Working Paper No. 490

Productivity, Technical Efficiency, and Farm Size in Paraguayan Agriculture

by

Thomas Masterson

Research Scholar, The Levy Economics Institute of Bard College

February 2007

The Levy Economics Institute
P.O. Box 5000
Annandale-on-Hudson, NY 12504-5000
http://www.levy.org

ABSTRACT

This essay assesses the relationship between farm size and productivity. Both parametric and nonparametric methods are used to derive efficiency measures. Smaller farms are found to have higher net farm income per hectare, and to be more technically efficient, than larger farms.

JEL Classifications: Q12, O12

Keywords: Farm Size, Productivity, Techincal Efficency, Paraguay

1. INTRODUCTION

One of the important economic arguments in favor of the equitable distribution of farmland is that smaller farms are more productive. A large portion of the economic development literature is devoted to this topic, with arguments going both for and against the notion that smaller farms are more productive. This essay, on the relationship between farm size and productivity, builds on the study J. Mohan Rao and I completed for the UNDP and Ministerio de Hacienda del Paraguay (Masterson and Rao 1999). This essay departs from the earlier work, using more recent data, allowing for comparison between two time periods, and by employing both stochastic and nonparametric techniques for generating technical efficiency measurements, an alternative to the factor productivity measures used in the original study. In addition, while the prior report was driven by the search for policy proposals to promote economic growth, this essay will focus on the inverse relationship itself. The results of the original paper support the hypothesis that farm size and productivity are inversely proportional in Paraguay. This result holds even taking into account the various other factors in the literature on the inverse relationship between farm size and productivity, such as land quality, Green Revolution technology, and supervision costs.

One critique leveled at the literature on the productivity-farm size relationship is that the measure used, land productivity, is inappropriate. Because it only compares total output to the size of the farm, ignoring other factors of production and inputs, land productivity is said to be, at best, an incomplete measure of economic efficiency. This study will address this issue in the Paraguayan context. Small farms have both higher land productivity and equal or better technical efficiency. This is true even when controlling for many of the factors the literature suggests as possible explanations for the inverse relationship. I will now discuss the literature on the farm size productivity relationship briefly, before moving on to review the data and the methodology I will use, and then my results.

2. LITERATURE REVIEW

Study of India's Farm Management Surveys sparked a debate in the 1960s on an observed inverse relationship between farm size and productivity (Sen 1962). Inputs, costs, and output per hectare seemed to decrease as farm size increased, while output per unit of input increased. Debates raged over whether this was due to differential factor prices, differential land use intensities (cropping and inputs), qualitative factor differences, class-based differences among farms of different sizes, or some combination of factors. The implications of these findings for agrarian reform added a great deal of fuel to the fire. Higher factor use intensities on small farms were clearly a phenomenon that demanded study (Mazumdar 1965; Dyer 1991).

The debate and the studies it provoked produced interesting findings and conclusions. It was found that there is an inverse relationship between total output divided by net cropped area and farm size, and that using gross cropped area reduces the strength of this relationship. The search for an inverse relationship for physical yield of individual crops yielded weak evidence, but a strong inverse relationship between cropping intensity and farm size was found. Inverse relationships were found between labor intensity and farm size, between family labor and farm size, between capital input intensity and farm size, but not between intermediate inputs and farm size. And an inverse relationship between percentage of land irrigated and farm size was discovered. The observed inverse relationship was not due to differences in factor endowments (soil, labor, management ability, etc.), but to higher land use and cropping intensities. While differential factor prices, property rights, and tenure play a part in this phenomenon, the inverse relationship reflects "the desperate struggle of poor and marginal peasants to scratch a bare subsistence" (Dyer 1991). This Indian debate sparked many similar debates and studies in the rest of the world, in which many explanations have been proffered for the inverse relationship, some by those advocating for land reform and others by those who question its wisdom.

Carter (1984) sets out many of the possible explanations for the observed inverse relationship. Village-specific factors might be correlated to farm size (such as the Malthusian argument that greater land quality would lead to greater population density). Then there are possible characteristics of small farms themselves: they may have better quality soil within villages; size may be a proxy for mode of production; there may be diminishing returns to scale; they may be more technically efficient. This section will review the literature for each proposed explanation of the inverse relationship.

Production conditions in developing countries seem to have certain characteristics in common: a bimodal production structure (large farms with lots of unused land and small farms with excess labor); capitalist relations of production are less prevalent than in industrialized nations; in some areas, markets in the means of production are controlled by rich landowners (Cornia 1985). Do these conditions contribute to the inverse relationship? Ajit Kumar Ghose (1979) investigates the contribution of the organization of production to the observed inverse relationship in Indian agriculture. He classifies farms along two axes, ownership and labor. Peasant farms are those on which family labor makes up fifty percent or more of the total labor employed in production. Tenant farms are those which lease or rent at least some of the land they operate. He finds that the intensity of labor, as well as other inputs, varies inversely with farm size for all types (combinations of ownership and labor) of farm. He finds that an inverse relationship does exist between farm size and output per acre for all farms in most samples, for peasant tenant and peasant owner farms in most samples, and employer farms. Ghose concludes that small farms' allocative efficiency is due not to the superiority of peasant organization of production, but relies on primitive technology and undeveloped markets: in the absence of labor-saving technologies and developed markets in inputs (such as fertilizer) and labor, small farms, with abundant labor and the use of farmyard manure, have the advantage. But Ghose hypothesized that this advantage would disappear with technological progress.

Many authors conclude that the inverse relationship is a result of differential factor use intensity (Carter 1984; Newell, Pandya, and Symons 1997). In a 1996 study typical of this approach, Byiringiro and Reardon find that small Rwandan farms achieve three times greater land yields, use four times more labor, and have four times the number of plots per hectare that larger farms do. They conclude that as a result of this, small farms have greater average and marginal productivity of land and are less allocatively efficient. The question of the source of this differentiated use of factors (especially family labor) is often attributed to imperfect labor markets (i.e., lack of off-farm employment opportunities [Verma and Bromley 1987]). This is one of the most well-developed areas of the overall inverse relationship literature.

One proposed explanation of high labor use intensities on small farms is that in the land market, smaller peasants face higher effective purchase prices for land. This skewed resource position for smaller farmers has several implications about their use of labor vis-à-vis larger farmers: they use labor more intensively for each crop; they use more of the available land; they choose more labor-intensive crops; and they use their own labor for land improvements. All of these implications lead to the conclusion that small farmers have a higher resource use per unit of land. This factor use intensity gives small farms a productivity advantage over large farms, but with the advent of green revolution technology, they might lose this advantage, since, in the absence of technical extension and credit services, small farmers do not have access to these technologies (Cornia 1985).

Another explanation for the greater intensity of family labor among small peasants is desperation. If small farmers are struggling at the edge of survival, they are more likely to work hard. It would not be prudent to equate the welfare of the small peasant household with its productivity, if that productivity is the result of poverty.[1]

Dualistic labor markets have also been proposed as an explanation—if family labor is cheaper, then there should be a higher labor to land ratio on the smaller farms. There are logical economic reasons for a gap between the supply prices of family and hired labor. There is less uncertainty about effort with family labor than with hired labor, making the opportunity cost for family labor lower (Mazumdar 1965). In addition, workers may prefer to work for themselves, or at least for their own family, than to work for someone else (Sen 1975). The control large landowners have, over factor markets especially, means that different size farms face different factor prices: for small farms, land and capital are more expensive than for large farms, while labor is less expensive. This leads to excess labor supply in the labor market, which would imply that wages in agriculture will tend towards zero. This is not observed, however, since the wage will not drop below some "minimum caloric requirement." Large farms will hire labor only until the marginal product of labor is equal to this minimum wage. Thus, there will be unemployed labor and the opportunity cost of employing family labor will be low on small farms (Verma and Bromley 1987; Cornia 1985).

