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Department of Economics

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The Size Distribution of Farms and International Productivity Differences

By Tasso Adamopoulos and Diego Restuccia

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Tasso Adamopoulos
York University

Diego Restuccia
University of Toronto

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Abstract

There is a 34-fold difference in average farm size (land per farm) between rich and poor countries and striking differences in their size distributions. Since labor productivity is much higher in large relative to small farms, we study the determinants of farm-size differences across countries and their impact on agricultural and aggregate productivity. We develop a quantitative model of agriculture and non-agriculture that features a non-degenerate size distribution of farms. We find that measured aggregate factors such as capital, land, and economy-wide productivity cannot account for more than 1/4 of the observed differences in farm size and productivity. We argue that, among the possible explanations, farm-level policies that misallocate resources from large to small farms have the most potential to account for the remaining differences. Such farm-size distortions are prevalent in poor countries. We quantify the effects of two specific policies in developing countries: (a) a land reform that imposes a ceiling on farm size and (b) a progressive land tax. We find that each individual policy generates a reduction of 3 to 7% in average size and productivity.

JEL classification: O11, O13, O4, E0.
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1 Introduction

Agriculture plays a key role in understanding the large disparities in aggregate labor productivity across countries. This is because poor countries are much more unproductive in agriculture than in non-agriculture when compared to rich countries and, at the same time, allocate a larger fraction of employment to agricultural activities than rich countries. Ever since T. W. Schultz (1953), the prominent explanation for the allocation of employment in agriculture in poor countries has been low productivity in that sector in the presence of subsistence requirements for food. The key question is then, why are poor countries so unproductive in farming? A substantial literature has emerged addressing the productivity problem in agriculture in poor countries. While the literature has provided many useful insights and a better understanding of the productivity gap in agriculture, a large unexplained gap still remains.[1]

We show that farm size is an important factor in unraveling the low productivity problem in agriculture in poor countries. There are two observations that motivate our inquire into farm size:

(a) There are striking differences in the size distribution of farms between rich and poor countries with the operational scale of farms being considerably smaller in poor countries. Using internationally-comparable data from the World Census of Agriculture, we show that in the poorest 20% of countries the average farm size is 1.6 hectares (Ha), while in the richest 20% of countries the average farm size is 54.1 Ha, a 34-fold difference. In poor countries very small farms (less than 2 Ha) account for over 70% of total farms, whereas in rich countries they account for only 15%. In poor countries there are virtually no farms over 20 Ha, while in rich countries they account for 40% of the total number of farms.[2]

[1] See for instance Kuznets (1971), Gollin, Parente, and Rogerson (2002), Caselli (2005), Restuccia, Yang, and Zhu (2008), Chanda and Dalgaard (2008), Vollrath (2009), Adamopoulos (2011), Lagakos and Waugh (2010), Gollin, Lagakos, and Waugh (2011), Herrendorf and Schoellman (2011), among others.

[2] To document facts about farm size across countries, we use data from the *Report on the 1990 World Census of Agriculture*, published by the Food and Agricultural Organization (FAO). We combine this data with aggregate productivity data from the Penn World Table and agricultural productivity and employment data from the FAO to

(b) Larger farms have much higher labor productivity than smaller farms, implying that farm size differences can potentially have large effects on measured agricultural productivity. Using data from the U.S. Census of Agriculture we document a 16-fold difference in value added per worker between the largest and smallest scale of operation of farms reported. Available data from other sources, based on national censuses and farm surveys, indicate that labor productivity rises with size in a large set of developing countries as well (see for instance Berry and Cline, 1979; Cornia, 1985). This occurs despite differences in land scarcity, soil, geography, agrarian structure, and form of agriculture observed among these countries.[3]

We investigate why farm size differs across countries and we assess quantitatively the effect of farm-size differences on agricultural and aggregate productivity across countries. To guide our investigation, we develop a simple two-sector model of agriculture and non-agriculture that features a non-degenerate distribution of farm sizes. Our theory endogenizes farm size by embedding a Lucas (1978) span-of-control model of farm size in agriculture into a standard two-sector model. The novelty of the model lies in that agricultural goods are not produced by a representative farm but instead by farmers who are heterogeneous with respect to their ability in managing a farm. A farm is a decreasing returns to scale technology that requires the inputs of managerial skills of a farm operator and land and capital under the farmer's control. The optimal scale of operation of a farm is determined by the managerial ability of the farmer. Then, for a given distribution of managerial abilities, the model implies a distribution of farm sizes. There is a representative stand-in household that has preferences over agricultural and non-agricultural goods but faces a subsistence constraint for consumption of agricultural goods. Hence, the allocation of labor across sectors is driven by the interaction between subsistence consumption of agricultural goods and productivity.

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construct a dataset of 63 countries. See Grigg (1966) for an early documentation of differences in farm size across countries and Eastwood, Lipton, and Newell (2007) for some more recent observations and historical trends.

[3]We note that rising labor productivity by size is not at odds with the stylized fact about the inverse relationship between land productivity (yields) and farm size. Labor productivity increases with farm size at the same time that land productivity falls with size in the current and past U.S. Census of Agriculture as well as in a wide range of developing countries across time and space (see for instance, Berry and Cline, 1979; Cornia, 1985; and Binswanger, Deininger and Feder, 1995).

We calibrate a benchmark economy to U.S. farm-level and aggregate observations. In particular, we approximate the distribution of farm-level productivity (farmer ability) by a log-normal distribution and choose its shape parameters to match the distribution of farm sizes in the U.S. Census of Agriculture. The model fits very well the farm-level data, and in particular, the distribution of labor productivity across farm sizes. In our theory, for a given distribution of farm-level productivity, higher aggregate TFP, capital, or land, results in larger farm sizes since fewer farmers are needed in agriculture to produce food with the remaining farmers increasing their farm size. To evaluate the importance of aggregate factors on farm size and productivity, we measure in the data disparities between rich and poor countries in economy-wide productivity, the capital-output ratio, and land per capita. We take these differences to be exogenous and feed them into the model, comparing the resulting equilibrium allocations and distributions to the data. We find that the aggregate factors taken together cannot account for more than 1/4 of the differences in average farm size and agricultural productivity across rich and poor countries. What accounts for the large unexplained gap?

There are two potential explanations in generating the remaining farm-size differences between rich and poor countries: differences in the distribution of farmer productivity and farm-level policies in poor countries that misallocate resources across farms of different sizes. We conduct two experiments where we attribute the entire remaining differences in the size distribution of farms (share of farms by size) and average farm size to differences in farmer productivity or farm-size distortions. Both experiments reach a common conclusion. By accounting for farm size, the model reproduces the differences in sectoral employment and agricultural and aggregate labor productivities between rich and poor countries. We argue that the available evidence on human capital and geography –as key determinants of farmer productivity– suggests that differences in the distribution of farm-level productivity are unlikely to be the source of small farm size and low agricultural productivity in developing countries. In turn, there is ample evidence on a wide variety of farm-level policies that distort size in poor countries suggesting that "smallness" is a symptom of misallocation within agriculture.

