The Size Distribution of Farms and International Productivity Differences

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Abstract

Using internationally comparable data from the World Agricultural Census, we document a factor of 36 difference in average farm size between rich and poor countries. Small farms of less than 2 hectares represent more than 70% of farms in poor countries but only 15% in rich countries, whereas large farms of more than 20 hectares represent none of the farms in poor countries and almost 40% in rich countries. Two questions emerge. First, what explains the striking differences in farm size across countries? Second, are farm-size differences important in understanding agricultural and aggregate productivity gaps across countries? We develop a two sector model with agriculture and non-agriculture that features a non-degenerate size distribution of farms. The theory embeds a Lucas (1978) span-of-control model of farm size into a standard sectoral model with non-homothetic preferences. In the model calibrated to the United States, a reduction in economy-wide productivity from 1 to 1/4 produces an increase in the share of employment in agriculture from 2.5% to 53%, a 21-fold reduction in average farm size, and a 25-fold reduction in agricultural labor productivity. These results are broadly consistent with data on the sectoral allocation of labor and the size distribution of farms across countries.

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1 Introduction

Recent research shows that agriculture plays a key role in understanding the large disparities in aggregate living standards across countries.[1] Poor countries are unproductive in all activities when compared to rich countries, but they are particularly unproductive in farming. Further, a large share of the population in poor countries is engaged in agricultural activities whereas in rich countries this share is very small.[2] The key question that emerges from these observations is: why are poor countries so unproductive in farming?

In this paper, we address this question by examining the size distribution of farms across countries. Our motivation for focusing on farm size is that, as we document, the average farm size in rich countries is 36 times higher than in poor countries, and the skewness of the size distribution of farms is systematically related to the level of development.[3] We ask two related questions, which we assess quantitatively. First, what can explain the dramatic differences in the size distribution of farms across rich and poor countries? Second, do differences in agricultural productivity stem from the allocation of resources across heterogeneous farms that differ in size? To assess these questions quantitatively we develop a two sector model with agriculture and non-agriculture that features a non-degenerate distribution of farm sizes. The theory embeds a Lucas (1978) span-of-control model of farm size into a standard sectoral model with non-homothetic preferences.

We use internationally comparable data from the *Report on the 1990 World Census of Agriculture*, published by the Food and Agricultural Organization (FAO) of the United Nations. This report processes national agricultural censuses to provide in a common format summary data describing the main characteristics of agricultural structures in a wide range of developed and developing countries. We use the information from this report to construct a data set of 63 countries for which we were able to obtain information on the distribution of agricultural holdings by size in Hectares (Ha). For several of the countries we also have data on the distribution of land across the different farm sizes. Our findings are stark. First, in the poorest countries the average farm size is 1.6 Ha, while in the richest the average farm size is 56.7 Ha (a 36-fold difference). Second, this disparity in scale of operation is not due to the fact that poor and rich countries produce different goods. Differences in average farm size are large even af-

[1] See for instance, Gollin, Parente, and Rogerson (2002, 2007), Restuccia, Yang, and Zhu (2005), Caselli (2005), and the references therein.

[2] See for example, Restuccia, Yang and Zhu (2008) for a systematic documentation of these observations.

[3] Incidentally, examination of historical US Agricultural Census data indicates that average farm size in the US has increased almost 3-fold from 1900 to 2007.

ter controlling for type of agriculture (livestock vs. crops); type of crop (e.g., wheat, maize, rice); and type of livestock (e.g. cattle, sheep, chicken). Third, the whole size distribution of farms is heavily skewed to the left in poor countries and to the right in rich countries. More specifically, in poor countries very small farms (less than 2 Ha) account for over 70% of total farms, while in rich countries only 15%. In poor countries there are no farms over 20 Ha, while in rich countries they account for 40% of the total number of farms. The substantial cross-country differences in the size distribution of farms date back to at least the early 1960s, as documented in Grigg (1966).

Data on farm labor productivity by size are not available for the cross-section of countries as the FAO does not report farm output or labor by farm size. However, using data from the 2007 US Census of Agriculture we find that there are large differences in labor productivity between large and small farms. More specifically, value added per worker rises monotonically with farm size, differing between the maximum and the minimum scale of operation by a factor of 26.[4] This suggests that producing at different scales can have non-trivial implications for average agricultural productivity differences across countries.[5]

Why do farmers in poor countries produce on such a small scale relative to rich countries, given that larger farms are more productive? In our model farming takes place with decreasing returns to land and farmers receive idiosyncratic productivity draws from a known distribution. Farmers managerial productivity differences are key in determining the observed differences in average farm size. Production in both the agricultural and non-agricultural sectors is affected by economy-wide productivity, which is meant as a catch-all for general type institutions, policies, and distortions or frictions that transpire the economy as a whole. While one can think of a number of specific factors affecting the size distribution of farms, such as high transport costs, capital market imperfections, risk of expropriation, among others, we do not take a particular stance on the importance of a single factor.[6] We view the above factors as economy-wide

[4]There is a large literature in agricultural economics that emphasizes the negative relationship between productivity and farm size but measures productivity as output per unit of farm land (e.g., yield per hectare). More recent evidence shows that farm productivity rises with size as we find here, when productivity is measured as labor productivity or TFP (see for example, Cornia, 1985; Kumbhakar, Ghosh, and McGuckin, 1991).

[5]To see the importance of differences in farm sizes for cross-country agricultural productivity differences, in the Appendix we do an accounting exercise: we use the productivity differences observed across farm sizes in the US, and ask how much would agricultural productivity rise in poor countries if they had the farm distribution of rich countries rather than their own. This accounting exercise yields substantial differences in agricultural productivity (by factors of 4 to 7). Of course, the exercise is silent about the source of shift in the distribution of farm sizes in poor countries as well as the impact on productivity levels by size.

[6]See for example, Adamopoulos (2009) for the role played by transportation frictions in misallocating resources across sectors.

problems that are not specific to agriculture. Hence, our interpretation is that the size distribution of farms is symptomatic of a general set of frictions facing poor countries.

In our quantitative analysis, we calibrate a benchmark economy to the United States. Two key features in our model are the parameter governing the extent of decreasing returns to scale at the farm level, and the distribution of managerial talent for farm operators. Based on evidence for the US agricultural sector we set the returns to scale parameter equal to 0.6 in our benchmark calibration (but also conduct sensitivity analysis). We calibrate the distribution of farmer productivity to match the observed distribution of farm sizes in the US economy. In our experiments the distribution of farmer productivity is common across countries. In the baseline experiment we assume that countries differ in economy-wide productivity, which we pin down with data on labor productivity in non-agriculture. We show that taking as given economy-wide productivity we can generate sizable differences in average farm size and agricultural productivity across countries. In particular, in our benchmark calibration, reducing economy wide productivity from 1 to 1/4 raises the share of labor in agriculture from 2.5% to 53%; reduces average farm size by a factor of 21; skews the distribution towards smaller farms; reduces agricultural labor productivity by a factor of 25; and reduces aggregate productivity by a factor of almost 8.

Our paper is related to a growing macroeconomic literature that studies quantitatively the role of agriculture in understanding international income differences, such as Gollin, Parente and Rogerson (2002, 2007), Restuccia, Yang and Zhu (2008), and Caselli (2005).[7] A different literature emphasizes the misallocation of aggregate resources across heterogeneous production units in generating aggregate and industry productivitity differences: Restuccia and Rogerson (2008), Guner, Ventura, and Xu (2008), Hsieh and Klenow (2009), Gollin (2008), among many others. We differ from this literature in emphasizing the size distribution of production units (farms) for the agricultural sector. Closest to our inquire is a recent paper by Lagakos and Waugh (2009). They consider a Roy model of occupational choice between agriculture and non-agriculture to emphasize the importance of selection in determining low productivity in agriculture relative to non-agriculture in poor countries. Our paper offers a different but complementary channel by emphasizing the factors that lead to differences in the size distribution of farms across countries.

[7] A close relative to this literature is the one that studies the sources and effects of the process of structural transformation that accompanies the process of development: Echevarria (1997), Kongsamut, Rebelo, and Xie (2001), Caselli and Coleman (2001), Ngai and Pissarides (2007), Acemoglu and Guerrieri (2008), Buera and Kaboski (2009). Buera and Kaboski (2008) emphasize the movement to large scale production units in manufacturing and services, and their role in the structural transformation.