Such labor market theories of the high family labor use of small farms and its contribution to the inverse relationship have relied on labor market dualism, but the fact remains that small farmers both hire in and hire out labor (though this is not to say that they are perfect substitutes; for more on that, see below). In addition, hired labor is necessary on larger farms, so family labor is an unlikely explanation for the inverse relationship between fifteen and fifty acres, for example. Thus, it is important not to go too far in identifying farm size with characteristics such as capitalization, mechanization, and use of wage labor (Dyer 1996). Feder (1985) offers an

[1] I am grateful to Vamsicharan Vakulabharanam for his observations.

alternative explanation of the more intense use of family labor, based on three propositions: first, that family labor is more efficient than supervised labor; second, that family labor is more motivated than hired labor and can supervise the latter; and third, that the supply of working capital is directly related to farm size.

The greater efficiency of family labor on small farms may be due to two factors. First, as the ratio of hired to family labor rises, supervision becomes more time consuming and less effective. Second, as the social distance between the supervisors and the hired labor increases (as it would on larger farms), the effectiveness of supervision will decrease (Boyce 1987).

Another common refrain is that, due to the stochastic effects of weather and so forth on agricultural output, farmers cannot use output to monitor the effort of employees. Thus, farm wage labor requires supervision. This results in the inverse relationship (the larger the farm, the thinner the family labor is spread, the greater the monitoring problems), as well as the structure of agrarian land and labor contracts, and the adoption of labor saving technology by larger farms. In his study, Frisvold (1994) determines that family and hired labor are not perfect substitutes. While the source of differential family labor use among farm sizes will not be examined in this study, its effects on productivity will be.

Neoclassical theorists argue that the segmentation of land, credit, and labor markets results in the inverse relationship. Large landowners have access to land and credit that small farmers do not. However, this segmentation implies that larger farms are more capital intensive, which should theoretically decrease the inverse relationship (Dyer 1996). While larger farms generally have higher land-to-labor and capital-to-labor ratios, they do not necessarily have higher capital-to-land ratios. If the capital-to-land ratio is higher for large farms, then the inverse relationship is weakened. In 1991, larger farms did indeed have higher capital to land ratios in Paraguay (Masterson and Rao 1999). Carter and Wiebe (1990) argue that small farms' hyperproductivity is eventually overwhelmed by capital constraints—as farm size increases, it becomes less easy to substitute family labor for hired labor and other purchased inputs. Since credit markets in many less-developed countries are characterized by undeveloped financial institutions (meaning local money lenders making high interest rate loans to small farmers, while lower interest rate, "institutional" credit goes to the richer peasants), the cost of and access to credit are inversely related to farm size (Cornia 1985). This credit market segmentation favors the reduction of the inverse relationship. Labor market segmentation, on the other hand, may intensify the inverse relationship. Segmentation in input markets may also tend to diminish the inverse relationship if larger farmers have first access to tractors, etc.

Land quality differences may contribute to the inverse relationship. More output may lead to greater population growth in areas with greater land quality, which could lead to greater fragmentation and, thus, smaller farms. Land quality differences have two possible sources: natural differences in soil types, climate, etc.; and man-made differences, due to investments in fertilizers, soil conservation, etc. In the latter case, small farm size could lead to better quality land, not the other way around. Smaller farms may be more likely to make labor-intensive investments in soil quality.[2] Bhalla and Roy (1988) argue that, if land quality and farm size are inversely correlated and farm size and cultivated area are directly correlated, then excluding land quality from regressions of land yields on cultivated area would bias the estimated coefficient of cultivated area downward. But this would be bias only if the soil quality differences were not due to investments made by farmers themselves. Thus, agro-climatic conditions and soil quality, crucial determinants of agricultural productivity, as well as measures of farmers' investments in soil quality must be included in investigations of said productivity.

Attempts to incorporate soil quality into empirical investigations of the inverse relationship have met with mixed results. Newell, Pandyal, and Symons (1997) argue that, in Gujarat, farms are smaller in fertile regions than in less fertile regions, so that output per hectare is larger on small farms. Benjamin (1995) tests land quality's contribution to the inverse relationship with inconclusive results—land quality may be a factor. He does not examine labor market effects, due to data limitations, but argues that local labor market conditions should remove the effect via cluster fixed effects. Carter (1984), on the other hand, finds that while land quality explains some of the inverse relationship, it does not explain all of it. Both natural soil quality and investments in soil quality must contribute to productivity, so I will test that contribution.

While decreasing returns to scale would explain the inverse relationship, evidence of constant returns to scale is widespread, even after the introduction of green revolution technology (Carter 1984). Constant returns to scale implies that there is no technological basis for the inverse relationship, but does not rule out scale related price differentials (Feder 1985). Increasing complexity and supervision/incentive problems may contribute to diseconomies of scale, but if technical economies of scale exist, they could dominate organizational diseconomies

(Dyer 1996). A. B. Deolalikar (1981), in another study on Indian agriculture, investigates the inverse relationship geographically and finds that the inverse relationship holds for the traditional sector, but concludes that the green revolution, where it has taken hold, has wiped out the inverse relationship.

The work of anthropologist Sol Tax in Mayan communities in Guatemala is the basis for a major Latin American version of this debate: the “efficient but poor” hypothesis put forward by Schultz in his seminal 1964 study of Guatemalan Indian villages. The two main contributions of Schultz’s work were: that low income levels among indigenous/peasant communities were the result of the low productivity of the available inputs and not due to allocative inefficiency by individual peasant farmers; and that outside experts could not improve productivity simply by suggesting reallocation of existing resources. Education was needed to facilitate new, higher productivity factors of production. Schultz’s real contribution was in pointing out that peasants are more than willing to respond to changing incentives. Schultz’s analysis employed a particular type of long-run economic equilibrium pertaining to peasant economy. Constant technology, preferences, and motives had been in place long enough for peasants to optimize at the margin. Thus, the low marginal product of labor led to the observed “idleness” of peasants, and low rate of return to savings to “lack of thrift.” The implication is that the “efficient but poor” hypothesis seems to be contradicted in changing conditions or imperfect markets. But for Schultz, it was *responsiveness* that leads to efficiency. Outside experts, though, can valuably advise on the use of new technologies (Ball and Pounder 1996).

The risks involved in agriculture can be expected to affect the behavior of both small and large farmers. Given a lack of crop insurance markets and an unequal distribution of land, food price risk will result in the hyperexploitation of household labor on smaller farms (Barrett 1996). Larger farmers (who presumably have options smaller farmers don’t) will substitute away from farming to less risky options. In a context of imperfect land and/or credit markets, this will lead to underutilization of land by large farms. This combination, or either effect separately, will contribute to an inverse relationship. I now discuss the data I use in this essay.

---

[2]These investments are also dependent on tenure security—a short-term renter is unlikely to invest labor on soil improvements.