The policies and institutions that directly or indirectly distort size in poor countries are usually "pro-small". For instance, many countries have implemented land reforms by setting an explicit ceiling for land holdings, breaking-up farms in excess of the ceiling (e.g., Bangladesh, Chile, Ethiopia, India, Korea, Pakistan, Peru, Philippines). Other countries distort size by imposing maximum and minimum size constraints (e.g., Indonesia and Zimbabwe). Several countries such as Zimbabwe, Pakistan, Brazil, and Namibia have imposed progressive land taxes, where larger farms are taxed at a higher rate than small farms. Ethiopia had a steep progressive agricultural income tax schedule for farmers. Several African countries (e.g. Kenya, Malawi, Tanzania, Zambia) have provided generous input subsidies to smallholders. In India, tenancy reforms provided tenure security and preferential right of purchase to tenants which could also hinder farm growth. Bridgman, Maio, Schmitz and Texeira (2011) show how production quotas (that disproportionately hurt large estates) and maximum farm size restrictions negatively affected the sugar-cane industry in Puerto Rico. We provide a detailed documentation of farm-size distortions in developing countries in Table D.1 in Appendix D.

We assess the quantitative importance of specific policies that distort size by focusing on the institutional detail of two particular applications. The first policy we examine is a land reform that caps farm size at a legislated ceiling. Land reforms with a size ceiling have been prevalent since the 1950s in many developing countries. The specific policy we study is the 1988 Comprehensive Agrarian Reform Program (CARP) in the Philippines, which imposed a ceiling of 5 Ha on land holdings. The second policy we examine, which is also wide-spread, is a progressive land tax. We study the 1976 Amendment to the West Pakistan Land Revenue Act, which substituted a uniform land tax with a progressive tax by eliminating the land tax for farms under 5 Ha while increasing the tax by 50% for medium size farms and by 100% for large farms. In the model, the observed farm-level policies in Philippines and Pakistan not only reduce size but also productivity. The land reform in the Philippines reduces average size and agricultural productivity by 7%, while the tax reform in Pakistan reduces size and productivity by 3%. To compare the implications of the model with data, we take into account other changes occurring alongside the farm-size policies. When farm-size policies are combined with observed changes in aggregate factors, we show that the model can account well for the evolution of key variables of interest in the period following the policy reform in the data for the Philippines and Pakistan.

Our paper is related to a growing macroeconomics literature that studies quantitatively the role of agriculture in understanding international income differences such as Gollin, Parente and Rogerson (2002, 2004, 2007), Caselli (2005), Restuccia, Yang and Zhu (2008), Chanda and Dalgaard (2008), Vollrath (2009), Adamopoulos (2011), Lagakos and Waugh (2010), Gollin, Lagakos and Waugh (2011), and Herrendorf and Schoellman (2011).[4] Another important and growing literature emphasizes misallocation of resources across heterogeneous production units in generating aggregate and industry productivity effects such as Restuccia and Rogerson (2008), Guner, Ventura, and Xu (2008), Hsieh and Klenow (2009), among many others. We differ from these two broad literatures in emphasizing the size distribution of production units (farms) for the agricultural sector and quantifying the effects of specific observable policies.

We recognize that important differences in size across countries are also observed in other sectors of the economy. We focus on agriculture because this is a stark example of a sector where the observed differences in size distributions and labor productivity by size indicate a potential for large productivity effects. Further, productivity effects in the agricultural sector can translate into large differences in aggregate productivity between rich and poor countries as emphasized in Restuccia, Yang, and Zhu (2008), Caselli (2005), and the related literature. In addition, the particular farm-

[4]A broader related literature studies the sources and effects of the process of structural transformation that accompanies development: Echevarria (1997), Kongsamut, Rebelo, and Xie (2001), Caselli and Coleman (2001), Ngai and Pissarides (2007), Acemoglu and Guerrieri (2008), Buera and Kaboski (2009), and Duarte and Restuccia (2010). Buera and Kaboski (2008) emphasize the movement to large scale production units in manufacturing and services and their role in the structural transformation.

level policies we study are land policies, and hence specific to agriculture where land is an important factor of production.

The paper proceeds as follows. In the next section we document facts pertaining to farm size across countries. In Section 3 we describe the model. Section 4 presents the calibration of the benchmark economy to U.S. data. In Section 5 we perform the cross-country quantitative experiments in terms of aggregate factors, farm-level productivity distribution, and farm-size distortions. Section 6 examines the quantitative effects of land reforms and progressive land taxes. We conclude in Section 7.

2 Facts on Farm Size

We document observations about farm size across countries using internationally-comparable data from the *Report on the 1990 World Census of Agriculture* of the Food and Agricultural Organization (FAO) of the United Nations. The World Census of Agriculture collects data on the number of agricultural holdings and land area in holdings classified by size in hectares (Ha) for a large number of countries spanning the world income distribution.[5] We combine these data with aggregate productivity data from the Penn World Table (PWT6.2) and agricultural productivity, employment, and land data from Rao (1993) to construct a data set of 63 countries in 1990.[6] We rank countries according to real GDP per capita and allocate them into quintiles of the income distribution. The list of countries within each quintile is provided in Appendix A. We summarize our main findings

[5] We use the term "farm" throughout to refer to an agricultural holding. According to 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. For countries that report their size classification using a metric other than hectares, such as acres in the United States, the World Census converts these units to hectares.

[6] A more detailed description of the data and the variables we use is provided in Appendix A. The year 1990 is chosen as the benchmark year for our comparisons because this is the year for which we have the most extensive coverage of farm-size data and it is the year closest to the year for which we have aggregate agricultural productivity data from Rao (1993).

with a special focus on the comparison of the richest (Q5) and the poorest (Q1) groups of countries.[7]

Farm Size across Countries

Fact 1: Average farm size rises with the level of development. Figure 1 shows average farm size against real GDP per capita (in logarithms) across countries. Even though there are some outliers (such as Argentina and Australia) there is a systematic relationship between farm size and income, whereby richer countries tend to produce agricultural goods on a larger scale than poorer countries. We find that the positive relationship between farm size and development remains even after controlling for type of crop and livestock, geographical location, and land endowment. Table 1 reports the mean of average farm size for each quintile of the income distribution. The average farm size in the poorest group of countries is 1.6 Ha whereas in the richest group is 54.1 Ha, a 34-fold difference.[8]

Although not explicitly reported, we note the general tendency for average farm size to increase over time in developed countries. For instance, average farm size increased almost 4-fold in the United States from 1880 to 1997 and more than 7-fold in Canada from 1871 to 2006. Moreover, the disparity in average farm size between rich and poor countries has more than doubled from 1960 to 1990.

Fact 2: The large differences in farm size between rich and poor countries are not due to compositional differences arising from the type of agriculture undertaken in these countries. In Table 1 we report the mean of average farm size by type of crop (wheat, maize, rice), and type of livestock

[7] The disparity in average real GDP per capita between the rich (Q5) and poor (Q1) groups of countries is 21-fold. Disparities, between these two groups, in other key variables are provided in Table A.1 of Appendix A. The size distribution of farms and the distribution of land within farms by income group are in a separate Appendix B (Tables B.1 and B.2).