The paper proceeds as follows. In the next section we document some facts pertaining to the distribution of farm sizes across countries. In section 3 we describe the model. Section 4 describes the calibration of the benchmark economy to U.S. data and reports quantitative experiments that lower the level of economy-wide productivity. In section 5 we discuss some extensions of the baseline model. Section 6 concludes. The appendix contains details of productivity differences across farm sizes in the United States and an accounting exercise across countries taking productivity by farm size and changes in the distribution of farms as given.

2 Some Facts on Farm Size

Our main source of farm size data is the *Report on the 1990 World Census of Agriculture*. We construct a sample consisting of 63 countries for which we were able to obtain data from both the World Census of Agriculture and the PWT6.2 for 1990. We use data on the number of agricultural holdings classified by size (in hectares - Ha) from the World Census to calculate the size distribution of farms for each country in our sample.[8] For most of the countries in our sample the World Census also provides data on the land area in farms classified by size (Ha), which we use to calculate the land distribution of farms for each country. From the data in the World Census we are also able to calculate total average farm size for each country, and average farm size by type of crop and livestock for several countries.

In Figure 1, where we plot average farm size against income (in logarithms), we observe a systematic relationship between farm size and the level of development: richer countries produce agricultural goods at a larger scale than poorer countries.

We organize the rest our observations by income group. In particular, we order countries in ascending order according to 1990 real GDP per capita from PWT 6.2, and we allocate them into the 5 quintiles of the income distribution.[9] In Table 1 we

[8] We use the term "farm" throughout this paper to refer to an agricultural holding. According to the definition of the World Census of Agriculture, an "agricultural holding" is an economic unit of agricultural production under single management regardless of title, legal form, or size, and may consist of one or more parcels, located in one or more separate areas. One can thus see the analogy between "agricultural holding vs. parcel" and "firm vs. plant" in the manufacturing data. For countries that report their size classification using a metric other than Ha (e.g. acres) the World Census converts them to Ha. The World Census' size classification in Ha can be found in the Appendix.

[9] The countries in each quintile are as follows. Quintile 1 (Q1): Ethiopia, Guinea Bissau, Malawi, Uganda, Burkina Faso, Dem. Rep. of Congo, Nepal, Zambia, Lesotho, Viet Nam, India, Pakistan. Quintile 2 (Q2): Guinea, Honduras, Samoa, Indonesia, Philippines, Egypt, Peru, Djibouti, Albania, Grenada, Iran, Namibia, Turkey. Quintile 3 (Q3): Thailand, Paraguay, Fiji, Colombia, St. Vincent, Panama, Dominica, Saint Lucia, Brazil, Argentina, St. Kitts & Nevis, Rep. of Korea, Greece. Quintile 4 (Q4): Ireland, Portugal, Barbados, Cyprus, Puerto Rico, Slovenia, Spain, Israel, Italy, United Kingdom, Finland, Australia, Bahamas. Quintile 5 (Q5): Belgium, Netherlands, Germany, France, Japan,

report average income, total average farm size, and average farm size by type of crop (wheat, maize, rice), and type of livestock (cattle, chicken, sheep, pigs).[10] The size distribution of farms and the land distribution of farms by income group is available in the Appendix, in Tables 7 and 8 respectively.

TABLE 1
Average Farm Size across Countries

	GDP per capita	Average Farm Size (Ha)				Livestock Per Farm			
		Total	Wheat	Rice	Maize	Cattle	Chicken	Sheep	Pigs
Q1	1,115	1.6	3.0	1.1	0.9	11.4	16.1	8.0	3.4
Q2	3,544	5.4	1.6	1.2	0.8	7.8	21.6	16.7	5.4
Q3	6,918	51.7	43.8	2.3	4.9	34.2	117.5	39.1	12.6
Q4	16,834	296.1	70.2	37.9	11.5	88.6	18275.3	449.9	184.3
Q5	23,562	54.1	27.9	41.3	33.0	52.6	4207.7	49.3	203.2

Note: GDP per capita is from PWT6.2, while all the other variables are from the World Census of Agriculture 1990. With the exception of Total Average Farm Size, we do not have observations for all countries in the other categories. Averages within each quintile for these categories are over the countries with available data.

In reporting our key observations below we emphasize the comparison of the richest (Q5) and the poorest (Q1) groups of countries. The average income in the richest group of countries is 21 times higher than that in the poorest group.

Observation 1: The average farm size in the poorest group of countries is 1.6 Ha, while in the rich group it is 54.1 Ha (34 times larger). See second column of Table 1.

Observation 2: The large disparity in farm size is not due to differences in the type of agriculture undertaken between rich and poor countries. In Table 1, we show that even if we focus on specific crops (maize, wheat, rice) or specific livestock categories (cattle, chicken, sheep, pigs), even though of varying degrees, there are very large differences in the size of farms between rich and poor countries.

Observation 3: The percentage of very small farms in total farms drops with income. In poor countries (Q1) over 70% of farms are less than 2 Ha. In rich countries (Q5) small farms account for about 15% of total farms. See Figure 2.

Canada, Denmark, Austria, Norway, U.S.A, Switzerland, Luxembourg.

[10]We note that in many of the subcategories observations are not available for several countries. When a particular country within a group does not have data for a particular crop or livestock, the average is over the rest of the countries in the group.

Observation 4: The percentage of very large farms in total farms rises with income. Poor countries (Q5) typically have no farm over 20 Ha. In rich countries (Q5) nearly 40% of farms are over 20 Ha. See Figure 3.

Observation 5: Figure 4 presents the histograms (percentage of farms in each size range) for the poorest (Q1) and richest (Q5) countries. Not only is the average farm size different between rich and poor countries but also their distributions. The histogram for rich countries is upward sloping while for poor countries downward sloping. Figure 5 shows the histograms for all income groups. Figures 6 and 7 show the histograms for three selected rich countries (Canada, US, UK) and three selected poor countries (Ethiopia, Malawi, Congo) respectively. These figures indicate that the average group patterns are present for individual countries as well.

Observation 6: In Figure 8 we plot the distribution of land across farm sizes for the richest and poorest countries. In the richest countries over 80% of land is concentrated in farms of 10 Ha or over, while in poor countries over 80% of land is concentrated in farms under 10 Ha.

These detailed observations about the distribution of farm sizes across countries motivate our inquire of their importance in accounting for the large productivity gaps observed in agriculture between rich and poor countries.

How does productivity differ across farms of different sizes? Given that there is no systematic data for the cross-section of countries (the World Census does not report output or other inputs by size) we turn to the US Census of Agriculture (2007), which has good and detailed data. In Appendix B, we calculate two measures of productivity for each classification of farm size: labor productivity, and total factor productivity. We find that larger farms are systematically more productive than smaller farms: for example the disparity in labor productivity between the max and min scale of operation in the US is 26-fold.

To see the potential importance of producing at different scales in understanding agricultural labor productivity differences across countries, we conduct a counterfactual experiment: we ask by how much would average agricultural productivity rise in the poorest countries if they had the distribution of farm sizes observed in the richest countries rather than their own? In this accounting exercise productivity differences across farm sizes are assumed to be those in the US Census. We find that poor countries could have as much as 7.7 times higher productivity, by re-allocating resources across farms in this manner. The details of this counterfactual are provided in Appendix C (see Table 9).

3 The Model

We develop a simple theory of the sectoral allocation of labor between agriculture and non-agriculture that features a non-degenerate size distribution of farms in the agricultural sector. We accomplish this by embedding a Lucas (1978) span-of-control model of farm size into a standard two sector model with non-homothetic preferences.

3.1 Environment

In each period there are two goods produced: agriculture (a) and non-agriculture (n). The economy is endowed with a fixed amount of total arable land L and is populated by a stand-in household with a constant unit-mass continuum of members. Each member of the household is endowed with one unit of time which is inelastically supplied to the labor market.