3. DATA AND METHODOLOGY

The work in this study will be done using the 2000–2001 MECOVI dataset, as well as soil quality data that I obtained from the Ministerio de Agricultura y Ganaderia (MAG) of Paraguay in the summer of 1998. The Mejoramiento de las Encuestas de Hogares y la Medición de Condiciones de Vida (MECOVI) dataset is a Living Standards Measurement Survey, following the World Bank's LSMS guidelines. It includes data on a sample of 8131 representative Paraguayan households, including demographic data for each household member, data on individual land ownership, data on land controlled in various forms of tenancy, data on the usage of land, and detailed output and price data for crops, livestock, dairy, and processed goods. Using these data, I am able to calculate the total value of agricultural output for each farm household. I am also able to derive a number of interesting and useful bits of information for use as explanatory variables, as described below. Additional notes on data are contained in Appendix A.

In the UNDP study, we used a variety of models to examine productivity in Paraguay. We ran regressions of land, labor, and capital productivity, as well as the three factor ratios (land/labor, land/capital, capital/labor) using a variety of determinants, including household size, age, education and sex of the household head, ratio of family to total labor, soil quality, use of green revolution technologies and soil conservation techniques, and access to credit and technical assistance. In addition, we created a new measure of efficiency, "relative efficiency," by running a log-normal production function regression and dividing the actual output values by the resulting predicted values. Unfortunately, the relative efficiency measure did not vary enough among farms to be useful for measuring differences (Masterson and Rao 1999).

What measure of productivity to use is certainly an open question. Most studies have used either a production function approach or used land productivity (aggregate output divided by farm size). This measure is subject to criticism as giving too much importance to one input, land. In the Paraguayan context of extremely high land concentration and high rates of rural poverty, a focus on land is appropriate. However, I will examine efficiency as well, since another critique of the use of land productivity is that it is not an accurate measure of actual efficiency. Thus, this paper will focus on two measures: land productivity (the subject of the inverse relationship literature) and technical efficiency.

I use two methods for deriving the technical efficiency measure. Both are production frontier techniques. One is a nonparametric technique—data envelopment analysis. The second is a regression technique, a stochastic production frontier. I'll now explain each in turn.

The data envelopment analysis method I employ,[3] unlike the stochastic method of frontier estimation, has the advantage of not imposing a functional form on the production data. In addition, this technique, unlike the stochastic method described below, allows for multiple outputs. I solve a linear program of the form:

$$\begin{aligned} &Min \quad \phi \\ &s.t. \quad \sum_j \lambda_j x_{ij} + S_i^+ = \phi x_{ij_o} \quad \forall i \\ &\qquad \sum_j \lambda_j y_{rj} + S_r^- = y_{rj_o} \quad \forall r \\ &\qquad S_i^+, S_r^- \geq 0 \quad \forall i, \forall r \\ &\qquad \lambda_j \geq 0 \quad \forall j. \end{aligned} \tag{1}$$

Where x_{ij} is the amount of input i for farm j, y_{rj} is the amount of output r from farm j, and j_o is the farm to be assessed. The objective variable ϕ measures the technical efficiency of farm j_o. The two slack variables, S_i^+ and S_r^-, measure slack in inputs and outputs, respectively. This linear programming model fits an n-dimensional (in this case n=10: 6 inputs plus 4 outputs) envelope around the data and determines each farm's distance from it. This distance gives a measure of each farm's technical efficiency relative to every other farm, a desirable characteristic.

The stochastic production frontier method uses a regression specification of the following general model:

$$y_i = \beta x_i + \nu_i - u_i \tag{2}$$

[3]Following the work of Fletschner and Zepeda (1998) and others: Chavas and Aliber 1993; Banker, Charmes, and Cooper 1984; and Emrouznejad 2004.

in which y_i is the total production of farm *i*, x_i is a vector of inputs for farm *i*, β is a vector of coefficients, n_i is a randomly distributed error term for each farm *i*, and u_i is a one-sided (positive only) inefficiency error term (Aigner and Chu 1968). The specification I use is as follows:

$$y_i = \beta_1 AreaOp_i + \beta_2 Fam_i + \beta_3 Hired_i + \beta_4 Rental_i + \beta_5 Dep_i + \beta_6 Inputs_i + \nu_i - u_i, \qquad (3)$$

where *y* is the net value of farm production in millions of Guaranies,[4] *AreaOp* is the operational area of the farm (the farm's size, in hectares), *Fam* is the family labor employed on the farm (in person years), *Hired* is the hired labor employed on the farm (in person years), *Rental* is the resources rented by the farm (in millions G), *Dep* is the depreciation of the capital stock of the farm (in millions G), and *Inputs* are the inputs used by the farm in production (in millions G). By estimating this model, we can derive a technical efficiency measure by comparing the actual output with the predicted output for each farm.[5] So, both methods base a measure of technical efficiency on the distance of each farm from a production frontier generated using all the farms in the sample.

I regress the land productivity (net farm income divided by farm size, a value that is much more straightforward to arrive at) and the technical efficiency measures on household characteristics, farm characteristics, farm management factors, and regional factors. There are a number of important household characteristics that I will include. The gender, age, and education of the household heads are the first and foremost of these. I expect age and education to increase land productivity and technical efficiency, since knowledge and experience should improve farming ability. The sexes of the household head and of landowners are included. The sex of the household head dummy variables are *female_head* and *male_head*. These two variables account for all the single-headed households. The most numerous group, the dual-headed households are left as the control case. The sex of landowners is represented by *FLR*, a dummy variable that takes the value of one if there is a female landowner in the household. These measures can capture the effects of gender on productivity and efficiency. Since these

---

[4]During the period of the MECOVI survey, one US$ exchanged for an average of 3,685 Guaranies (hereafter simply G).
[5]Stata version 8 provides a procedure called "frontier" to accomplish this.

effects can include both bias against women in input and output markets, and actual differences in allocating resources among farm production options, their impact on productivity and efficiency is difficult to predict, and, once arrived at, to interpret.

The farm characteristics I use include both the operational area and the area owned by the household (Binswanger, Deininger, and Feder 1995), household size, an index of tenure security,[6] an index of the mode of production,[7] and assets. Farm management characteristics include the receipt of credit, technical, and marketing assistance. Regional factors include the zone (see Appendix A) and the district-level soil quality index (see Appendix A).

4. MEASURING TECHNICAL EFFICIENCY

Table 1 contains the summary statistics for the variables used in the stochastic and nonparametric frontier estimates. The average total farm output for 2,885 rural farm households was 13.99 million G (about $3,682). Of this total, most (9.63 million G, or 68.8%) was from crops, with the balance made up of cattle (1.52 million G, or 10.9%) and dairy income (2.17 million G, or 15.5%). Processing accounted for only an average of 670 thousand G (4.8%). The average farm size was 17.46 hectares, while the average farm household owned 9.21 hectares of land. Farms used, on average, 1.79 person years in family labor, while spending about 510 thousand G per year on hired help. Farms' rental of nonlabor resources averaged 490 thousand G annually, while their depreciation averaged 3.31 million G. Finally input costs averaged 3.3 million G per year.

I ran the linear programming model, using crop, cattle, dairy, and processed as outputs and operated land, hired labor, family labor, depreciation, resource rental, and agricultural inputs[8] as inputs, using the linear program in Equation 1, above.[9] I call the resulting measure nonparametric technical efficiency, *eff*1. Its mean is 0.22, which seems somewhat low for an average technical efficiency.