[8] We note that the high average in Q4 is entirely accounted for by Australia. The median of average farm size rises smoothly with income (1.1, 2.6, 4.3, 14.2, 29.0 for each group in the "Total" category).

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. All other variables are from the World Census of Agriculture 1990.

(cattle, chicken, sheep, pigs) for each income group.[9] The data suggest that differences in farm size between rich and poor countries are large even within narrowly defined crop or livestock categories although the exact magnitude differs by category (e.g., 39-fold difference in rice and maize and 9-fold difference for wheat).

Fact 3: Farm size differences across countries are not dictated by geography. In Figure 2, panel A, we group countries by the latitude of each country's centroid and calculate the mean of average farm size for each group. The equator is at 0 and positive values of latitude indicate a movement north of the equator while negative values indicate a movement south of the equator. The lack of symmetry indicates that farm size is not systematically related to the distance from the equator. In Figure 2, panel B, we plot average farm size against the share of a country's land in the tropics or subtropics according to the Koeppen-Geiger climate zone classification (a value of 1 means that the entire country is in the tropics/subtropics).[10] We observe that there is considerable variation in farm size within the group of countries in the tropics and subtropics as well as within the group of countries in temperate climates. Further, if geography was a key determinant of farm-size differences

[9] In many of these subcategories observations are not available for several countries. Averages within each quintile for these crop and livestock categories are over the countries with available data.

[10] All our geography variables come from Gallup, Sachs and Mellinger (1999). The countries in the figures are those for which we have a value for the geography variable in addition to farm size.

we should not expect to see substantial changes in the distribution of farm sizes over time as is the case in many countries.[11]

Fact 4: There are stark differences in the size distribution of farms between rich and poor countries. Figure 3 focuses on the percentage of farms that are small (less than 5 Ha) and large (more than 20 Ha) across countries. Richer countries have fewer small farms and more large farms than poorer countries. In the poorest countries (Q1) over 90% of farms are small and almost none of the farms are large, whereas in the richest countries (Q5) small farms account for about 30% of farms and large farms for nearly 40%. Figure 4 documents the share of farms by size across income groups, for a finer breakdown of size categories. The share of farms is decreasing in size in poor countries suggesting that small farms constitute the most common form of production unit in these countries, whereas the share of farms is increasing in size in rich countries. Large farms constitute the dominant production unit in rich countries. Figure 5 shows the share of farms by size for selected poor countries such as Ethiopia, Malawi, and Congo, and selected rich countries such as Canada, United States, and United Kingdom. The Figure illustrates that the differences in farm size across groups of countries is even more striking at the individual country level.

Fact 5: In poor countries, small farms account for a disproportionate share of land, whereas in rich countries large farms account for most of the land. In Figure 6 we plot the distribution of land area in farms 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. This fact together with the distribution of farm sizes implies that the size that accounts for most of farm mass also accounts for most of the land mass. This is in contrast to the typical (manufacturing) establishment level data whereby large establishments

[11] Although not reported, we also find no correlation between average farm size and the mean distance to the nearest coastline or sea navigable river across countries.

(100+ employees) constitute a small fraction of the total number of establishments, yet account for a disproportionate fraction of employment.

Farm Productivity and Inputs by Size

The World Census does not report output or other inputs in addition to land by size. To gauge the importance of differences in productivity and inputs by farm size we look at farm-level data in the United States. Table 2 provides summary statistics from the 2007 U.S. Census of Agriculture.

Table 2: Statistics By Farm Size in the United States

Farm Size (Acres)	Farm Distribution	Land Share	Value Added Per Acre	Value Added Per Worker	Capital-Land Ratio
1-9	0.1056	0.0012	33.31	1.00	84.85
10-49	0.2813	0.0173	6.54	1.10	17.88
50-69	0.0698	0.0097	4.23	1.54	9.65
70-99	0.0871	0.0171	3.2	1.92	7.49
100-139	0.0794	0.022	2.67	2.22	5.96
140-179	0.0633	0.0238	2.4	2.67	4.98
180-219	0.0397	0.0187	2.59	3.38	4.73
220-259	0.031	0.0176	2.76	4.15	4.56
260-499	0.0964	0.0823	2.7	5.63	4.05
500-999	0.0679	0.1129	2.92	10.03	3.54
1,000-1,999	0.042	0.1384	2.52	14.25	2.95
2,000+	0.0365	0.5389	1.00	16.45	1.00

Source: Authors' calculations with data from the 2007 U.S. Census of Agriculture. Value added per acre and capital to land ratio are normalized relative to the maximum range values. Value added per worker is normalized relative to the minimum range value.

Fact 6: As is well known in the literature, labor productivity (value added per worker) increases with farm size.[12] The factor difference between the largest and smallest scale of operation reported

[12] In calculating value added per worker we take into account the relative hours worked by operators and hired labor. See Appendix A for details.

in the Census is 16-fold.[13] As is also well known, land productivity (value added per unit of land) decreases with farm size. The capital to land ratio also decreases with farm size.[14] These patterns are not unique to the United States. For example, Cornia (1985) reports data on 15 developing countries from Africa, Asia and Latin America for the 1970s where value added per worker tends to rise with farm size and both value added per unit of land and the capital to land ratio tend to fall with farm size.

These 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.

3 A Model of Farm Size

We consider a two-sector model of agriculture and non-agriculture featuring an endogenous distribution of farm sizes. In each period the economy produces two consumption goods: an agricultural good (a) and a non-agricultural good (n). The economy is endowed with fixed amounts of total farm land L and capital K.[15] The economy is also populated by a stand-in household with a constant unit-mass continuum of members.

[13] 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 labor productivity differences across farm sizes are assumed to be those in the U.S. Census. We find that poor countries would experience a 4-fold rise in agricultural productivity by re-allocating resources across farms in this manner. The details of this counterfactual are provided in separate Appendix C.

[14] Large farms utilize more capital per farm than smaller ones, however, they also have much more land per farm so the capital to land ratio declines with size.

[15] We abstract from capital accumulation in order to emphasize the direct efficiency effects that result from the reallocation of resources across farms of different sizes.

Production Technologies The non-agricultural good is produced by a representative firm with a constant returns to scale technology that requires labor and capital,

$$Y_n = AK_n^{\alpha} N_n^{1-\alpha},$$

where Y_n is the total amount of non-agricultural output produced, K_n and N_n are the total amounts of capital and labor services employed in non-agriculture. A is an economy-wide productivity parameter (TFP), which is meant to capture institutions, policies, and distortions affecting the entire economy.