Production Technologies The non-agricultural good is produced with a constant returns to scale technology that requires only labor,

$$Y_n = A \cdot N_n, \tag{1}$$

where Y_n is the total amount of non-agricultural output produced and N_n is the total amount of labor employed in non-agriculture. A is a sector-neutral productivity parameter. We refer to this term as total factor productivity (TFP) but in our quantitative exercise the term englobes all factors that affect labor productivity, including capital accumulation. The production unit in the agricultural sector is the farm. A farm is a technology that requires the input of a worker with managerial skills s and a land input. The farm technology is characterized by decreasing returns to scale. In particular, a farmer of type s produces agricultural output according to,

$$y_a = As^{1-\gamma}\ell^{\gamma}, \tag{2}$$

where y_a is output of the farm and ℓ is the amount of land input. Thus, a farm consists of a farmer and the amount of land under the farmer's control. There are two sources of productivity affecting the farming technology: the farmer's idiosyncratic productivity s and the sector-neutral productivity A which is common across all farms. The parameter $0 < \gamma < 1$ governs returns to scale at the farm level, often referred to as "span-of-control" parameter.

Stand-in Household The household has preferences over the two goods according to

$$\phi \cdot \log(c_a - \bar{a}) + (1-\phi) \cdot \log(c_n), \tag{3}$$

where $\bar{a} > 0$ is a subsistence constraint for agricultural consumption, and ϕ is a preference weight for the agricultural good. Consumption in each sector is denoted by c_i for $i \in \{a, n\}$. These preferences account for Engel's Law, as they imply that the income elasticity with respect to food is less than unity. Each household member is endowed with one unit of productive time that is supplied inelastically to the market. Whereas each household member is equally productive in the non-agricultural sector, their productivity differs in operating a farm. The productivity level of each household member working in a farm is drawn from a known distribution of managerial ability with with cdf $F(s)$ and pdf $f(s)$, and has support in $S = [\underline{s}, \overline{s}]$.

Market Structure We assume that the stand-in household, firms in the non agricultural sector, and farms in the agricultural sector are competitive in factor and output markets. The representative firm in non-agriculture takes the wage rate w as given and chooses the demand for labor to maximize profits, this implies $w = A$. A farm manager with farming ability s maximizes profits taking the rental price of land q and the relative price of the agricultural good p_a as given,

$$\max_{\ell} \left\{ p_a A s^{1-\gamma} \ell^{\gamma} - q\ell \right\}.$$

The first order condition to this problem implies that the demand for land that a farmer with own productivity s, faced with sector-neutral productivity A and prices (q, p_a), has is,

$$\ell(A, s, q, p_a) = s \left(\frac{\gamma A p_a}{q} \right)^{\frac{1}{1-\gamma}} \tag{4}$$

This is the optimal farm size for a farmer of type s. This farmer will produce farm output,

$$y_a(A, s, q, p_a) = s A^{\frac{1}{1-\gamma}} \left(\frac{\gamma p_a}{q} \right)^{\frac{\gamma}{1-\gamma}} \tag{5}$$

which is also labor productivity for the farm since there is one farmer per farm. This farm operator will make profits,

$$\pi(A, s, q, p_a) = (1-\gamma)\, s\, (p_a A)^{\frac{1}{1-\gamma}} \left(\frac{\gamma}{q} \right)^{\frac{\gamma}{1-\gamma}} \tag{6}$$

These equations imply that, other things equal, more able (higher s) farmers will operate larger farms, produce more output, have higher profits, and have higher labor productivity. The household maximizes utility subject to the budget constraint. Letting the non-agricultural good be the numeraire, and denoting the relative price of agricultural goods by p_a, the budget constraint faced by the stand in household is,

$$p_a \cdot c_a + c_n = (1 - N_a)w + N_a \int_S \pi dF(s) + qL.$$

The first order condition with respect to the share of household members working in agriculture implies that,

$$w = \int_S \pi(A, s, q, p_a) dF(s). \tag{7}$$

The household's consumption of the two goods follows standard rules,

$$c_n = (1 - \phi) \cdot (w - \overline{a} p_a),$$

$$c_a = \overline{a} + \frac{\phi}{p_a} \cdot (w - \overline{a} p_a). \tag{8}$$

According to these conditions, households will consume $\overline{a}$ of food and will allocate the rest of their income proportionally between the two goods.

Market Clearing The market clearing condition for land is,

$$L = N_a \int_S \ell(A, s, q, p_a) dF(s). \tag{9}$$

The market clearing condition for labor is,

$$N_a + N_n = 1$$

The market clearing conditions for the agricultural and nonagricultural goods respectively are,

$$c_a = N_a \int_S y_a(A, s, q, p_a) dF(s), \tag{10}$$

$$c_n = Y_n.$$

Definition of Equilibrium A *competitive equilibrium* is a set of allocations and prices such that: (*i*) given prices, households optimize, (*ii*) given prices firms and farmers optimize, and (*iii*) markets clear.

Combining the first order condition of the non-agricultural firm, with the farmer profit function (6), into the household no-arbitrage condition (7) we obtain,

$$1 = (1-\gamma)\, p_a^{\frac{1}{1-\gamma}} \left(\frac{\gamma A}{q}\right)^{\frac{\gamma}{1-\gamma}} \int_S s dF(s). \tag{11}$$

From the farmer's land demand function (4), and the market clearing condition for land (9) we have,

$$\left(\frac{L}{N_a \int_S s dF(s)}\right)^{1-\gamma} \frac{1}{A} = \frac{\gamma p_a}{q}. \tag{12}$$

Combining the household's food consumption condition (8), with the farmer's output function (5) into the food market clearing condition (10) we obtain,

$$\frac{\phi}{p_a} A + (1-\phi)\, \overline{a} = N_a A^{\frac{1}{1-\gamma}} \left(\frac{\gamma p_a}{q}\right)^{\frac{\gamma}{1-\gamma}} \int_S s dF(s). \tag{13}$$

Equations (11)-(13) constitute a system of three equations in three unknowns (N_a, q, p_a). After some manipulations of these equations we can see that N_a is the solution to,

$$\phi\,(1-\gamma) = N_a - \frac{(1-\phi)\,\overline{a}}{\widehat{A}} N_a^{\gamma},$$

where $\widehat{A} \equiv A \left(\int_S s dF(s)\right)^{1-\gamma} L^{\gamma}$. Once we obtain N_a we can calculate any other variable in equilibrium.

4 Quantitative Analysis

We calibrate the parameters of our benchmark economy, including the distribution of farming idiosyncratic productivities to 1990 U.S. data. Then we consider experiments in which economies differ relative to the benchmark economy in economy-wide productivity A and land per capita L.

4.1 Calibration

Our methodology involves calibrating differences in idiosyncratic productivities across farms to observed differences in farm sizes for the US. In our model there is a simple mapping from relative farm size to relative productivity,

$$\frac{\ell_i}{\ell_j} = \left(\frac{s_i}{s_j}\right)$$

We approximate the US distribution of farms across different farm sizes as reported by the 1990 World Census of Agriculture in hectares (and thus the distribution of abilities), by a log-normal distribution with mean μ and standard deviation σ. We note here that the distribution of farm sizes in the U.S. Census of Agriculture is reported in acres rather than hectares. When converting categories in acres to categories in hectares, the World Census reports all residual mass after 500 Ha in the $500-1000$ Ha category and no mass in the 1000+ for the US. The reason is that the US Census does not report mass in these two categories separately. For the purpose of consistency we focus on distributions that are truncated at 500+. The implied parameters of the log-normal distribution of idiosyncratic productivities that best fit the US cdf of farm sizes is one with $\mu = 0.21$ and $\sigma = 1.61$.[11]

We normalize the economy-wide productivity parameter A to 1. We choose the subsistence term $\bar{a}$ to match a 1990 share of labor in agriculture of 2.5%. In the model, ϕ determines the long-run share of agricultural employment. We set $\phi = 0.01$ to target a long run share of labor in agriculture of 1%. We choose land L in our model to match an average farm size of 187 Ha for the US economy.

In our model, γ the span of control parameter determines the extent of decreasing returns to scale at the farm level. This parameter is critical because it regulates how responsive the share of labor in agriculture and farm size are to changes in economy-wide productivity A. We set this parameter equal to 0.6 based on a conservative estimate from a priori information. In particular for agriculture, Hoch (1976) reports a value for this elasticity of 0.8 with farm effects, but finds that it varies across samples between 0.6-0.9. These values conform with earlier findings by Mundlak (1961).