---

[6]I derive the tenure security index by assigning a security value for each type of tenure (1, the highest for owned, titled land, etc.) and taking the average of the tenure security value for each farm, weighted by the share of the total operated area of each farm under the various farms of tenure.

[7]The mode index is constructed by taking the family labor employed in agriculture on the farm and dividing by the sum of family and hired labor employed on the farm. Thus, if *mode*=1, the farm uses family labor only, and if *mode*=0, the farm uses hired labor only.

[8]Fertilizers, pesticides, dietary supplements, and the like, aggregated by amount spent on each item.

[9]The SAS statistical software package includes a linear programming procedure. The SAS program for creating the technical efficiency measure is a slight modification of the program provided by Ali Emrouznejad SASDEA.

I estimated six separate specifications of a stochastic production frontier using total output *y* as the dependent variable, the same set of six inputs as the nonparametric model (see footnote 4). The specifications I use are, in order: linear, quadratic, and log in the dependent variables, for *y* and then *lny*. All six regressions yielded significant results. The built-in technical efficiency diagnostic of this *STATA* module provides a new variable containing the estimated technical efficiency for each observation in the regression estimation. I call the resulting variables, *seff*1 through *seff*6, stochastic technical efficiency. Interestingly, the means of *seff*1-*seff*3 are quite high (0.95) and their standard deviations are very close to zero. This quality makes these variables unattractive choices for dependent variables, since there is little variation to explain. It also appears that they are not very good measures of technical efficiency, unless we believe that all farms are quite efficient and quite similar. I do not. Thus, *seff*4-*seff*6 are likelier candidates. Of the latter three regressions, the last (log-log model) yielded the strongest result (highest χ^2). The resulting variable, *seff*6, also has a higher mean than the rest of the estimates. I report the result of this regression in Table 2, below. Now that I have all of my dependent variables in hand, I move on to explaining the variations among rural farm households.

5. EXPLAINING PRODUCTIVITY AND EFFICIENCY

I now examine each of three measures of productivity or efficiency: land productivity, *LP* (total value of farm output divided by farm size), and the two technical efficiency (stochastic technical efficiency, *seff*, and nonparametric technical efficiency, *eff*) measures, the derivation of which was described in the previous section. For each, I attempt to explain variations by farm size, controlling for other factors. First, notice that the land productivity measure clearly shows a tendency to decrease with farm size. See Figure 1, which graphs the result of a nonparametric regression of the log of land productivity on the log of farm size. The relationship between farm size and the stochastic technical efficiency measure is similar, though not as clear (Figure 3). The relationship between farm size and nonparametric technical efficiency is U-shaped (see Figure 2). The following descriptive statistical analysis by farm size will shed some more light on these relationships before I test them with regression analysis.

First, I present the descriptive statistics for all of the dependent and independent variables I use in the regression analysis (Table 3). For the sample as a whole, the average area owned is 9.9

hectares, while the average area operated is 16.7 hectares. The average farm had a tenure security index of 0.8. The average farm had a forty-four year old female head and a forty-eight year old male head, each of whom had five years of education. Twelve percent of households were headed by a single female and 10% were headed by a single male. Women owned land in only 7.8% of households. The average household had five members. The average farm had productive assets worth 26 million G. Seven percent of farms received technical assistance, 10% received credit assistance, and less than one percent received marketing assistance. The average farm used family labor almost exclusively (the mode of production index for the average farm was 0.96). The average soil quality was 0.4. None of the farms in the sample were in the Chaco region (because I have no soil quality data for that sparsely populated part of the country).

Dividing up the farms in the sample according to size categories (based on operated area, or farm size), we can see that land is quite unequally distributed among rural farms (see Table 4). Of the 2,492 farms, 277 operate less than one hectare, 721 operate between one and five hectares, and another 539 operate between five and ten hectares. Thus, 61.7% of farms operate on less than ten hectares, which is still short of the overall average of 16.7 hectares! The very smallest farms enjoy the highest land productivity (13.7 million G per hectare), labor to land ratios (18.1 person years per hectare, see Table 6), and capital to land ratio (1.7 billion G per hectare). Land productivity drops steadily as we move into larger farm size categories, until farms larger than 50 hectares, after which land productivity rises slightly (though the three largest farms have more than double the land productivity that the farms in the 50 to 100 hectare range do). The smallest farms (those with farms less than 10 hectares in size) operated a total of 831 thousand hectares, which accounts for only 13.1% of the total land operated by farms in the survey, and they owned 13.7% of the total land owned (see Table 5). The labor to land and capital to land ratios fall steadily as the farm size increases, until leveling off for farms above 50 hectares, then increasing slightly for the largest farms (in the case of the labor/land ratio only, see Table 6). Clearly, smaller farms are engaged in more intensive use of their land. This is an intuitive result, since households with limited access to productive resources are under great pressure to use everything they have in order to survive. This intensity no doubt is the source of the land productivity advantage small farms have.

This advantage does not carry over into either of the technical efficiency measures that I use here. In Table 7, we see that there is a slow decrease in the nonparametric measure among the smaller farms (below 50 hectares), after which, technical efficiency increases. The stochastic measure increases through the smaller farm size categories, peaks in the 5 to 10 hectare range, and then falls fairly slowly. The farms in the largest farm size category have the highest average stochastic efficiency measure at .551. Are these patterns due in fact to farm size (or something related to farm size)? The following regression analysis will shed light on this question.

I first present five specifications of a land productivity model, in Table 8.[10] The full specification is of the form:

$$\begin{aligned}LP=&\beta_1 AreaOperated+\beta_2 tenure+\beta_3 FemaleYears+\beta_4 FemaleAge\\&+\beta_5 MaleYears+\beta_6 MaleAge+\beta_7 female\_head+\beta_8 male\_head\\&+\beta_9 FLR+\beta_{10} hhsize+\beta_{11} Assets+\beta_{12} tech\_ass\\&+\beta_{13} cred\_ass+\beta_{14} mkt\_ass+\beta_{15} mode+\beta_{16} soil\_quality\\&+\beta_{17} central+\beta_{18} colonizacion+\beta_{19} frontera,\end{aligned} \qquad (4)$$

in which *LP* is land productivity (in millions of G per hectare), *AreaOperated* is farm size (in hectares), *tenure* is the tenure security index, *FemaleYears* is years of education of the female head of household, *FemaleAge* is age of the female head of household, *MaleYears* is years of education of the male head of household, *MaleAge* is age of the female head of household, *female_head* is a dummy variable for households with single female heads, *male_head* is a dummy variable for households with single male heads, *FLR* is a dummy variable for households with female landownership, *hhsize* is the number of members in the household, *Assets* is the amount of productive assets owned by the household in millions of G, *tech_ass* is a dummy variable for households that have received technical assistance, *cred_ass* is a dummy variable for households that have received credit assistance, *mkt_ass* is a dummy variable for households that have received marketing assistance, *mode* is the mode of production index as described above, *soil_quality* is the soil quality index, and *central*, *colonizacion*, and *frontera* are the regional dummy variables. I begin with a simple regression of land productivity on farm size, the basic model of the literature on the inverse relationship (column 1), and then step by step add in the factors that others were unable to control for (columns 2 through 5). In the basic model, the inverse relationship between farm size and land productivity holds (and conforms to the descriptive analysis above): the coefficient on the log of operated area (*logAreaOP*) is negative

[10] I test for multicollinearity using variance inflation factors.

and significant.[11] In the next model, I include the soil quality index. Much has been made of the possibility that soil quality might explain the relationship between land productivity and farm size. But, though soil quality is, predictably, both positive and significant, the impact of farm size on land productivity is unchanged. In fact, it is slightly higher!