The production unit in the agricultural sector is a farm. A farm is a technology that requires the inputs of a farm operator with managerial skills s and land and capital under the farmer's control. The farm technology is characterized by decreasing returns to scale. Our specification of the farming technology is guided by the farm-level observations outlined in Section 2. In particular, a farmer of type s produces agricultural output according to a CES production function,

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

where y_a is output of the farm, ℓ is the amount of land input, and k is the amount of capital.[16] There are three sources of productivity affecting the farming technology: (a) economy-wide productivity A which is common across sectors and all farms; (b) the sector-specific productivity term κ, that affects all units operating in the agricultural sector; and (c) the farmer's idiosyncratic productivity s. Our motivation for introducing farmer ability s as being land augmenting in a CES production function is to account for the observation that the capital to land ratios vary systematically with

[16]We abstract from hired labor in our analysis. The evidence suggests that hired labor as a share of agricultural labor does not vary systematically with the level of development across countries (see Chart 2.6 in Eastwood, Lipton, and Newell, 2007). Historical data for the United States reveals that the share of hired labor in total agricultural labor has remained remarkably stable at around 25% between 1910 and 1970, rising to about 35% since then (Historical Statistics of the U.S., Millennial Edition, Table Da612 -614). Further, while the inclusion of hired labor may be justified in other applications for which labor policies are important, the evidence suggests that land policies are at the core of farm-size differences across countries.

farm size.[17] The parameter $0 < \gamma < 1$ governs returns to scale at the farm level, often referred to as "span-of-control" parameter. The parameter $0 < \theta < 1$ captures the relative importance of capital to land in the farming technology and ρ determines the elasticity of substitution $1/(1-\rho)$.

Stand-in Household The representative household has preferences over the two goods according to the following per-period utility function

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

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 $i \in \{a, n\}$. Each household member is endowed with one unit of productive time that is supplied inelastically to the labor market. Whereas each household member is equally productive in the non-agricultural sector, household members are heterogeneous with respect to their productivity in the agricultural sector. The household decides what fraction of its members work in the non-agricultural sector. The rest of the household members become farmers in the agricultural sector, and draw their managerial ability from a known time-invariant distribution with cdf $F(s)$ and pdf $f(s)$, with support in $S = [\underline{s}, \overline{s}]$. Household members face a barrier to the mobility of labor between agriculture and non-agriculture. In particular, the return to working in agriculture is a fraction $(1-\xi)$ of that in non-agriculture. We introduce this barrier in order to account for the observation that average agricultural productivity is only half of non-agricultural labor productivity but has otherwise no relevance in our results.

Market Structure We assume that the stand-in household, firms in the non-agricultural sector, and farms in the agricultural sector behave competitively in factor and output markets. The

[17] If farmer ability was introduced as a factor-neutral productivity parameter in the CES, or if the farming technology was restricted to Cobb-Douglas, then all farmers would choose the same capital-land ratio (independent of farm size).

representative firm in non-agriculture takes the wage rate w and the rental price of capital r as given and chooses its demand for capital and labor services to maximize profits. The first order conditions to this maximization problem imply that the non-agricultural firm hires inputs until their marginal products equal their market prices,

$$w = (1-\alpha) A \left(\frac{K_n}{N_n}\right)^{\alpha}, \tag{1}$$

$$r = \alpha A \left(\frac{K_n}{N_n}\right)^{\alpha-1}. \tag{2}$$

These conditions imply that the capital-labor ratio in non-agriculture depends on relative factor prices and relative factor intensities,

$$\frac{K_n}{N_n} = \frac{\alpha w}{(1-\alpha) r}.$$

A farmer with managerial ability s maximizes profits taking the rental prices of land and capital (q, r) and the relative price of the agricultural good p_a as given,

$$\max_{\ell,k} \left\{ p_a A \kappa \left[\theta k^{\rho} + (1-\theta)(s\ell)^{\rho}\right]^{\frac{\gamma}{\rho}} - q\ell - rk \right\}. \tag{3}$$

The first order conditions of this problem are,

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

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

These conditions imply that the capital-land ratio chosen by a manager depends on the farmer ability s,

$$\frac{k}{\ell} = \left[\frac{\theta}{1-\theta} \frac{q}{r}\right]^{\frac{1}{1-\rho}} s^{-\frac{\rho}{1-\rho}}.$$

In order to generate the pattern that the capital-land ratio falls with farm size in the U.S. data, the theory would need $0 < \rho < 1$, which implies more substitutability between capital and land than Cobb-Douglas. Manipulation of the first order conditions implies that a farm operator with own productivity s, faced with sector-neutral and sectoral productivities (A, κ) and prices (q, r, p_a), chooses farm size (demand for land),

$$\ell(s) = \left[\gamma (1-\theta) A\kappa \frac{p_a}{q}\right]^{\frac{1}{1-\gamma}} \left[\theta \left(\frac{\theta}{1-\theta}\frac{q}{r}\right)^{\frac{\rho}{1-\rho}} + (1-\theta)\, s^{\frac{\rho}{1-\rho}}\right]^{\frac{\gamma-\rho}{\rho(1-\gamma)}} s^{\frac{\rho}{1-\rho}}, \tag{4}$$

and chooses demand for capital,

$$k(s) = \left[\frac{\theta}{1-\theta}\frac{q}{r}\right]^{\frac{1}{1-\rho}} \left[\gamma (1-\theta) A\kappa \frac{p_a}{q}\right]^{\frac{1}{1-\gamma}} \left[\theta \left(\frac{\theta}{1-\theta}\frac{q}{r}\right)^{\frac{\rho}{1-\rho}} + (1-\theta)\, s^{\frac{\rho}{1-\rho}}\right]^{\frac{\gamma-\rho}{\rho(1-\gamma)}}. \tag{5}$$

This operator's farm produces output,

$$y_a(s) = (A\kappa)^{\frac{1}{1-\gamma}} \left[\gamma (1-\theta) \frac{p_a}{q}\right]^{\frac{\gamma}{1-\gamma}} \left[\theta \left(\frac{\theta}{1-\theta}\frac{q}{r}\right)^{\frac{\rho}{1-\rho}} + (1-\theta)\, s^{\frac{\rho}{1-\rho}}\right]^{\frac{\gamma(1-\rho)}{\rho(1-\gamma)}},$$

and makes profits,

$$\pi(s) = (1-\gamma)\, p_a y_a(s).$$

The optimal scale of operation of a farm is determined by the managerial ability of the farmer. The above optimality conditions imply that, other things equal, more able (higher s) farmers operate larger farms, demand more capital, produce more output, and have higher profits, as long as, $0 < \rho < \gamma < 1$. These parameter restrictions are satisfied in the U.S. data in the calibration of the model. Then, for a given distribution of managerial abilities the model implies a distribution of farm sizes.

The household maximizes utility subject to the budget constraint. Letting the non-agricultural good be the numeraire, the budget constraint faced by the stand in household is,

$$p_a \cdot c_a + c_n = I,$$

where p_a is the relative price of agricultural goods and I is household income given by,

$$I \equiv (1 - N_a) w \, (1 - \xi) + N_a \int_S \pi\,(s)\, dF(s) + qL + rK.$$

The household faces three allocation decisions: (1) income allocation across the two consumption goods, (2) employment allocation across sectors, and (3) capital allocation across sectors.

The above preferences imply that the income elasticity with respect to food is less than one and thus, at low levels of income, a disproportionate amount of income is allocated to food consumption. The first order conditions to the household's problem with respect to consumption imply the following consumption allocations,

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

$$c_a = \overline{a} + \frac{\phi}{p_a} \cdot (I - \overline{a} p_a)\,.$$

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

$$w(1 - \xi) = \int_S \pi\,(s)\, dF(s). \tag{6}$$

Capital is allocated across sectors until the marginal return to capital is equated across sectors.