This parameterization reproduces well the size distribution of farms (by construction) and the corresponding distribution of land (by result) for the U.S. economy. The implied cdfs of both of these distributions, along with the corresponding cdfs from the data, are provided in Figures 9 and 10.

4.2 Experiments

We conduct the following thought experiment. We consider an economy that is otherwise identical to the benchmark, including the distribution of farming productivities, except in economy-wide productivity. In particular, we assume that the economy-wide productivity parameter A is 1/4 the productivity of the benchmark economy. Note that in the context of our model differences in A map one-to-one with differences in

[11] We also tried a non parametric estimate of the cdf of farm idiosyncratic productivity as in Restuccia and Rogerson (2008) that fits the mass points in the data exactly. The results with this different approach are nearly identical.

Table 2
Effects of A Differences

	$A = 1$	$A = 1/4$
N_a (%)	2.5	52.7
Rel. AFS (Ha)	1	1/21.1
Distribution:		
Farms < 5 Ha (%)	9.8	68.8
Farms > 20 Ha (%)	73.2	9.1
Share of Land (%)		
Farms < 5 Ha (%)	0.2	12.6
Farms > 20 Ha (%)	98.8	62.5
Rel. Y_a/N_a	1	1/24.9
Rel.Y	1	1/7.7

non-agricultural labor productivity. Such a difference in economy-wide productivity is reasonable to consider, since for example Restuccia, Yang and Zhu (2008) find that the ratio of 5% rich and 5% poor economies differ by a factor of 5 in non-agricultural real GDP per worker.

We find that a reduction in A has substantial quantitative effects for the distribution of labor across sectors, average farm size, distributions of land and farms, agricultural productivity, and aggregate productivity. In particular, a 75% decrease in A increases the share of labor in agriculture to 53% (from 2.5% in the benchmark economy), reduces the average farm size by a factor of 21, reduces agricultural labor productivity by a factor of 25, and the land and farm distributions are skewed to the left (see Figures 11 and 12). These implications of the model are broadly consistent with the data on the size distribution of farms discussed earlier.

Land per capita differences can be as important in accounting for size and labor productivity differences across countries. Using data from the FAO we find that land per capita is 30% larger in the rich relative to poor countries. In Table 3 below we conduct another experiment where TFP is reduced by a factor of 4 but also land per capita by 30%. As expected the effects on farm size and labor productivity are larger in this case.

We recognize that our results are sensitive to the choice of γ and that there is not a tight restriction for the value of this parameter. We view our choice of $\gamma = 0.6$ as conservative given the evidence from micro studies. Table 4 shows the sensitivity of the results to larger and smaller values of γ.

Table 3

Effects of A and L Differences

	$A = 1$	$A = 1/4$ $L = 1/1.3$
N_a (%)	2.5	77.7
Rel. AFS (Ha)	1	1/40.4
Distribution:		
Farms < 5 Ha (%)	9.8	81.2
Farms > 20 Ha (%)	73.2	4.1
Share of Land (%)		
Farms < 5 Ha (%)	0.2	22.5
Farms > 20 Ha (%)	98.8	47.1
Rel. Y_a/N_a	1	1/36.8
Rel.Y	1	1/14.9

Table 4

Sensitivity of Results to γ for $A = 1/2$

	γ			
	0.2	0.4	0.6	0.8
N_a (%)	4.7	6.0	10.1	53.7
Rel. AFS (Ha)	1/1.9	1/2.4	1/4.0	1/21.5
Distribution:				
Farms < 5 Ha (%)	19.2	19.2	26.8	68.8
Farms > 20 Ha (%)	57.6	50.5	38.7	8.8
Share of Land (%)				
Farms < 5 Ha (%)	0.6	0.6	1.2	12.6
Farms > 20 Ha (%)	96.6	95.0	91.0	61.9
Rel. Y_a/N_a	1/2.3	1/2.8	1/4.6	1/23.3
Rel.Y	1/2.0	1/2.0	1/2.1	1/4.0

TABLE 5
Summary Aggregate and
Agricultural Statistics

	$\frac{GDP}{N}$	$\frac{FO_a}{N_a}$	$\frac{GDP_a}{N_a}$	$\frac{GDP_n}{N_n}$	$\frac{N_a}{N}$
Richest	1	1	1	1	0.04
Poorest	1/34	1/109	1/78	1/5.0	0.86

Source: Restuccia, Yang, and Zhu (2008)

N denotes labor, FO denotes final output in agriculture.
Subscripts a and n denote agriculture and non-agriculture.

4.3 Comparison to Data

Can this simple model broadly reproduce the disparities observed between rich and poor countries in terms of average farm size, distribution of farm sizes and land share, agricultural employment shares, agricultural labor productivity, and aggregate labor productivity? Restuccia, Yang and Zhu (2008), using comparable cross-country data from Rao (1993) of the FAO, provide data on the disparities between the richest and poorest countries in agriculture. In Table 5 we reproduce their main observations.

As is evident from Table 5, the poorest countries are particularly unproductive in agriculture (disparity in agricultural labor productivity is 78) and devote an inordinate amount of labor to farming (86%). Data in Table 1 show that the poorest countries have an average farm size that is 34 times lower than that of the richest countries, and Figures 4 and 8 indicate that the distributions of farm size and land are skewed to the left for the poorest countries. How does the model do quantitatively in accounting for these cross-country observations?

Our quantitative experiment involves comparing economies that differ relative to the benchmark in one dimension, economy-wide productivity A. As we emphasized earlier we interpret this parameter as a catchall for a general set of factors influencing productivity in both agriculture and non-agriculture within a country. Note that in the context of our model differences in A map one-to-one with differences in non-agricultural labor productivity. Thus, in our experiment we feed into the model exogenously differences in non-agricultural productivity. Table 5 indicates that the disparity in non-agricultural labor productivity between the richest and poorest countries is 5-fold, hence we set in our experiment $A = 1/5$. In Figure 6 we report the disparities in key variables of interest produced by the model for the poor economy with $A = 1/5$, along with the data. In Figure 13 we show the density for the size distribution of farms produced by

TABLE 6
Disparities in Model vs. Data

	Data	**Model** ($A = 1/5$)
N_a in Poorest (%)	86	89.5
Rel. AFS (Ha)	1/34	1/35.8
Distribution:		
Farms $<$ 5 Ha (%)	93.6	79.0
Farms $>$ 20 Ha (%)	0.2	4.8
Share of Land (%)		
Farms $<$ 5 Ha (%)	68.2	20.3
Farms $>$ 20 Ha (%)	3.4	49.9
Rel. Y_a/N_a	1/78	1/42.5
Rel.Y	1/34	1/21.6

the model for the distorted economy against the one for the poorest group of countries (Q1).

As can be seen the model's predictions are broadly consistent with the data. The share of employment in agriculture, the average farm size, and the distribution of farm sizes in the poor economy are very close to the ones in the data. The model can also account for 55% of the disparity in agricultural labor productivity, and for 24% of the income gap between the richest and poorest countries.

5 Discussion

We have abstracted from many potentially important factors in determining farm size and agricultural labor productivity. For instance, we abstracted from hired labor and physical capital in the farm production function. We have abstracted from other barriers to size and selection in farming activities. We have also assumed perfect risk sharing among household members. In this section we briefly discuss some of these extensions.

