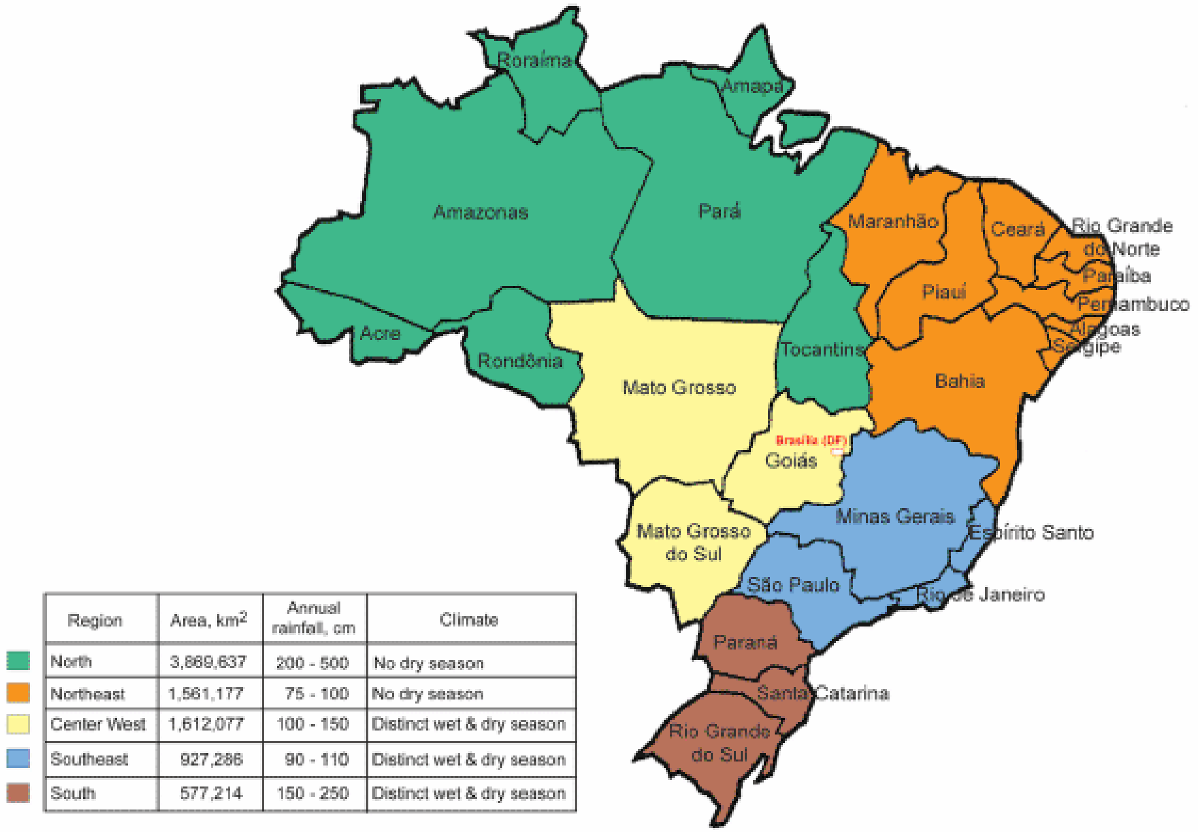
Source: (Baer, 2008); n/a implies unavailable data

Table 2: Structural Changes of the Agricultural Sector

	1975	1985	1995/1996	2006	1975-1985 Growth Rate	1985-1996 Growth Rate	1996-2006 Growth Rate
Establishments	4,993,252	5,801,809	4,859,865	5,204,130	0.150	-0.177	0.068
Total Land (Ha)	323,896,082	374,924,929	353,611,246	354,865,534	0.146	-0.059	0.004
Crop Lands (Ha)	40,001,358	52,147,708	41,794,455	76,697,324	0.265	-0.221	0.607
Pastures (Ha)	165,652,250	179,188,431	177,700,472	172,333,073	0.079	-0.008	-0.031
Forests (Ha)	70,721,929	88,983,599	94,293,598	99,887,620	0.230	0.058	0.058
Labor	20,345,692	23,394,919	17,930,890	16,414,728	0.140	-0.266	-0.088
Tractors	323,113	665,280	803,742	788,053	0.722	0.189	-0.020

Source: IBGE website

Figure 1: Brazil



	Region	Area, km^2	Annual rainfall, cm	Climate
🟩	North	3,869,637	200 - 500	No dry season
🟧	Northeast	1,561,177	75 - 100	No dry season
🟨	Center West	1,612,077	100 - 150	Distinct wet & dry season
🟦	Southeast	927,286	90 - 110	Distinct wet & dry season
🟫	South	577,214	150 - 250	Distinct wet & dry season

Figure 1 - The regions, area, and general climate of Brazil. Adapted from FAO (2005).