Market Clearing The market clearing condition for labor is standard,

$$N_a + N_n = 1.$$

The market clearing condition for land requires that the total supply of land equals the total demand for land by all farmers of different sizes in the agricultural sector,

$$L = N_a \int_S \ell(s) dF(s). \tag{7}$$

The market clearing condition for capital requires that capital demands by agriculture and non-agriculture exhaust the capital endowment,

$$K_a + K_n = K, \tag{8}$$

where agricultural capital is the sum of capital hired across all farmers of different sizes, $K_a = N_a \int_S k(s) dF(s)$. Finally, the market clearing conditions for the agricultural and nonagricultural goods respectively are,

$$c_a = N_a \int_S y_a(s) dF(s), \tag{9}$$

$$c_n = Y_n.$$

Definition of Equilibrium A *competitive equilibrium* is a set of allocations for households, firms and farmers $\{c_a, c_n, N_a, K_a, N_n, K_n, Y_n, [\ell(s), k(s), y_a(s)]_S\}$ and prices $\{p_a, q, r, w\}$ such that: (i) given prices, households make their choices maximizing utility, (ii) given prices firms and farmers choose their allocations to maximize profits, and (iii) all markets clear.

The equilibrium equations of the model can be easily manipulated to reduce the solution of the model to a system of three equations in three unknowns (N_a, K_n, q). We use this system to solve the model numerically as a function of the exogenous variables.

4 Calibration

We calibrate a benchmark economy to U.S. data. The parameters to be calibrated are: preference parameters $\{\overline{a}, \phi\}$, technological parameters $\{A, \kappa, \alpha, \theta, \gamma, \rho, \{s\}\}$, distributional parameters, barriers to labor mobility ξ, and endowments $\{K, L\}$. While some of the model's parameters are shared with standard sectoral models, those pertaining to the farming technology and the distribution of farmer ability are new. Our calibration strategy involves choosing some parameters based on a-priori information and finding the rest as part of the solution of the model to match aggregate and farm-level targets in the benchmark economy.

We choose the distribution of farm-level productivity (farmer ability) to match the distribution of farm sizes in hectares for the U.S. economy from the 2007 U.S Census of Agriculture. Given that the distribution of farm sizes resembles a log-normal distribution, we assume a log-normal distribution for the distribution of farm-level productivity with mean μ and variance σ^2. We approximate the set of farmer productivities with a log-spaced grid of 6000 points in $[\underline{s}, \overline{s}]$, with $\underline{s}$ arbitrarily close to 0 and $\overline{s}$ equal to 100 which ensures farms of over 2,000 hectares. Our calibration involves a loop for the parameters of the productivity distribution: given values for (μ, σ), we construct a discrete approximation to a log-normal distribution of ability and solve the model matching the rest of the targets. The model then yields a distribution of farm sizes. We choose (μ, σ) to minimize the distance between the size distribution of farms in the model relative to the data. We normalize economy-wide productivity A and sector-specific agricultural productivity κ to 1 for the benchmark economy. We set the elasticity parameter in the non-agricultural technology $\alpha = 0.33$ to match the non-agricultural capital income share and $\gamma = 0.54$ to match the agricultural capital (including land) income share both at producer prices as reported in Table 1 of Herrendorf and Valentinyi (2008). Assuming a long-run share of employment in agriculture of 1% we set $\phi = 0.010$.

We choose parameters $(\overline{a}, \rho, \theta)$ to match three data targets: (1) a share of employment in agriculture of 2.5%, (2) an agricultural land income share of 18% (see Table 2 in Herrendorf and Valentinyi, 2008), and (3) a disparity in the capital to land ratio between the minimum and maximum farm sizes of 84.8.[18] Note that this target is informative for the elasticity of substitution between capital and land in the farming technology since in the model the capital to land ratio between any two farm sizes i and j is,

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

This approach results in values of $\overline{a} = 0.035$, $\rho = 0.24$, and $\theta = 0.89$. The implied elasticity of substitution between capital and land is 1.32 which is very close to Binswanger's (1974) estimate of 1.22 using U.S. state-level data.

Finally, we select the aggregate endowments of capital (K) and land (L). Given A and α we choose the aggregate capital stock K to match a capital-output ratio for the U.S. economy of 2.5.[19] We choose the aggregate agricultural land to match an average farm size of 169.3 hectares for the U.S. economy consistent with the 2007 U.S Census of Agriculture.[20] The barrier parameter ξ is chosen to reproduce the observation that average agricultural labor productivity in the U.S. is 1/2 of the non-agricultural labor productivity. The arbitrage condition between becoming a farmer or a worker (in non-agriculture) implies,

$$(1-\xi)(1-\alpha)\frac{Y_n}{N_n} = (1-\gamma)p_a\frac{Y_a}{N_a}.$$

[18] One concern could be that the disparity in the aggregate capital-land ratio between large and small farms may reflect a compositional bias. This bias could be dual: (a) that large farms may be producing different agricultural goods (e.g., ranching) than the small farms; (b) that the set of goods in US agriculture may not be reflective of the set of goods produced in poor countries. To see how sensitive the aggregate capital-land ratio disparity across farms is to these issues, we calculate the capital-land ratio for the agricultural goods (NAICS categories in the U.S. Census of Agriculture) which tend to be produced by both rich and poor countries: grains, vegetables, fruit, nuts, sheep, goats, pigs, eggs and poultry. The average disparity between the minimum and maximum scale of operation over these categories is 83.6, which suggests that the aggregate number is not biased by the other forms of agriculture. The same is true for the average disparity between other size categories. Note, that these numbers exclude ranching, feedlots, tobacco, cotton, sugarcane etc. which may be conducive to more large-scale production and may not be produced by most poor nations.

[19] Note that output per worker in non-agriculture can be written as $\frac{Y}{N} = A^{\frac{1}{1-\alpha}}\left(\frac{K}{Y}\right)^{\frac{\alpha}{1-\alpha}}$.

[20] In our model average farm size is L/N_a. Thus given $N_a = 0.025$, we choose $L = 4.2$ to match the target.

Using the values for α and γ along with the target for $\frac{p_a Y_a / N_a}{Y_n / N_n}$ this equation implies a value for ξ of 0.66. The model parameters along with their targets and calibrated values are provided in Table 3.

Table 3: Parameterization

Parameter	Value	Target
Technological Parameters		
A	1	Normalization
κ	1	Normalization
α	0.33	Non-agricultural capital income share
γ	0.54	Agricultural capital income share
θ	0.89	Agricultural land income share
ρ	0.24	Capital-land ratio between min-max sizes
Preference Parameters		
$\overline{a}$	0.035	Current employment share in agriculture
ϕ	0.010	Long-run employment share in agriculture
Parameters of Ability Distribution		
μ	-1.83	Size distribution
σ	4.66	Size distribution
Endowments		
K	3.9	Aggregate capital-output ratio
L	4.2	Average farm size
Sectoral Barrier		
ξ	0.66	Agricultural/Non-agricultural Productivity

The calibrated model matches quite well several pertinent features of the U.S. agricultural sector. By choice of parameters of the distribution of ability, the model closely matches the size distribution of farms in the data (see Figure 7). While not a calibration target, the model matches well the distribution of land across sizes by reproducing for example the observation that about 80% of the land is in farms over 200 Ha in size (see Figure 8). The model accounts well for the capital to land ratios across farm sizes (see Figure 9) even though the calibration only targets the disparity between the largest and smallest size categories. The model also accounts for the well-known negative relationship between value added per hectare and size (see Figure 10). Finally, the model is also consistent with the positive relationship between farm size and labor productivity (value added per worker) observed in the data (see Figure 11).