The next model presented includes the tenure security index. This addition does not affect the impacts of farm size or soil quality on land productivity. Tenure security is estimated to significantly increase land productivity. Next I add the mode of production index.[12] Mode is estimated to decrease land productivity, though this is not a significant result. So, the more a farm operates like an independent family farm, the lower land productivity that farm will enjoy. Since the farm's size is still estimated to decrease land productivity, the relatively more intensive use of family labor cannot be the source of small farms' land productivity advantage. In addition, inclusion of the mode index changes the sign of the tenure security index. When I complete the model, adding in the influence of the demographic, gender, economic, regional, and assistance variables, we see that the sign and significance of farm size and soil quality remain unchanged. So these estimated impacts seem to be robust. However, higher tenure security is now estimated to *reduce* land productivity, though not significantly, while higher levels of family labor now significantly reduce land productivity. Female- and male-headed households are estimated to have significantly lower land productivity.[13] Additional years of the female head's education are estimated to have a significant positive impact on land productivity. Female land rights' impact is positive, though not significant. Household size and assets significantly increase land productivity. Both technical and credit assistance significantly increase land productivity, as well. Finally, farms in the central region have significantly lower land productivity.

Since both of the technical efficiency measures are bounded at zero and one, we must use Tobit rather than Ordinary Least Squares to estimate coefficients. Tobit analysis applies maximum likelihood estimation to dependent variables that are censored. The resulting estimated coefficients have properties similar to OLS estimated coefficients, if the sample size is sufficiently large. The sample size in this analysis is large enough to allow interpretation of the

[11]By significant, I mean statistically different from zero at least the 90% confidence level when referring to estimated coefficients from this point forward, unless otherwise specified

[12]Mode is defined as the ratio of family labor to hired plus family labor. Thus, it is the portion of total farm labor represented by family labor, and takes on the value of one for a family farm that hires no labor and zero for a purely capitalist farm.

estimates as though they were OLS estimates. Unfortunately, there are no easy methods to assess the relative merits of different specifications with Tobit analysis. I compare c^2 statistics for lack of a better method. In both cases, the quadratic-log model gave the best results. The results of the Tobit regressions of the technical efficiency measures appear in Tables 9 and 10.

First, turning our attention to the nonparametric technical efficiency measure (Table 9), we see that the area operated significantly reduces efficiency, but the quadratic turn is significantly positive, so, as we observed in Figure 2, efficiency falls with size for smaller farms, but rises for larger farms. Both female and male household heads have significantly lower technical efficiency. More educated male and female heads significantly increase technical efficiency, as do older male heads. Female land rights are estimated to lower efficiency, but not significantly. Smaller household size significantly contributes to technical efficiency, while higher shares of family labor reduce it. Greater household assets, as well as soil quality, have significant positive impacts on technical efficiency.

Turning next to the regression of the stochastic efficiency measure *seff* (Table 10), we notice that technical efficiency decreases slightly, but significantly, with farm size. The quadratic term in this regression is positive, so we expect that efficiency drops off faster with larger than smaller farms. Again this confirms the visual observation in Figure 3. The effect of tenure security is significantly negative in this case. Technical efficiency increases significantly with female heads' years of education and age. Again, both female- and male-headed households are significantly less efficient than dual-headed households. The amount of physical capital, the household size, and soil quality also contribute significantly to increased technical efficiency.

In all three measures, we see significant declines with farm size for smaller farms, while for larger farms nonparametric technical efficiency increases with farm size. Clearly we are talking about two different modes of production. Many of these larger farms are the mechanized, capitalist farms found in the frontier zone. This pattern has policy implications, which I turn to in the conclusion below.

[13]This is in comparison to dual-headed households, the default category.

6. CONCLUSION

Several interesting conclusions come out of this study. First, this essay provides a cautionary tale about methodology. The fact that the stochastic and the nonparametric methods employed to estimate farms' technical efficiency produced quite different results stands as a warning to anyone attempting to use either one separately. Although there was significant correlation between the two, their relationships to farm size (the variable of interest here) were quite different. Each method has its advantages and disadvantages, but using both together may be the best approach to take in any study of this sort.

The impact of tenure security is an interesting phenomenon—it was estimated to decrease land productivity and technical efficiency. However, in the thinner models (with just tenure and farm size, for example), tenure appeared to have a significant positive impact on land productivity. This result suggests that titling, the *wunderkind* of mainstream policy proposals, is not so clearly beneficial and that its supposed benefits may be based on a combination of theory and incomplete empirical analysis. In theory, titling is supposed to improve farm productivity by providing secure collateral for input loans. Better credit terms means more and better inputs and so, better productivity. But my results suggest otherwise. This analysis does not tell us why better tenure security should lead to lower productivity and efficiency. Definitive answers to this question will have to await more detailed research.

Another consistent result of this study is that rising shares of household labor employed in agriculture result in lower productivity and efficiency. This is in opposition to theory on this point—that household labor requires less supervision and is more motivated than hired labor, and so should be more productive and efficient. The share of family labor in total labor is significantly negatively correlated with both the amount of physical capital and the amount of land owned by the household. These possible indirect effects are controlled for in the regression analysis (in the form of the *Assets* variable, which had significantly positive impacts on both productivity and efficiency). Another possible explanation is that there is a process of selection happening, with households' "better" farmers opting to hire themselves out, rather than working on the farm. This makes sense if the wages they can earn are higher than the returns to working on their own farm.

Another important contribution is in terms of gender—its impact on productivity and efficiency amounts to nothing. Female land rights were never significant in their impact on productivity or efficiency. Both types of single-headed households are at a disadvantage, both in terms of productivity and efficiency, with single male-headed households being slightly worse off in terms of efficiency. So there is no evidence in this study that there are significant productivity or efficiency differences between men and women.

Finally, this study's most important contribution to the continuing debate over the relationship between productivity and farm size is an affirmation of the inverse relationship in the case of Paraguay. Of the three measures I have used, the first, land productivity, is significantly greater for smaller farms (especially the very smallest farms). This result confirms earlier work using the 1991 agricultural census (Masterson and Rao 1999). The analysis of the two technical efficiency measures does little to disabuse us of the notion that smaller farms are more efficient or productive. The nonparametric technical efficiency measure decreased significantly with farm size, among small farms. Those farms (with less than 50 hectares operated) amounted to all but 123 of the 2,676 farms in the sample. The stochastic efficiency measure decreased significantly with farm size for the whole sample. At the very least, the policy conclusion to be drawn from these results is that policies favorable to large-scale farms in Paraguay may foment overall growth in the agricultural sector, but they will do less than nothing to combat the problem of rural poverty. They will contribute neither to the well being of small farmers nor to employment opportunities for landless peasants, since the larger farms are so capital intensive.

It is no stretch to say that the argument for redistribution of land is bolstered by this study. Giving land to smaller farms will increase overall production, as well as improve the welfare of the small and landless peasantry. The questions of how to achieve this goal can and will be addressed elsewhere.