Table 3: Regions and States of Brazil

Regions:	States:								
North	Rondônia	Acre	Amazonas	Roraima	Pará	Amapá	Tocantins		
Northeast	Maranhão	Piauí	Ceará	Rio Grande do Norte	Paraiba	Pernambuco	Alagoas	Sergipe	Bahia
Southeast	Minas Gerais	Espírito Santo	Rio de Janeiro	São Paulo					
South	Paraná	Santa Catarina	Rio Grande do Sul						
Center-West	Mato Grosso do Sul	Mato Grosso	Goiás	Federal District (Brasilia)					

Table 4: Currency Changes in Brazil 1984-1994

Currency	Period	Equivalence
Cruzeiro (Cr$)	08/1984 to 02/1986	
Cruzado (Cz$)	02/1986 to 01/1989	Cz$1 = Cr$1,000
Cruzado Novo (NCz$)	01/1989 to 03/1990	NCz$1 = Cz$1,000
Cruzeiro (Cr$)	03/1990 to 08/1993	Cr$1 = NCz$1
Cruzeiro Real (CR$)	08/1993 to 05/1994	CR$1 = Cr$1,000
Real (R$)	05/1994 to Present	R$1 = CR$2,750

Source: IBGE

Table 5: 1995/1996 Agricultural Output Growth (relative to 1.00 in base year 1985)

REGION	STATE	ANNUAL CROPS	PERENNIAL CROPS	LIVESTOCK	OUTPUT FISHER
North	Rondônia	0.73	1.15	7.01	1.67
North	Acre	1.47	1.59	2.89	1.99
North	Amazonas	1.12	1.39	1.87	1.25
North	Roraima	1.44	3.27	1.80	1.74
North	Pará	0.72	1.08	2.40	1.19
North	Amapá	0.63	2.01	2.47	1.11
North	Tocantins	0.67	0.62	1.99	1.36
Northeast	Maranhão	0.81	1.11	2.05	1.15
Northeast	Piauí	0.98	1.57	2.00	1.33
Northeast	Ceará	0.91	1.13	1.59	1.16
Northeast	Rio Grande Do Norte	0.66	1.25	1.55	1.15
Northeast	Paraiba	0.64	0.66	1.33	0.75
Northeast	Pernambuco	0.80	0.67	1.50	0.76
Northeast	Alagoas	1.10	0.83	2.02	0.88
Northeast	Sergipe	0.62	1.15	1.59	1.11
Northeast	Bahia	0.94	0.72	1.28	0.91
Southeast	Minas Gerais	1.03	1.13	1.34	1.18
Southeast	Espírito Santo	0.54	1.24	1.25	1.18
Southeast	Rio De Janeiro	0.61	0.61	1.30	0.73
Southeast	São Paulo	0.70	1.07	1.62	1.07
South	Paraná	1.26	0.84	2.22	1.25
South	Santa Catarina	1.16	0.96	2.76	1.73
South	Rio Grande Do Sul	1.00	1.12	1.96	1.26
Center-West	Mato Grosso Do Sul	1.27	1.81	2.76	2.04
Center-West	Mato Grosso	2.35	3.53	3.39	2.82
Center-West	Goiás	1.41	1.41	1.57	1.48
Center-West	Federal District (Brasilia)	1.63	1.85	2.76	2.01
	Brazil	1.07	1.03	1.90	1.20

Table 6: 1995/1996 Agricultural Input Growth (relative to 1.00 in base year 1985)

REGION	STATE	LABOR	MATERIALS	CAPITAL	INPUT FISHER
North	Rondônia	0.92	4.33	2.06	1.50
North	Acre	1.38	1.52	1.56	1.40
North	Amazonas	0.70	1.22	1.04	0.75
North	Roraima	1.50	3.96	1.31	1.57
North	Pará	0.70	1.95	1.02	0.87
North	Amapá	0.87	1.68	0.82	0.93
North	Tocantins	0.84	2.25	0.99	1.03
Northeast	Maranhão	0.78	2.37	0.85	0.81
Northeast	Piauí	0.79	2.27	0.68	0.77
Northeast	Ceará	0.92	1.43	0.68	0.85
Northeast	Rio Grande Do Norte	0.82	2.18	0.76	0.88
Northeast	Paraiba	0.72	1.42	0.76	0.76
Northeast	Pernambuco	0.73	1.59	0.91	0.85
Northeast	Alagoas	0.69	1.97	0.93	0.84
Northeast	Sergipe	0.85	2.15	0.90	0.91
Northeast	Bahia	0.79	2.97	0.97	0.94
Southeast	Minas Gerais	0.79	2.33	0.93	1.08
Southeast	Espírito Santo	1.18	1.74	0.88	1.02
Southeast	Rio De Janeiro	0.52	1.35	0.67	0.70
Southeast	São Paulo	0.73	2.00	0.72	0.92
South	Paraná	0.70	2.24	1.00	1.06
South	Santa Catarina	0.85	1.99	0.96	1.16
South	Rio Grande Do Sul	0.76	2.43	0.93	1.11
Center-West	Mato Grosso Do Sul	1.19	2.59	1.02	1.35
Center-West	Mato Grosso	0.89	3.68	1.58	1.64
Center-West	Goiás	0.77	3.15	0.95	1.21
Center-West	Federal District (Brasilia)	0.83	1.76	1.11	1.32
	Brazil	0.783	2.247	0.916	0.998