5.1 Hired Labor

In our benchmark model all household members allocated to agriculture are farm operators. Each farm operator receives a draw from the distribution of managerial ability, which determines the farm size that the farmer chooses. We can extend our framework to allow for hired workers in farms. Allowing for hired labor the farming technology facing a farm operator is,

$$y_a = As^{1-\gamma} g(\ell, h)^{\gamma},$$

which requires in addition to the farmer's managerial ability (s) and land input (ℓ), the input of hired labor h. If $g(.)$ is Cobb-Douglas, then $g(\ell, h) = \ell^{\theta} h^{1-\theta}$, where $0 < \theta < 1$ captures the relative importance of land to hired labor in the farming technology. Introducing hired labor implies that not all of the household members allocated to agriculture become farm operators – some will become workers. In other words, in addition to the consumption allocation decision, and the sectoral labor allocation decision, the household faces an occupational choice decision within agriculture. Who becomes an operator and who becomes a worker is determined by the ability draws household members receive when allocated to agriculture. More specifically, household members with ability above some cutoff level $\widehat{s}$ will become operators and make profits $\pi(s)$, and household members with ability below $\widehat{s}$ will become agricultural workers and earn agricultural wage w_a. The cutoff level of managerial ability is such that the marginal farmer is indifferent between being a hired worker and an operator,

$$w_a = \pi(\widehat{s}).$$

The budget constraint faced by the stand-in household is now,

$$p_a \cdot c_a + c_n = (1 - N_a) w_n + N_a \left(w_a F(\widehat{s}) + \int_{\widehat{s}}^{\overline{s}} \pi f(s) ds \right) + qL.$$

The market clearing condition for labor is,

$$F(\widehat{s}) = \int_{\widehat{s}}^{\overline{s}} h(s) f(s) ds.$$

What is the quantitative relevance of introducing hired labor? For the US economy we calculate that in 2007, 65% of persons employed in agriculture are operators, with hired workers accounting for 35%.[12] We calibrate θ to match a share of operators in total agricultural labor of 65%. Combining the market clearing condition for land with that

[12] In this calculation we define hired workers in terms of "full time equivalents," whereby we assign a weight of 1 to workers employed on the farm for more than 160 days and 1/2 to workers working for under 160 days. If we just use (un-weighted) raw numbers then the fraction of operators is 56%.

for labor reveals how this mapping works,

$$\frac{L/Na}{F(\widehat{s})}\left(\frac{q}{w_a}\right) = \frac{\theta}{1-\theta}.$$

Recalibrating our model to account for hired labor we find that there are no substantial differences in the quantitative results relative to the benchmark model.

5.2 Physical Capital

Adding physical capital in the farm production function can potentially be important, as capital can operate potentially as a constraint on farm size in poor countries. An issue is how to introduce capital in the farming technology. A simple Cobb-Douglas production function between land and capital would imply that the capital to land ratio and capital intensity (capital to output) would be constant across farm sizes. Using data from the 2007 US Census of Agriculture, and measuring capital as the value of machinery and equipment (e.g., trucks, tractors, combines, harvesters etc.) we find that as farm size increases, capital does not increase proportionally. In particular, we find that the capital to land ratio and capital intensity drop as farm size rises. These observations suggest that a CES farming technology of the following form may be appropriate,

$$y_a = A\left[\theta k^{\rho} + (1-\theta)\,(s\ell)^{\rho}\right]^{\frac{\gamma}{\rho}},$$

where θ determines the relative importance of capital in the farming technology and ρ determines the elasticity of substitution between capital and land. The first order conditions to the farmer's problem with this technology, imply that the capital to land ratio between a small farm i and a large farm j is,

$$\frac{\left(\frac{k}{\ell}\right)_i}{\left(\frac{k}{\ell}\right)_j} = \left(\frac{s_j}{s_i}\right)^{\frac{\rho}{1-\rho}},$$

which would require $0 < \rho < 1$ for the capital-land ratio to change with farm size according to the US data (i.e., more factor substitutability than that implied by Cobb-Douglas). We plan to explore the quantitative importance of this channel.

6 Conclusions

Differences in economy-wide productivity appear to go a long way in accounting for cross-country differences in the allocation of labor across sectors and in explaining the small farm sizes and low agricultural labor productivity in poor countries. Overall, incorporating farm size heterogeneity seems to go a long way in accounting for cross-country differences in agricultural and aggregate labor productivity.

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A Farm and Land Distributions by Income Group

Table 7
Size Distribution of Farms
across Income Groups

	< 1	1 to < 2	2 to < 5	5 to < 10	10 to < 20	20 to < 50	50 to < 100	100 to < 200	200 to < 500	500+
Q1	0.55	0.17	0.22	0.05	0.01	0.00	0.00	0.00	0.00	0.00
Q2	0.39	0.17	0.27	0.09	0.04	0.03	0.00	0.00	0.00	0.00
Q3	0.36	0.18	0.17	0.09	0.07	0.05	0.03	0.02	0.01	0.01
Q4	0.25	0.11	0.20	0.12	0.11	0.10	0.04	0.03	0.02	0.03
Q5	0.12	0.07	0.13	0.13	0.17	0.21	0.10	0.04	0.03	0.02

Source: Authors' Calculations. Data from the Report on the 1990 World Census of Agriculture. Reported values are averages over countries in each income group.

Table 8
Land Distribution of Farms
across Income Groups

	< 1	1 to < 2	2 to < 5	5 to < 10	10 to < 20	20 to < 50	50 to < 100	100 to < 200	200 to < 500	500+
Q1	0.23	0.19	0.26	0.15	0.13	0.02	0.02	0.00	0.00	0.00
Q2	0.10	0.12	0.25	0.14	0.09	0.18	0.09	0.01	0.01	0.00
Q3	0.08	0.07	0.12	0.09	0.07	0.10	0.07	0.08	0.11	0.22
Q4	0.02	0.03	0.08	0.09	0.18	0.11	0.15	0.16	0.11	0.07
Q5	0.03	0.03	0.05	0.06	0.14	0.28	0.22	0.08	0.02	0.08

Source: Authors' Calculations. Data from the Report on the 1990 World Census of Agriculture. Reported values are averages over countries in each income group.

B Productivity Differences across U.S. Farm Sizes

To get a sense of the productivity differences across different farm sizes, we calculate productivity measures for the different classes of farms in the United States, using the 2007 US Census of Agriculture data.

Let y_i denote total sales of agricultural products (note this does not include government payments) in dollars by all farms of size i. Let x_i be the dollar value of all intermediate inputs used by farms of size i.[13]

Then value added for all farms of size i is $va_i = y_i - x_i$. Our measure of labor productivity is va_i/n_i where n_i is the total number of workers for farms of size i. In particular n_i consists of operators of farms and hired labor. Note, then that va_i/n_i is the (weighted) average labor productivity under farm size i. An alternative measure of labor productivity presented below is sales per worker y_i/n_i.

We also consider a measure of TFP based on an agricultural production function, identical to that in Restuccia, Yang and Zhu (2008),

$$y_i = x_i^{\alpha} \left[(A_i \cdot n_i)^{\sigma} l_i^{1-\sigma} \right]^{1-\alpha}$$

where l_i is total land acreage of farms of size i, and A_i is a measure of TFP for farms of size i. For the elasticity parameters we use as $\alpha = 0.4$ and $\sigma = 0.7$, as in Restuccia, Yang, and Zhu (2008). The above production function can be re-arranged to obtain residually an estimate of TFP,

$$A_i = \left[\frac{y_i/n_i}{\left(\frac{x_i}{y_i}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{l_i}{n_i}\right)^{1-\sigma}} \right]^{\frac{1}{\sigma}}$$

Note that this measure of TFP is not the average of the TFPs of individual farms within each class size, but rather the TFP of the average farm.

Figures 14 - 16 present the three productivity measures for each class of farm size. The classification is the one used in the US Census of Agriculture, in acres. Productivity measures have been normalized relative to the min size (1-9 acres). All measures are based on the 2007 US Census of Agriculture. The three measures convey a similar message, namely that productivity rises with farm size.

C An Accounting Exercise

We focus on two measures of productivity, value added per farm and value added per worker. Let va_i denote value added in farm size class i. We denote the corresponding

[13]These intermediate inputs include: Fertilizer, lime, and soil conditioners purchased; Chemicals purchased; Seeds, plants, vines, and trees; Livestock and poultry purchased or leased; Breeding livestock purchased or leased; Other livestock and poultry purchased or leased; Feed purchased; Gasoline, fuels, and oils; Utilities; Supplies, repairs, and maintenance

number of farms in class i, by n_i, and the number of workers e_i. Then average value added per *farm* is,

$$\frac{va}{n} = \sum_i \frac{n_i}{n} \cdot \frac{va_i}{n_i} \tag{14}$$

For each country that has data in the World Census of Agriculture we can directly calculate n_i/n in (14) for each class size. Further, from the US Census of Agriculture 2007 we can calculate differences in farm productivity across the different class sizes va_i/n_i.

Average value added per worker is,

$$\frac{va}{e} = \sum_i \frac{e_i}{e} \cdot \frac{va_i}{e_i} \tag{15}$$

While we can still use the US labor productivities for each country va_i/e_i, we do not directly observe the labor shares e_i/e for each country from the World Census. So in the accounting below we assume that the labor weights e_i/e are equal to the farm shares n_i/n. (The distribution of farms and the distribution of labor in the 2007 US Census of Agriculture shows that this assumption is reasonable, farms have been and remain mostly a family business).