FIGURES

Figure 1: Land Productivity and Farm Size

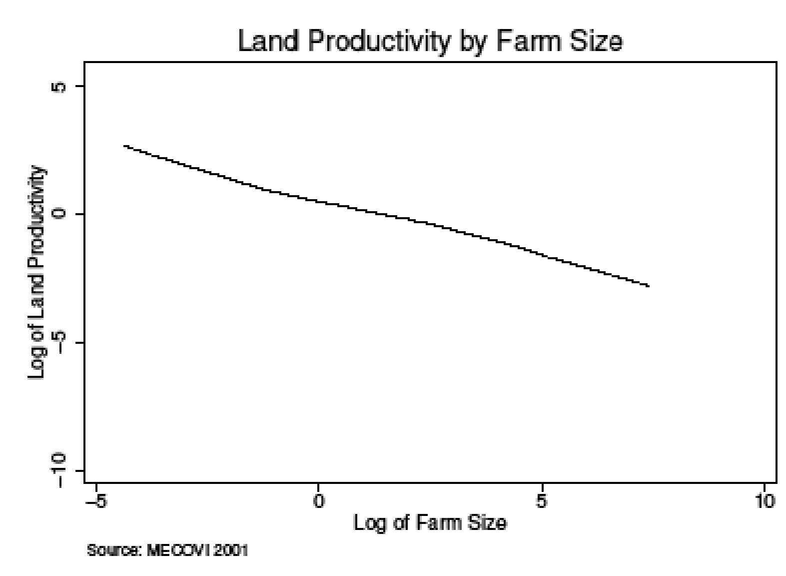


Figure 2: Nonparametric Technical Efficiency and Farm Size

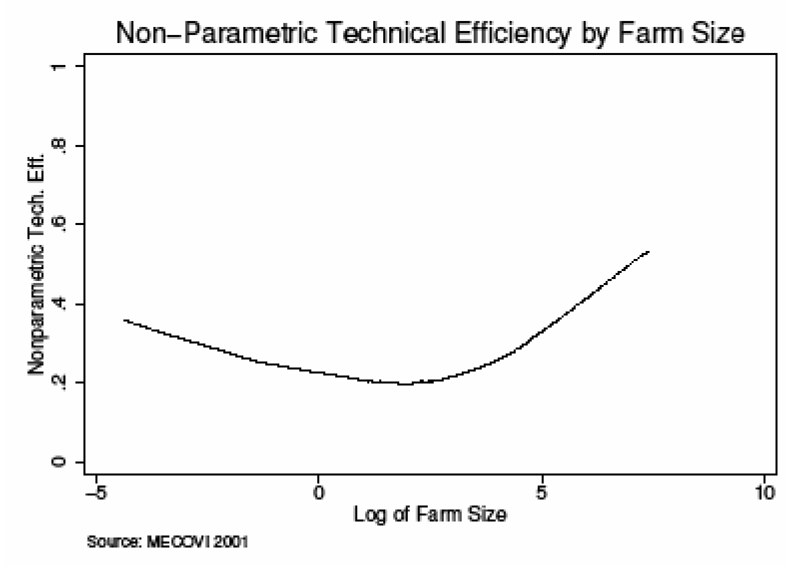
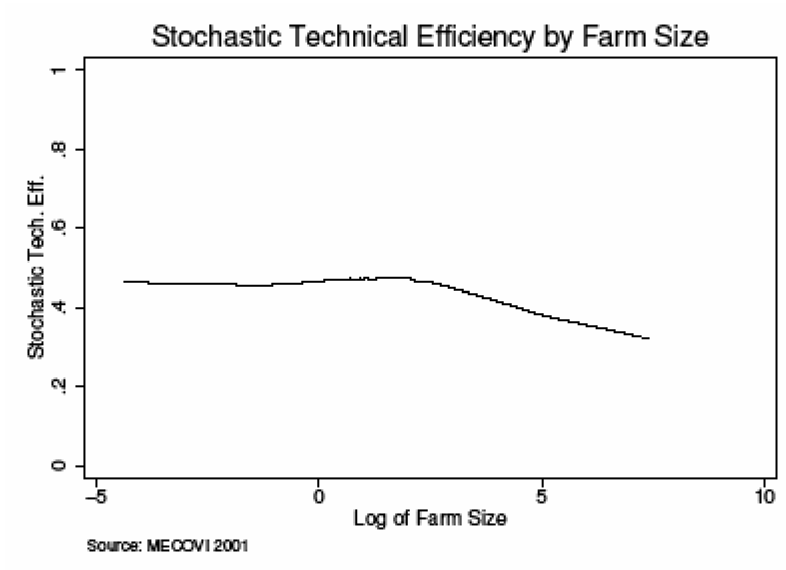


Figure 3: Stochastic Technical Efficiency and Farm Size



TABLES

Table 1: Summary Statistics for Stochastic Frontier Regression Variables

Variable	Mean	Std. Dev.
Total Farm Income (millions G)	13.99	100.61
Crop income (millions G)	9.63	98.69
Cattle income (millions G)	1.52	5.69
Dairy income (millions G)	2.17	9.44
Processed income (millions G)	0.67	3.06
Operated area (Has.)	17.46	183.55
Owned area (Has.)	9.21	45.02
Family labor (Person Years)	1.79	1.31
Hired labor (millions G)	0.51	4.82
Resource rental (millions G)	0.49	6.45
Depreciation (millions G)	3.31	11.18
Input costs (millions G)	3.3	49.37
N	2885	

Source: MECOVI 2001

Table 2: Stochastic Frontier Regression 6

Variable	Coefficient	(Std. Err.)
	Equation 1 : lny	
logAreaOP	0.545**	(0.001)
logFam	0.064**	(0.002)
logHired	0.033**	(0.001)
logRental	0.045**	(0.001)
logDep	0.002**	(0.001)
logInputs	0.123**	(0.001)
Intercept	2.266**	(0.005)
	Equation 2 : lnsig2v	
Intercept	-0.806**	(0.005)
	Equation 3 : lnsig2u	
Intercept	0.568**	(0.005)

N	2885	
Log-likelihood	-632500.136	
$c^{2}_{(6)}$	745574.906**	

Source: MECOVI 2001

Table 3: Summary Statistics for Regression Variables

Variable	Mean	Std. Dev.	N
Land productivity (millions G/Ha.)	3.38	15.48	2492
Nonparametric Tech. Eff.	0.22	0.22	2492
Stochastic Tech. Eff.	0.46	0.17	2492
Area Owned (Has.)	9.89	46.31	2492
Area Operated (Has.)	16.67	80.17	2492
Tenure Security Index	0.8	0.24	2492
Female Years of Education	4.82	2.87	1935
Female Age	43.93	15.3	2267
Male Years of Education	4.93	3.09	1963
Male Age	47.7	14.94	2182
Female-Headed Household (%)	12.31	32.86	2492
Male-Headed Household (%)	10.03	30.05	2492
Female Land Rights (%)	7.77	26.77	2492
Household Size	5.21	2.7	2492
Assets (millions G)	26.02	93.35	2492
Technical Assistance (%)	7.29	26	2492
Credit Assistance (%)	9.56	29.41	2492
Marketing Assistance (%)	0.83	9.1	2492
Mode of Production	0.96	0.15	2492
Soil Quality Index	0.4	0.21	2492
Central Region (%)	30.4	46.01	2492
Colonization Region (%)	24.86	43.23	2492
Minifundia Region (%)	16.01	36.67	2492
Frontier Region (%)	28.74	45.26	2492
Chaco Region (%)	0	0	2492

Source: MECOVI 2001

Table 4: Number of Farms and Average Land Productivity (millions G/Ha.) by Farm Size