Table 7: Agricultural Fisher TFP Indices (relative to base 1.00 in 1985) and Logarithmic TFP Growth Rates from 1985 to 1995/1996

REGION	STATE	FISHER TFP IDEX	FISHER TFP % CHANGE
North	Rondônia	1.117	0.117
North	Acre	1.419	0.419
North	Amazonas	1.667	0.667
North	Roraima	1.113	0.113
North	Pará	1.369	0.369
North	Amapá	1.192	0.192
North	Tocantins	1.327	0.327
Northeast	Maranhão	1.417	0.417
Northeast	Piauí	1.734	0.734
Northeast	Ceará	1.372	0.372
Northeast	Rio Grande Do Norte	1.315	0.315
Northeast	Paraiba	0.989	-0.011
Northeast	Pernambuco	0.894	-0.106
Northeast	Alagoas	1.040	0.040
Northeast	Sergipe	1.216	0.216
Northeast	Bahia	0.966	-0.034
Southeast	Minas Gerais	1.099	0.099
Southeast	Espírito Santo	1.154	0.154
Southeast	Rio De Janeiro	1.034	0.034
Southeast	São Paulo	1.165	0.165
South	Paraná	1.184	0.184
South	Santa Catarina	1.494	0.494
South	Rio Grande Do Sul	1.132	0.132
Center-West	Mato Grosso Do Sul	1.510	0.510
Center-West	Mato Grosso	1.718	0.718
Center-West	Goiás	1.226	0.226
Center-West	Federal District (Brasilia)	1.522	0.522
	Brazil	1.202	0.202

Table 8: Regularity Condition:

MONOTONICITY			
Outputs		Inputs	
$\frac{\partial TF}{\partial \ln Y_{Annuals}}$	0.26	$\frac{\partial TF}{\partial \ln X_{Capital}}$	-0.17
$\frac{\partial TF}{\partial \ln Y_{Perennials}}$	0.08	$\frac{\partial TF}{\partial \ln X_{Materials}}$	-0.19
		$\frac{\partial TF}{\partial \ln X_{Labor}}$	-0.58

Table 9: Regularity Condition:

CONVEXITY	
Hessian Principal Minors:	Determinant
1	0.252224
2	0.008565
3	0.001853
4	-0.000519
5	0.000074

Table 10: Technical Efficiency Changes and Imputed Technical Changes and Imputed Technical Changes from 1985 to 1995/1996

REGION	STATE	TECHNICAL EFFICIENCY CHANGES	IMPUTED TECHINCAL CHANGES
North	Rondônia	0.993	0.117
North	Acre	0.811	0.517
North	Amazonas	0.999	0.668
North	Roraima	0.912	0.124
North	Pará	0.980	0.377
North	Amapá	0.684	0.281
North	Tocantins	0.931	0.351
Northeast	Maranhão	0.979	0.426
Northeast	Piauí	0.994	0.738
Northeast	Ceará	0.999	0.373
Northeast	Rio Grande Do Norte	0.955	0.330
Northeast	Paraiba	0.997	-0.011
Northeast	Pernambuco	0.994	-0.107
Northeast	Alagoas	0.991	0.040
Northeast	Sergipe	0.990	0.218
Northeast	Bahia	0.998	-0.034
Southeast	Minas Gerais	0.971	0.102
Southeast	Espírito Santo	0.848	0.182
Southeast	Rio De Janeiro	0.854	0.040
Southeast	São Paulo	0.767	0.215
South	Paraná	0.862	0.213
South	Santa Catarina	0.790	0.625
South	Rio Grande Do Sul	0.791	0.167
Center-West	Mato Grosso Do Sul	0.841	0.606
Center-West	Mato Grosso	0.884	0.812
Center-West	Goiás	0.979	0.231
Center-West	Federal District (Brasilia)	0.637	0.820
	Brazil	0.912	0.222

Table 11: Explaining Technical Inefficiency

DEP. VARIABLE: $\ln \sigma^2_{u,it}$	ESTIMATED COEFFICIENTS	P > |Z|
Constant	-18.38901	0.013
LnPublicEducation	1.587913	0.046
LnRuralEducation	10.22454	0.030