TABLE 9
Accounting: Aggregate Productivity Disparity Between Rich-Poor

	Value Added Per Farm	Value Added Per Worker
Accounting 1	5.4	3.6
Accounting 2	7.7	4.1

Source: Authors' Calculations.

We conduct two kinds of accounting exercises.

In the first, denoted *Accounting 1*, we focus on only two classes of farms: "small" and "large." By small we define any farm under 20 Ha and by large any farm above 20 Ha. The choice is not arbitrary. The 20 Ha cutoff is one that is present both in the data from the US Census of Agriculture (2007), and in the cross-country data of the World Census of Agriculture. Without having to make any assumptions regarding the mapping from the classes of the US Census to the World Census, we can calculate productivity for "small" and "large" farms for the US, and use the weights from the

World Census to calculate aggregate productivity for any country or group of countries (assuming that the difference in productivity between large and small farms for any country is as large as the one observed in 2007 US). In Table 9 we present disparities in value added per worker and value added per farm for the poor quintile of countries (Q1), and the rich quintile of countries (Q5). Interestingly, poor countries in Q1 have virtually no farm over 20 Ha. In other words, not only is the share of farms above 20 Ha, equal to zero for Q1, but so is the share of labor (since virtually no such farms exist). For rich countries, we assume that the share of farms in each class is equal to the share of labor.

In the second accounting exercise, denoted *Accounting 2*, we fit a curve to the observed productivities for the US farm sizes (average farm size within each range), and use the fitted equation to calculate productivity for the midpoints of the ranges in the World Census. In particular, we posit a power function of the following form,

$$y = c \cdot s^b$$

where s is the size of the farm, y is the measure of productivity (i.e., either va/n or va/e), and c and b are parameters to be estimated. We run the following regression for the US in log form,

$$ln(y) = c_0 + b \cdot ln(s)$$

where for s we use the average size of farm in each range and for y we use the average productivity in each range. Running a simple OLS regression for the US we get estimates for the parameters c_0 and b. We find that when our measure of productivity is value added per farm $b = 0.54$, and when it is value added per worker $b = 0.50$. We then use the estimated parameters to calculate "predicted" productivity for each of the midpoints of the ranges in the World Census (these are the s's we plug in). Then using these predicted productivities and the weights we observe from the World Census for each range, we calculate predicted aggregate productivity for poor (Q1) and rich (Q5) countries, as well as their ratio. These results are presented in Table 9 as "Accounting 2".

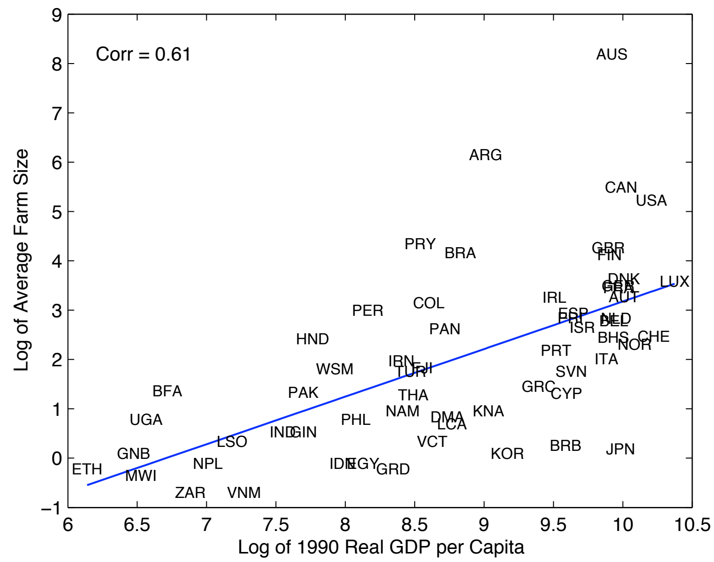

FIGURE 1
Average Farm Size vs. Income

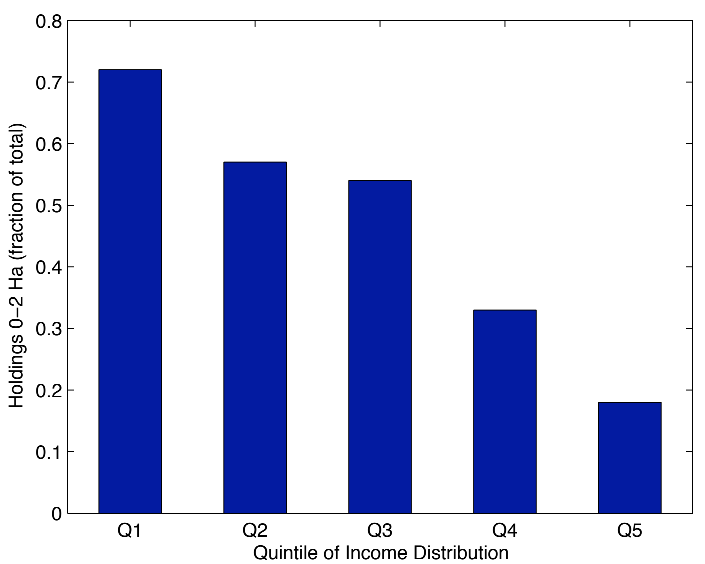

FIGURE 2
Percentage of Small Sized Farms
(0-2 Ha) by Income Group

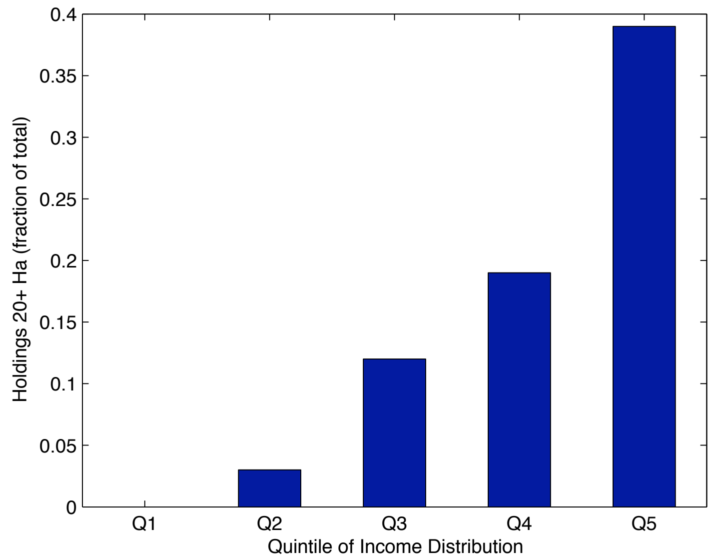

FIGURE 3
Percentage of Large Sized Farms
(20+ Ha) by Income Group

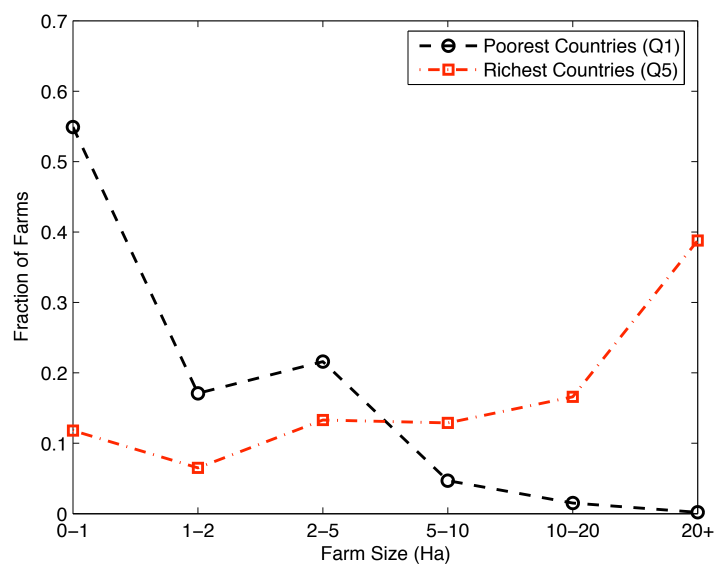

FIGURE 4
Histograms for Distributions of Farm
Size: Poorest and Richest Countries