Farm Size Category	N	mean
Less than 1 ha.	277	13.7
>=1 to <5 ha.	721	2.04
>=5 to <10 ha.	539	1.31
>=10 to <20 ha.	567	1.01
>=20 to <50 ha.	260	.812
>=50 to <100 ha.	66	.598
>=100 to <200 ha.	28	.642
>=200 to <500 ha.	18	.639
>=500 to <1000 ha.	12	.642
>=1000 ha.	4	1.35
Total	2492	3.38

Source: MECOVI 2001

Table 5: Total Area Operated and Owned (Hectares) by Farm Size

Farm Size Category	Area Operated	Area Owned
Less than 1 ha.	13763.83	5540.02
>=1 to <5 ha.	255901.82	121581.12
>=5 to <10 ha.	561689.25	387811.21
>=10 to <20 ha.	991521.50	770082.13
>=20 to <50 ha.	898675.40	696843.65
>=50 to <100 ha.	529546.40	416583.75
>=100 to <200 ha.	387915.74	227037.24
>=200 to <500 ha.	619211.30	310481.50
>=500 to <1000 ha.	1175271.00	681831.52
>=1000 ha.	921388.00	152800.00
Total	6354884.25	3770592.14

Source: MECOVI 2001

Table 6: Average Labor-Land Ratio (Person Years/Ha.) and Capital-Land Ratio (millions G/Ha.) by Farm Size

Farm Size Category	Labor/Land	Capital/Land
Less than 1 ha.	18.07	1565.64
>=1 to <5 ha.	0.93	6.07
>=5 to <10 ha.	0.36	0.97
>=10 to <20 ha.	0.19	0.64
>=20 to <50 ha.	0.12	0.56
>=50 to <100 ha.	0.05	0.66
>=100 to <200 ha.	0.03	0.58
>=200 to <500 ha.	0.03	0.65
>=500 to <1000 ha.	0.02	0.66
>=1000 ha.	0.07	0.63
Total	3.32	255.94

Source: MECOVI 2001

Table 7: Average Stochastic Technical Efficiency and Nonparametric Technical Efficiency by Farm Size

Farm Size Category	Nonparametric	Stochastic
Less than 1 ha.	0.272	0.447
>=1 to <5 ha.	0.210	0.468
>=5 to <10 ha.	0.182	0.485
>=10 to <20 ha.	0.194	0.470
>=20 to <50 ha.	0.190	0.432
>=50 to <100 ha.	0.272	0.437
>=100 to <200 ha.	0.410	0.420
>=200 to <500 ha.	0.563	0.449
>=500 to <1000 ha.	0.564	0.402
>=1000 ha.	0.799	0.578
Total	0.216	0.464

Source: MECOVI 2001

Table 8: Survey Regression of Land Productivity

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.386**	(0.031)
Intercept	0.582**	(0.066)
N	2492	
R^2	0.298	
$F_{(1,323)}$	156.667**	

Source: MECOVI 2001

Table 9: Survey Regression of Land Productivity

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.392**	(0.030)
soil_quality	0.881**	(0.136)
Intercept	0.236**	(0.069)
N	2492	
R^2	0.318	
$F_{(2,323)}$	87.044**	

Source: MECOVI 2001

Table 10: Survey Regression of Land Productivity

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.403**	(0.030)
tenure	0.427**	(0.140)
soil_quality	0.845**	(0.135)
Intercept	-0.079	(0.129)
N	2492	
R^2	0.323	
$F_{(3,323)}$	64.477**	

Source: MECOVI 2001

Table 11: Survey Regression of Land Productivity

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.406**	(0.029)
tenure	0.424**	(0.140)
mode	-0.222	(0.221)
soil_quality	0.844**	(0.136)
Intercept	0.141	(0.261)
N	2492	
R^2	0.324	
$F_{(4,323)}$	53.471**	

Source: MECOVI 2001

Table 12: Survey Regression of Land Productivity

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.477**	(0.031)
tenure	-0.236	(0.170)
logFemaleYears	0.131†	(0.068)
logFemaleAge	0.198	(0.208)
logMaleYears	0.018	(0.055)
logMaleAge	0.108	(0.285)
female_head	-0.277**	(0.095)
male_head	-0.268*	(0.124)
FLR	0.073	(0.123)
hhsize	0.035**	(0.009)
logAssets	0.130**	(0.034)
tech_ass_recvd	0.181*	(0.089)
cred_ass_recvd	0.248**	(0.076)
mkt_ass_recvd	0.159	(0.208)
mode	-0.330†	(0.189)
soil_quality	0.603**	(0.155)
central	-0.283**	(0.100)
colonizacion	0.086	(0.083)
frontera	-0.041	(0.086)
Intercept	0.712**	(0.257)

N	2492
R^2	0.395
$F_{(19,323)}$	20.858**

Source: MECOVI 2001

Table 13: Tobit Regression of Nonparametric Technical Efficiency Measure

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.026**	(0.003)
logAOPSQR	0.009**	(0.001)
tenure	-0.126**	(0.022)
logFemaleYears	0.022*	(0.009)
logFemaleAge	-0.011	(0.021)
logMaleYears	0.020*	(0.009)
logMaleAge	0.069**	(0.023)
female_head	-0.029†	(0.016)
male_head	-0.059**	(0.015)
FLR	-0.011	(0.018)
hhsize	-0.008**	(0.002)
logAssets	0.009**	(0.002)
tech_ass_recvd	-0.006	(0.019)
cred_ass_recvd	-0.008	(0.016)
mkt_ass_recvd	0.070	(0.049)
mode	-0.055†	(0.030)
soil_quality	0.053*	(0.026)
central	-0.072**	(0.014)
colonizacion	0.024†	(0.014)
frontera	-0.023	(0.015)
Intercept	0.397**	(0.038)
_se	0.213**	(0.003)

N	2492
Log-likelihood	-198.438
$F_{(20,2472)}$	315.847**

Source: MECOVI 2001

Table 14: Tobit Regression of Stochastic Technical Efficiency Measure

Variable	Coefficient	(Std. Err.)
logAreaOP	-0.011**	(0.002)
logAOPSQR	-0.002**	(0.001)
tenure	-0.039*	(0.017)
logFemaleYears	0.012†	(0.007)
logFemaleAge	0.033*	(0.016)
logMaleYears	0.005	(0.007)
logMaleAge	0.024	(0.017)
female_head	-0.039**	(0.012)
male_head	-0.046**	(0.012)
FLR	0.004	(0.014)
hhsize	0.006**	(0.001)
logAssets	0.017**	(0.002)
tech_ass_recvd	0.007	(0.014)
cred_ass_recvd	0.003	(0.012)
mkt_ass_recvd	0.048	(0.037)
mode	0.019	(0.023)
soil_quality	0.075**	(0.020)
central	-0.070**	(0.011)
colonizacion	0.013	(0.011)
frontera	-0.024*	(0.012)
Intercept	0.454**	(0.029)
_se	0.163**	(0.002)

N	2492
Log-likelihood	608.729
$F_{(20,2472)}$	274.8**

Source: MECOVI 2001

APPENDIX

Data

The sources of the data for this dissertation are the following. First, the 1991 Censo Agropecuario, carried out by the Ministerio de Agricultura y Ganadería (MAG) of the government of Paraguay. The second is a listing of soil types and quality for each district of Paraguay, furnished by MAG. The third is a list of prices for agricultural products and capital equipment, obtained directly from MAG and from a 1991 MAG publication entitled *Costos de Producción*. The fourth and final data set is the MECOVI (Living Standards Measurement Survey) carried out by MAG in 2000–2001, and obtained for use in the World Bank project.