5 Quantitative Analysis

We use the calibrated model as a framework for understanding cross-country differences in the size and land distribution of farms, the share of employment in agriculture, and agricultural and aggregate labor productivity. We focus on the differences between the richest and poorest countries.[21]

5.1 Aggregate Factors

We examine the effects of aggregate factors land L, capital K, and economy-wide productivity A as potential sources of low average size and productivity in agriculture. We first examine the effect of land differences since low land endowments are often cited as a source of small farm size in developing countries. We then examine the effect imparted by differences in all aggregate factors. The results of these experiments are reported in Table 4 along with statistics for the benchmark economy.[22]

We measure land endowments as arable land per capita in the data consistently with our model.[23] While richer countries have higher arable land per capita than poorer countries, this disparity is only 1.3-fold.[24] Not surprisingly then the model implies small disparities in the variables of interest across rich and poor economies. The share of employment in agriculture is roughly the same (2.6% rather than 2.5% in the benchmark economy). Given that in the model average farm size is L/N_a

[21] Appendix A reports the countries in the richest and poorest groups in our sample and the disparities between these groups in the statistics of interest.

[22] We calculate real GDP measures across countries in the model using a common set of prices. In our calculations we use the relative price of agriculture from the benchmark economy.

[23] While we use the term "per capita," in mapping consistently the model to the data, we divide total arable land by the total number of workers in the economy rather than total population.

[24] We feed in the rich-poor disparity in land per capita to the benchmark economy. Given that land per capita differs not only between the US and poor countries (2.96-fold), but also between the US and rich countries (2.20-fold), we repeat the experiment for each pair in turn, and then calculate the implied rich-poor ratio for each variable of interest. The results from this alternative approach are very similar to our approach of feeding in the rich-poor disparity in land directly.

Table 4: Effects of Aggregate Factors

	Benchmark Economy	+ Land $L_{BE}/1.3$	+ (TFP, Capital) $(A_{BE}/2.5, (K/Y)_{BE}/2.9)$
Size Distribution (%):			
Farms < 5 Ha	13.3	16.3	58.1
Farms > 20 Ha	61.4	56.6	20.5
Share of Land (%)			
Farms < 5 Ha	0.2	0.3	4.7
Farms > 20 Ha	99.1	97.3	84.1
N_a (%)	2.5	2.6	16.6
Ratio B.E./Poor:			
Relative AFS	-	1.3	8.6
Relative $\frac{Y_a}{N_a}$	-	1	11.2
Relative $\frac{Y}{N}$	-	1	7.6

and N_a is close between the two economies, average farm size differs essentially by the disparity of the land endowment. Relative agricultural, non-agricultural, and aggregate productivities are virtually the same. We conclude that while differences in land endowments can potentially account for differences in size between rich and poor countries, this effect is quantitatively small, less than 4% of the observed differences in average size.

Next we ask whether differences in economy-wide productivity A and capital endowments K in addition to land endowment differences can account for the disparities between rich and poor countries. In this experiment we vary economy-wide productivity A and capital K for the poor economy such that the model matches a 6.8-fold disparity in non-agricultural productivity Y_n/N_n and a 2.9-fold disparity in the capital-output ratio K/Y as observed in the data between rich and poor countries. The model implies a share of employment in agriculture of 16.6% versus 2.5% in the benchmark economy. The poor economy experiences an 8.6-fold drop in average farm size and an 11.2-fold decline in agricultural labor productivity. Hence, the model can account for about 1/4 of the differences in farm size and agricultural productivity observed in the data between rich and poor countries. This experiment also generates a 7.6-fold disparity in aggregate labor productivity.

Turning to the distributions of farms and land, we note that although the aggregate factors can yield a large share of farms under 5 Ha (58.1% in the model versus 93.6% in the data), they fail in generating a sizeable share of land in farms under 5 Ha (4.7% in the model compared to 68.1% in the data). Overall, aggregate factors alone cannot account for the bulk of the differences in agriculture between rich and poor countries. Other factors that are specific to the agricultural sector must be affecting not only farm size but also agricultural productivity.

We emphasize that the model with aggregate factors explains the bulk of differences in size and productivity among developed countries, even for developed countries with higher and lower average farm size than in the United States such as Canada and Netherlands. Table 5 shows the results of the model with aggregate factors differences for Canada and Netherlands.[25] The model generates closely the agricultural employment shares, the differences in agricultural labor productivity, and hence the differences in aggregate labor productivity. Aggregate factors taken together account for most of the farm size and productivity differences for developed economies.

Table 5: Effects of Aggregate Factors in Rich Countries

	Netherlands		Canada	
	Model	Data	Model	Data
N_a (%)	3.28	3.32	2.74	3.12
AFS (i/BE)	1/15.2	1/11	2.0	1.3
Relative $\frac{Y_a}{N_a}$ (i/BE)	1/1.56	1/1.16	1/1.17	1/1.41
Relative $\frac{Y}{N}$ (i/BE)	1/1.19	1/1.18	1.20	1.31

We conclude that while aggregate factors account for most of the differences in size and productivity among rich countries, they only account for 1/4 of the differences between rich and poor countries. What accounts for the rest of the differences? We consider two potential broad explanations: (a) differences in the distribution of farmer productivity between rich and poor countries, and (b)

[25] We measure differences in A, K/Y, and L between the U.S. and the Netherlands of 1.18, 0.91, and 11.6. The corresponding differences for the U.S. relative to Canada are 1.3, 0.76, 0.46.

farm-level policies in poor countries that misallocate resources across farms of different sizes. We conduct two extreme experiments where in each case we attribute the entire remaining differences in average farm size and the farm-size distribution to differences in farmer productivity and farm-size distortions. Then we ask whether there is evidence supporting the implied differences in farmer productivity and farm-size distortions across rich and poor countries.

5.2 Farmer Productivity Distribution

While the distribution of (raw) innate ability at farming is unlikely to differ between rich and poor countries, in the context of our model "ability" can be interpreted broadly as farm-level productivity. Under this broad interpretation, differences in the distribution of farmer's ability between rich and poor countries can reflect differences in human capital and land quality. These features may be observed as differences in the mean and/or dispersion of productivity in poor relative to rich countries. For instance, a lower mean in the distribution of farmer's productivity can result if farmers in poor countries have lower human capital relative to non-agriculture than in rich countries or if the entire mass of a country is in the tropics-subtropics entailing a productivity difference. Differences in the dispersion of farmer's productivity can result from differences in human capital across farmers of different sizes that are smaller or larger in magnitude than those in rich countries and from more pronounced differences across farm sizes in climate and soil quality within a poor country as compared to a rich country.