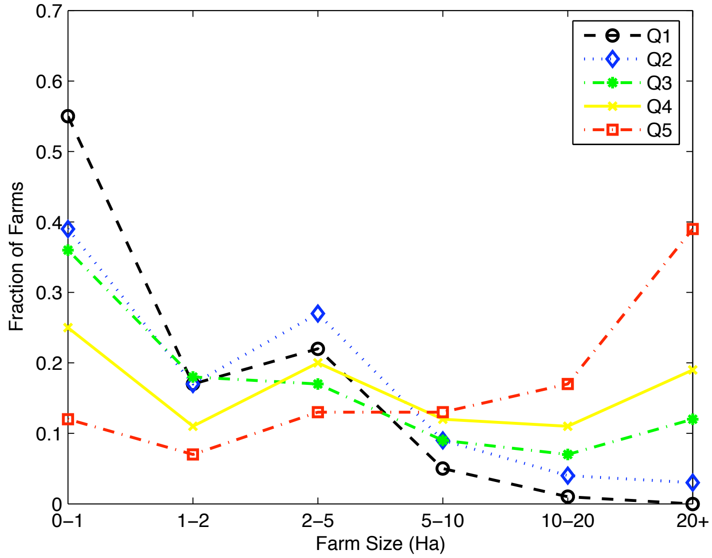

Figure 5
Histograms for Distributions of
Farm Size: All Income Groups

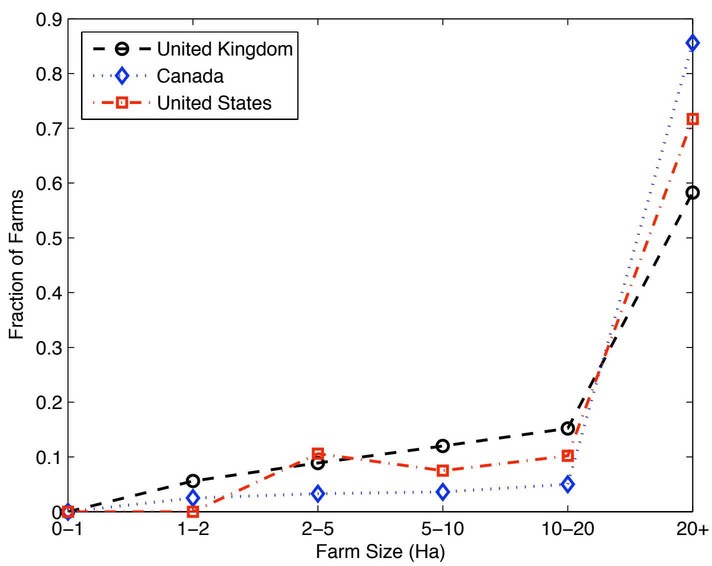

Figure 6
Histograms for Distributions of
Farm Size: Selected Rich Countries

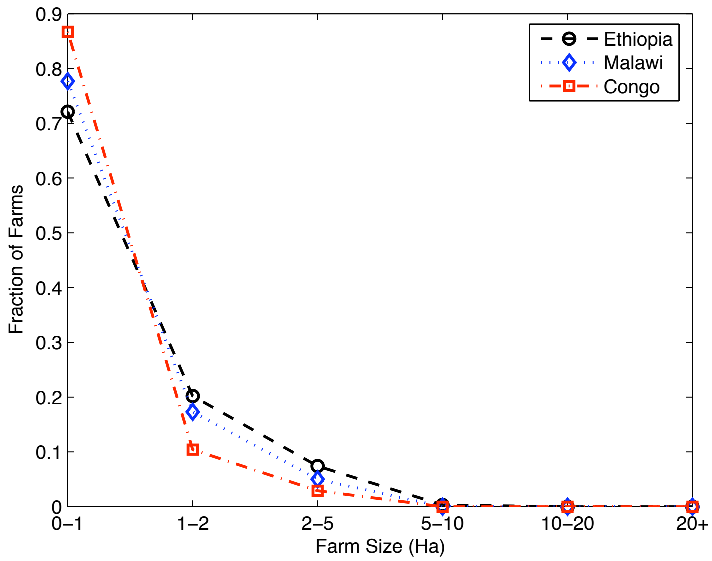

FIGURE 7
Histograms for Distributions of
Farm Size: Selected Poor Countries

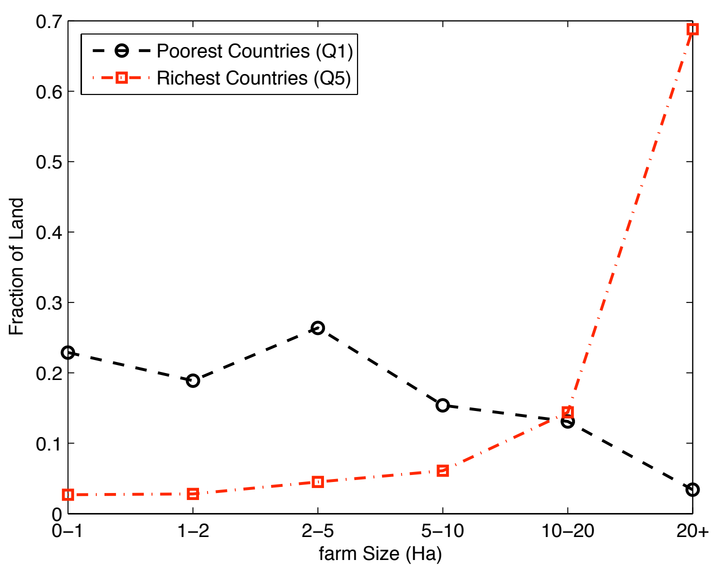

FIGURE 8
Histograms for Land Distributions in
Farms: Poorest and Richest Countries