1. Regions

The Departamentos of Paraguay can be categorized into regions based on the history of agrarian policy and development, as well as geography and climate. The Central region, centered on Asunción, is the oldest region settled by Europeans in the country and is the most thickly settled area today. The departamentos that belong to this region are: Central, Cordillera, and Guairá. The farms in this region are, for the most part, quite small. Excess labor is absorbed into the urban informal and industrial sectors. The next region is characterized by the minifundia/latifundia pattern of agrarian structure, with many small farms and relatively few very large farms, and by long term European occupation. The Minifundia region includes the departamentos of Paraguarí, Caazapá, Concepción, Misiones, and Ñeembucú. The next region is similar in structure to the Minifundia zone. The difference is that this region was settled under the colonization policy of the 1960s. The Colonización region includes San Pedro and Caaguazú. The Minifundia and Colonización zones are characterized by intense land conflicts. The agricultural frontier region is characterized by both immigration from Brazil, Argentina, Germany, and Japan, as well as by highly mechanized capitalist agriculture. It is also the scene of the greatest peasant differentiation, the highest land rents, least nonfarm employment opportunities, and, as a result of these pressures, the most intense struggles over land. The Frontera zone includes Alto Paraná, Amambay, Canindeyú, and Itapúa. The final region is the arid western half of the country, the Chaco. The Chaco includes Alto Paraguay, Boquerón, Chaco, Nueva Asunción, and Presidente Hayes (Carter and Galeano 1995).

2. Soil Quality

The soil quality index I will use in these papers is one I obtained from MAG in 1998. It includes, for most of the districts of the country, a comprehensive list of soil types found in the district, the percent of that district in which the soil type is found, and an index of that soil type's quality. I generate my soil quality index by taking a weighted average of the soil quality index for each district:

$$Q_D = \sum P_D T Q_T \qquad (5)$$

where Q_D is the soil quality index for the district, $P_D T$ is the percentage of a district's land area of a particular soil type, and Q_T is the quality of that soil type. The resulting index is a number between zero and one, with higher values indicating a greater average soil quality for that district.

REFERENCES

Aigner, D. J. and S.-F. Chu. 1968. "On Estimating The Industry Production Function." *American Economic Review* 58(4): 826–839.

Ball, R. and L. Pounder. 1996. "'Efficient But Poor' Revisited." *Development and Cultural Change* 44(4): 753–60.

Banker, R. D., A. Charnes, and W. W. Cooper. 1984. "Some Models For Estimating Technical And Scale Efficiencies In Data Envelopment Analysis." *Management Science* 30(9): 1078–1092.

Barrett, C. B. 1996. "On Price Risk And The Inverse Farm Size-Productivity Relationship." *Journal of Development Economics* 51(2): 193–215.

Benjamin, D. 1995. "Can Unobserved Land Quality Explain The Inverse Productivity Relationship?" *Journal of Development Economics* 46(1): 51–84.

Bhalla, S. S. and P. Roy. 1988. "Mis-Specification In Farm Productivity Analysis: The Role Of Land Quality." *Oxford Economic Papers* 40(1): 51–73.

Binswanger, H. P., K. Deininger, and G. Feder. 1995. "Power, Distortions, Revolt And Reform In Agricultural Land Relations." in J. Behrman & T. Srinivasan (eds.) *Handbook of Development Economics*, Vol. III. Amsterdam: Elsevier Sciences B.V.

Boyce, J. K. 1987. *Agrarian Impasse in Bengal: Institutional Constraints to Technological Change.* Oxford: Oxford University Press.

Byiringiro, F. and T. Reardon. 1996. "Farm productivity in Rwanda: Effects of farm size, erosion, and soil conservation investments." *Agricultural Economics* 15(2): 127–136.

Carter, M. R. 1984. "Identification of the inverse relationship between farm size and productivity: A analysis of peasant agricultural production." *Oxford Economic Papers* 36(1): 131–145.

Carter, M. R. and L. A. Galeano. 1995. *Campesinos, Tierra Y Mercado.* Madison, WI: Land Tenure Center .

Carter, M. R. and K. D. Wiebe. 1990. "Access To Capital And Its Impact On Agrarian Structure And Productivity In Kenya." *American Journal of Agricultural Economics* 72(5): 1146–1150.

Chavas, J.-P. and M. Aliber. 1993. "An Analysis Of Economic Efficiency In Agriculture: A Nonparametric Approach." *Journal of Agricultural and Resource Economics* 18(1): 1–16.

Cooper, W. W., L. M. Seiford, and K. Tone. (2000), *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software.* Boston: Kluwer Academic Publishers .

Cornia, G. A. 1985. “Farm Size, Land Yields And The Agricultural Production Function: An Analysis For Fifteen Devloping Countries.” *World Development* 13(4): 513–34.

Deolalikar, A. B. 1981. “The Inverse Relationship Between Productivity And Farm Size: A Test Using Regional Data From India.” *American Journal of Agricultural Economics* 63(2): 275–9.

Dyer, G. 1991. “Farm Size–Farm Productivity Re-Examined: Evidence From Rural Egypt.” *Journal of Peasant Studies* 19(1): 59–92.

———. 1996. “Output Per Acre And Size Of Holding: The Logic Of Peasant Agriculture Under Semi-Feudalism.” *Journal of Peasant Studies* 24(1/2): 103–31.

Emrouznejad, A. 2004. “An Extension To Sas/Or For Decision System Support.” Statistics and Data Analysis, Paper 274-25.

Feder, G. 1985. “Relation Between Farm Size And Farm Productivity: The Role Of Family Labour, Supervision And Credit Constraints.” *Journal of Development Economics* 18: 297–313.

Fletschner, D. K. and L. Zepeda. 1998. “Efficiency Of Small Landholders In Eastern Paraguay: A Non-Parametric Measurement.” Unpublished Manuscript.

Frisvold, G. B. 1994. “Does Supervision Matter? Some Hypothesis Tests Using Indian Farm-Level Data.” *Journal of Development Economics* 43(2): 217–38.

Ghose, A. K. 1979. “Farm size and land productivity in indian agriculture: A reappraisal.” *Journal of Development Studies* 16(1): 27–49.

Masterson, T. & Rao, J. M. 1999. *Agricultural Productivity In Paraguay: Analysis And Proposals For Economic Growth Policies*. Technical report, Ministério de Hacienda de la República del Paraguay and the United Nations Development Programme.

Mazumdar, D. 1965. “Size Of Farm And Productivity: A Problem Of Indian Peasant Agriculture.” *Economica* 32(126): 161–173.

Newell, A., K. Pandya, and J. Symons. 1997. “Farm Size And The Intensity Of Land Use In Gujarat.” *Oxford Economic Papers* 49(2): 307–15.

Schultz, T. W. 1964. *Transforming Traditional Agriculture.* New Haven, CT: Yale University Press.

Sen, A. 1975. *Employment, Technology And Development.* Oxford: Clarendon Press.

Sen, A. K. 1962. “An Aspect Of Indian Agriculture.” *Economic Weekly* 14(4–6): 243–6 .

Verma, B. and D. W. Bromley. 1987. ‘The Political Economy Of Farm Size In India: The Elusive Quest.” *Economic Development and Cultural Change* 35(4): 791–808.