We perform an experiment where we ask what distribution of farmer productivity can reproduce the farm structure of poor countries given aggregate factors. From the benchmark economy that differs in aggregate factors for poor countries, we select the shape parameters in the farmer ability distribution (μ, σ) to match two targets in the data: (a) average farm size and (b) the size distribution of farms. We find that these parameters can successfully reproduce the size distribution of farms but not average farm size. The best fit of the model implies $\mu = -12.6$ and $\sigma = 0.0048$ and generates a disparity in average farm size of 16.5 (roughly only half of the 34-fold rich-poor disparity in the data). The inability of this experiment to generate a low average farm size is related to its failure in generating a large share of employment in agriculture. The share of employment in agriculture in this experiment is $N_a = 32\%$, roughly half of the 65% in the data for poor countries. Intuitively, the mean and dispersion in farmer's productivity does not generate enough differences in average productivity in agriculture. As a result, it cannot reproduce the large share of employment in agriculture and average farm size. We carry out a slightly modified experiment where we select (μ, σ) as well as the agriculture-specific parameter κ to match average farm size and the size distribution of farms. Unlike the previous experiment, this experiment is able to reproduce the observations targeted. However, it is subject to the qualification that it requires variation in the agriculture specific productivity parameter, which is precisely what this research and the related literature aim to explain. Considering exogenous differences in agricultural productivity can be done in a model without heterogeneity as in the broad agricultural development literature. As we explain in Section 5.3, measurable factors cannot justify large differences in the sector-specific productivity parameter.

Nevertheless, for completeness we carry out the experiment where we select the agriculture-specific productivity parameter κ and the shape parameters of the ability distribution (μ, σ) to match average farm size and the size distribution of farms in poor countries. This procedure yields $\kappa = 1/2.1$, $\mu = -8.4$, and $\sigma = 2.4$. These results imply that if farm size in poor countries was accounted for entirely by a difference in the distribution of farm-level productivity compared to rich countries, then it must have considerably lower mean (captured by κ and μ) and lower variability (captured by σ). The results of the experiment are presented in Table 6 along with data. Comparing the second and third columns, it is evident that the model reproduces sectoral employment in poor countries as well as the gaps in agricultural and aggregate labor productivity between rich and poor countries. The model misses the land distribution, accounting for just over 1/3 of the share of land in farms under 5 Ha.

Table 6: Effects of Differences in Farmer Productivity Distribution

	Aggregate Factors	+Farmer Productivity Distribution	Data
Size Distribution (%):			
Farms $<$ 5 Ha	58.1	93.8	93.6
Farms $>$ 20 Ha	20.5	1.5	0.2
Share of Land (%)			
Farms $<$ 5 Ha	4.7	25.6	68.1
Farms $>$ 20 Ha	84.1	66.6	3.4
N_a (%)	16.6	65.1	65.0
Ratio B.E./Poor:			
Relative AFS	8.6	34	34
Relative $\frac{Y_a}{N_a}$	11.2	46.3	46.7
Relative $\frac{Y}{N}$	7.6	16.9	19.2

5.3 Farm-Size Distortions

An alternative explanation to the low agricultural productivity in poor countries is the presence of farm-size distortions that create misallocation of resources from large productive farms to small less productive farms. Following the approach in Restuccia and Rogerson (2008), we model farm-size distortions as generic output taxes on individual farmers ($\tau_y \geq 0$). Taxes are meant to englobe the variety of policies and institutions affecting farm size. The government balances the budget by rebating tax receipts lump-sum to the stand-in household. Idiosyncratic output taxes introduce variation in the prices faced by individual farmers leading to a reallocation of aggregate resources across productive units.

To study quantitatively the effects of misallocation we consider an economy that differs relative to the benchmark in aggregate factors as described in Section 5.1. Then we choose an output tax vector to account for: (a) average farm size and (b) the size distribution of farms in poor countries. The required tax vector involves no tax on the low 1% of the ability distribution of farmers and progressively higher tax rates that rise with farmer ability, culminating in a 100% tax on the 5%

Table 7: Effects of Farm-Size Distortions

	Aggregate Factors	+Farm-Size Distortions	Data
Size Distribution (%):			
Farms $<$ 5 Ha	58.1	93.6	93.6
Farms $>$ 20 Ha	20.5	5.0	0.2
Share of Land (%)			
Farms $<$ 5 Ha	4.7	39.1	68.1
Farms $>$ 20 Ha	84.1	59.5	3.4
N_a (%)	16.6	65.2	65.0
Ratio B.E./Poor:			
Relative AFS	8.6	34	34
Relative $\frac{Y_a}{N_a}$	11.2	46.5	46.7
Relative $\frac{Y}{N}$	7.6	17.0	19.2

most able farmers.[26] We note that this tax vector is not unique. There are several other tax configurations that achieve the same average farm size and farm-size distribution. While the point of the exercise is to show that we can find *a* tax vector that accounts for farm size and generates misallocation, we have found that all of these have very similar implications for agricultural and aggregate productivity. We present results for the tax vector that, in addition, produces more closely the share of land in farms under 5 Ha in poor countries.

The results of this experiment are in Table 7. Farm-size distortions, while chosen to match the farm structure in poor countries, entirely match other pertinent features of poor countries, in particular employment shares and agricultural and aggregate labor productivities (compare columns 2 and 3 in Table 7). The share of land in farms under 5 Ha, while much higher than in the farmer ability experiment is not as pronounced as in the data (39.1% in the model vs. 68.1% in the data). Accounting for the land share in small farms is more challenging because of the induced general equilibrium effects that the tax policy causes. Since the policy curtails production of high productivity farms it raises the relative price of agriculture to land thus inducing the low-tax low-

[26]The exact tax schedule is available in separate Appendix E – Figure E.1.

ability farmers to grow in size.

5.4 Discussion

The experiments on farmer productivity and farm-size distortions reach a common conclusion. By accounting for farm size, the model reconciles the entire differences in sectoral employment and agricultural and aggregate labor productivities between rich and poor countries. However, the two explanations have very different policy implications. Under the farmer productivity explanation, differences in size are simply due to differences in the distribution of farm-level productivity and agriculture-specific productivity. The observed farm size distribution is efficient conditional on the ability distribution, agricultural specific productivity, and aggregate factors. The policy implication is that the farm-size distribution does not need "fixing", instead policy should deal with the features explaining the gap in farm-level productivity and aggregate factors relative to the rich countries. Under the farm-size-distortions explanation, the observed distribution of farm sizes is to a large extent –save for the part accounted for by the aggregate factors– inefficient. It reflects misallocation across farmers due to farm-level policies that discriminate on the basis of size. The policy implication is to remove farm-level distortions as they constitute barriers to higher agricultural and consequently aggregate productivity. Which of the two explanations is more likely to account for the gap in farm size between rich and poor countries? We examine the available evidence for each case.