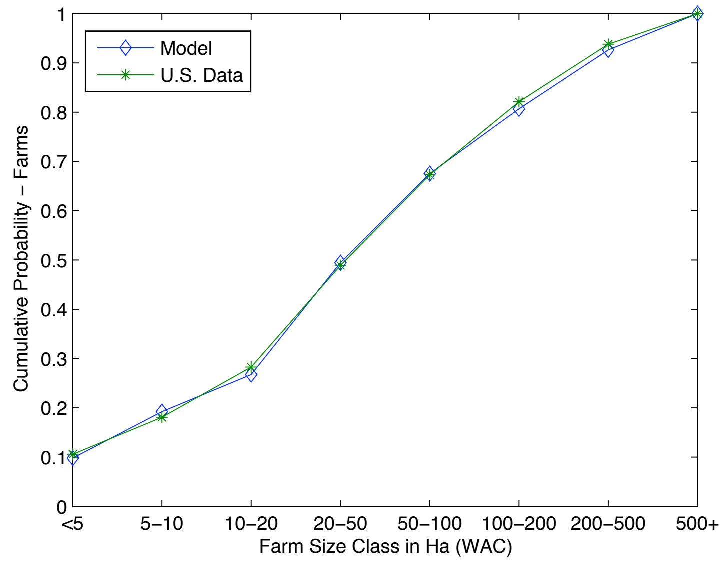

FIGURE 9
CDF for Farm Distribution

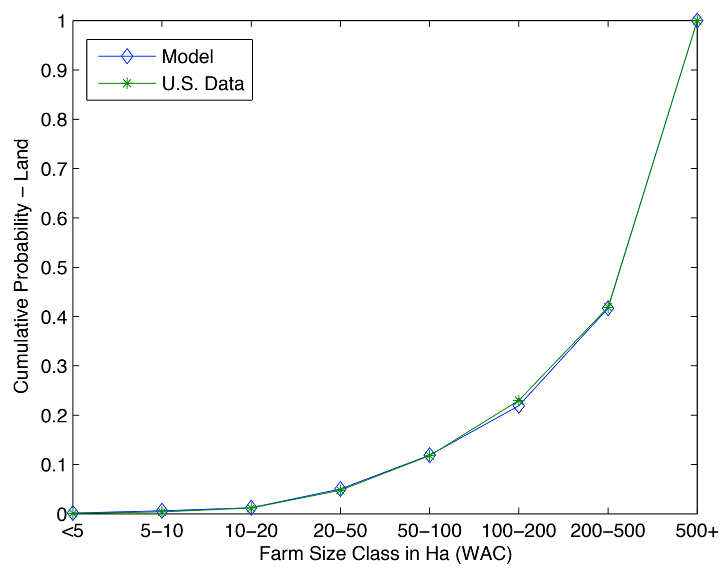

FIGURE 10
CDF for Land Distribution

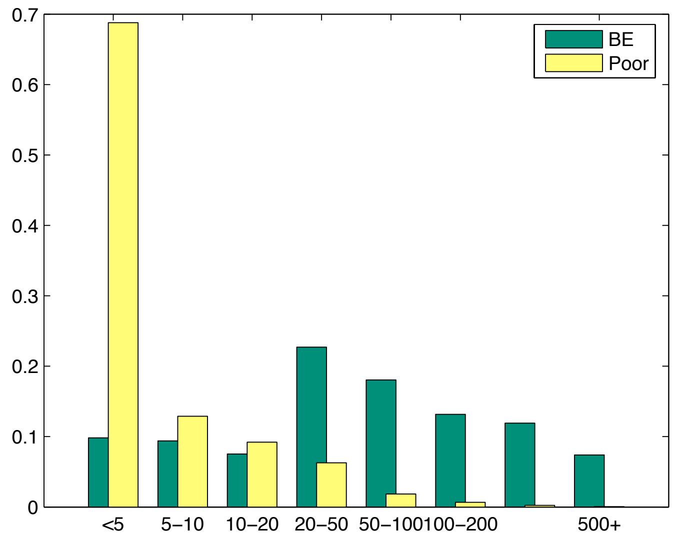

Figure 11
Distribution of Farms by Farm Size (Ha)

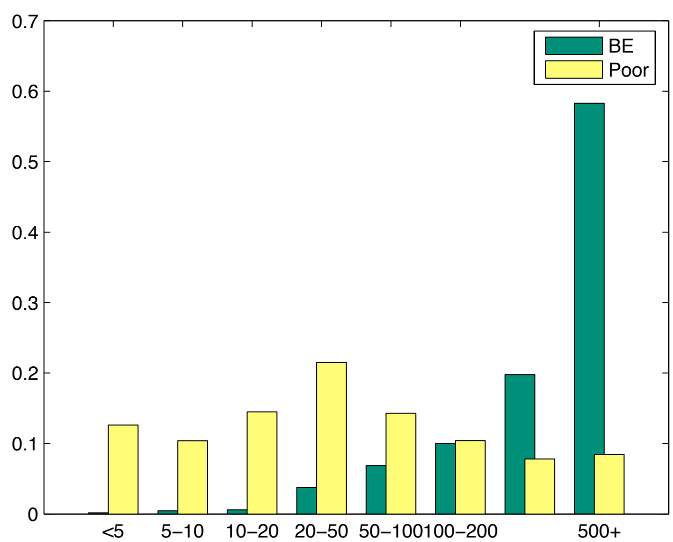

Figure 12
Distribution of Share of
Land by Farm Size (Ha)

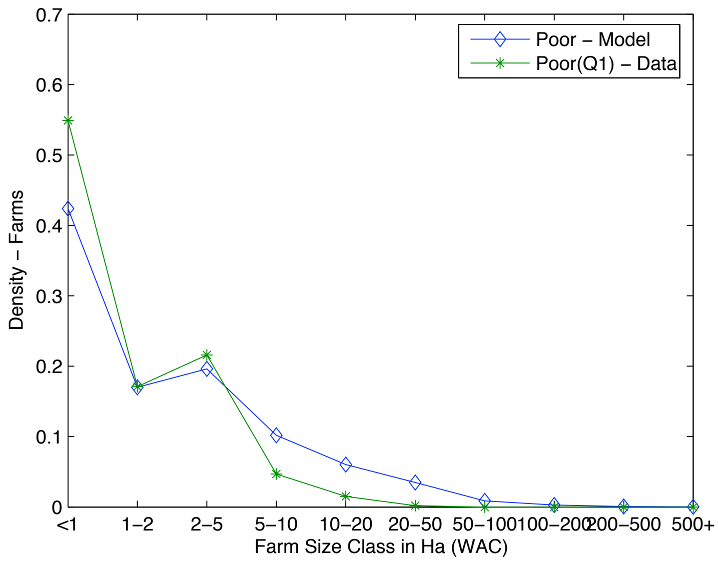

FIGURE 13
Farm Size Density for Poorest Countries: Model vs. Data

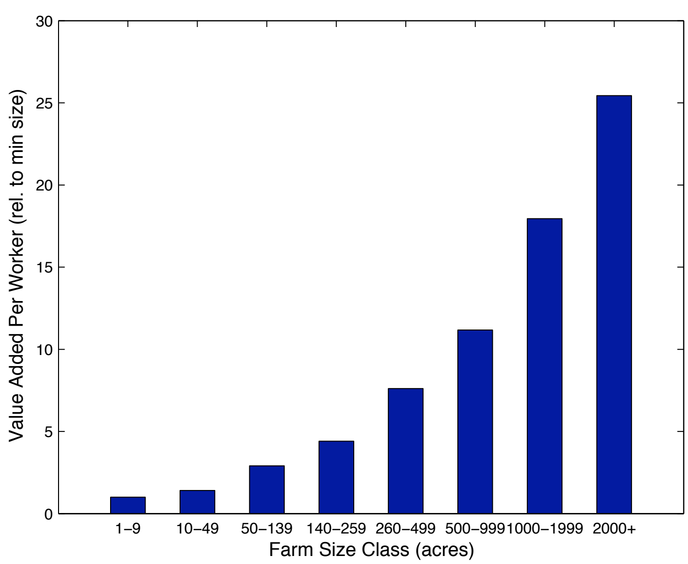

FIGURE 14
Value Added Per Worker

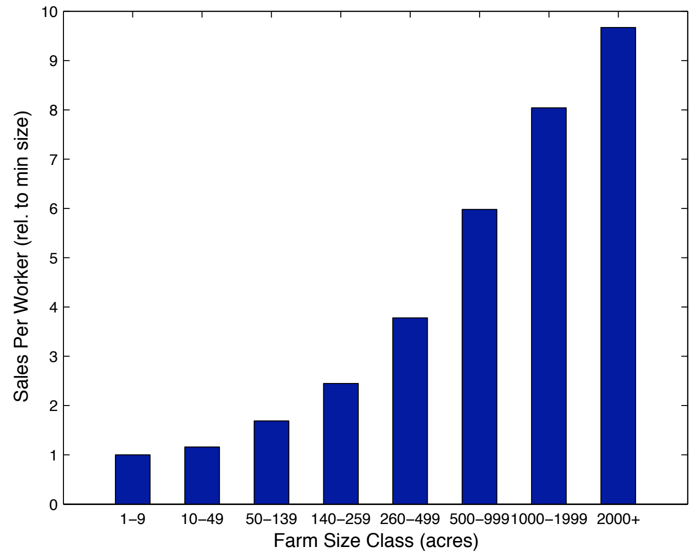

FIGURE 15
Sales Per Worker

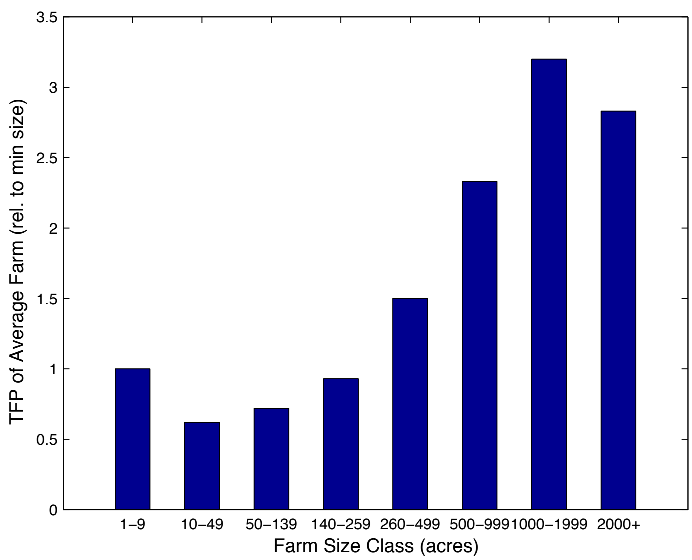

FIGURE 16
TFP