5.4.1 Evidence on Farmer and Agricultural Productivity

The results from the farmer productivity experiment imply that the mean and the dispersion of the distribution of farm-level productivity are lower in poor than in rich countries. Is there evidence to corroborate these implications? We look at differences in human capital and geography (land quality) as the leading factors explaining farmer productivity differences across countries. We argue that observed differences in human capital and geography cannot generate the required differences in farm-level productivity across rich and poor countries.

Human Capital Differences A well-known observation is that at the aggregate level poor countries have lower human capital than rich countries. However, poor countries have lower human capital not only in agriculture but also in non-agriculture. Thus, low aggregate human capital is already captured in the model by the parameter A which is common across sectors. Key for our purposes is whether the disparity in human capital between agriculture and non-agriculture is larger in poor relative to rich countries. The data indicate that there are differences in human capital between agriculture and non-agriculture in poor countries but these differences do not seem to be systematically different between rich and poor countries. For example, Herrendorf and Schoellman (2011) calculate an average 1.8-fold disparity in human capital between non-agriculture and agriculture in the United States and Gollin, Lagakos and Waugh (2011) find that the average disparity for poor countries is 1.4. Hence, this evidence suggests that productivity differences due to human capital across sectors and countries, if anything, move in the opposite direction from what is required to account for farm size differences. The fact that observable differences in human capital cannot account for differences in labor productivity in agriculture across countries is also echoed in the development accounting literature (Caselli, 2005; Chanda and Dalgaard, 2008; and Vollrath, 2009). While we do not have evidence on the dispersion of human capital across farms and countries, there is some related evidence from Gini coefficients on education calculated by the World Bank. An education Gini measures inequality in years of schooling within a country and is meant to proxy for dispersion in human capital within a country. The EdStats database of the World Bank reports the Gini coefficient of average years of schooling for ages 15+, which is calculated based on demographic and health surveys for developing countries. The average Gini for all the poor countries in our sample (Q5) is 0.55 ranging from 0.34 in Vietnam to 0.88 in Burkina Faso. A breakdown by rural vs. urban areas in these countries indicates that inequality in education is much more pronounced in rural areas than in urban areas (average Gini is 0.59 vs. 0.39). While the same source does not report Gini coefficients for the rich countries in our sample, these are considerably lower. For example, according to Thomas, Wang, and Fan (2002) the Gini coefficient in the U.S. and Canada for ages 15+ is 0.13, while in France it is 0.33. This evidence points to more dispersion in human capital in rural areas in poor countries, not less as the model requires to account for the farm size distribution in poor countries.

Geography Differences Are differences in geography such as climate and soil quality important? In our quantitative application of the model, we use arable land which is an homogeneous measure of farm land. According to the FAO definition, arable land includes "land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years)." This measure of land is devoid of major constraints that would make it unsuitable for crop farming. As discussed earlier, arable land per capita in rich countries is only 1.3 times that of poor countries. We can use data from the *Global Agro-Ecological Zones - 2000* program of the FAO which classifies a country's land area according to climate and soil characteristics. Using this data we calculate for the rich (Q5) and poor (Q1) countries in our data set land "without soil, terrain or climate constraints" per capita. The disparity in this measure between rich and poor countries is merely 1.1, suggesting that it is unlikely that geography related concerns can account for the large differences in farm-productivity required to generate the farm-size distribution in poor countries. We do not have direct evidence on soil quality and climate differences across farm sizes in the United States and across countries. There is however some indirect evidence suggesting that this is unlikely to be the main factor driving differences in the dispersion of farm-level productivity. Using again data from *Global Agro-Ecological Zones - 2000* we calculate for the rich and poor countries in our data set the share of land that is subject to severe climate constraints. We find this to be on average identical in rich and poor countries (3%). From the TERRASTAT database of the FAO we find that the average share of soil without major constraints is virtually identical (27.6% in poor countries and 27.4% in rich countries). The evidence suggests that there are no major differences in the mean and variability of geographic characteristics across rich and poor countries in our sample.

5.4.2 Evidence on Farm-Size Distortions

Is there evidence on farm-size distortions? We find that the agricultural sector in developing countries is exposed to a variety of policies and institutions that distort size at the farm level. In some cases distortions in farm size may not be intentional, such as in the cases of inheritance norms favoring fragmentation (e.g. India), or high transport costs that force local small-scale farm production.[27] Most often however farm-size distortions are the result of deliberate policy measures. Furthermore, in recent times these policies typically exhibit a systematic pattern whereby larger farms are disadvantaged in favor of small farms, thus encouraging "smallness."[28] In Table D.1 in separate Appendix D we provide a documentation of farm-size policies for several countries in Africa, Asia and the Americas.

Many countries have set direct restrictions on farm size. In most cases these restrictions were ceilings on the size of permitted land holdings and were imposed as part of post-war-period land reforms that redistributed land in excess of the ceiling (e.g., Bangladesh, Chile, Ethiopia, India, Korea, Pakistan, Peru, Philippines). In many cases the ceiling on land holdings were accompanied by prohibitions on selling and/or renting of the redistributed land. Other countries have distorted size by also imposing minimum size requirements. This is done either directly by setting an explicit lower bound, as in the case of Indonesia and Puerto Rico or indirectly by setting conditions for subdivisions, such as a "viability assessment" in the case of Zimbabwe. Several countries have imposed progressive land taxes where larger farms are taxed at a higher rate than smaller farms (e.g., Brazil, Namibia, Pakistan, Zimbabwe). Several African countries have offered input subsidies

[27] See for instance Adamopoulos (2011) for a study on the role played by transportation frictions in misallocating resources across sectors.

[28] Historically there have been land market interventions in several countries to establish and support large farms. For a documentation of such interventions see Ch.2 in Deininger (2003). In our framework policies favoring small or large farms are both distortionary.

for fertilizer and seed that either directly targeted smallholders or disproportionately benefited them (e.g., Kenya, Malawi, Tanzania, Zambia). In other cases smallholders were provided with subsidized credit (e.g., Kenya, Philippines) or grants to purchase land (e.g., Malawi). Tenancy regulations, such as rent ceilings, tenure security, preferential right of purchase (e.g., India), can also provide smallholders with an advantage.

In summary, we think the documented evidence is quite compelling that farm-size distortions and the associated misallocation may be behind small farm size and low agricultural productivity in poor countries.

6 Specific Farm-Size Policies

Given the prevalence of farm-size distortions in developing countries we ask, what are the quantitative effects of specific farm-size policies? While the list of potential policy distortions that affect size is very large, the quantitative impact of each individual policy is difficult to measure. We study two specific policies, land reforms and progressive land taxes, that are easier to measure and isolate their contribution to observed outcomes in particular developing countries. In contrast to the broad cross-country experiments in Section 5.3, we focus on the institutional detail of the policy change in each country and examine the size and productivity effects in the period following the implementation of the policy.

6.1 Land Reforms

We first examine the quantitative effects of land reforms, the most prevalent policy in developing countries distorting farm size. Land reform generically refers to the redistribution of land from large landowners to tenants, smallholders or landless. Such redistribution is implemented through legislation that often involves direct restrictions on size and intervention in the sales and rental markets for land. Understanding the effects of land reforms is important because these policies have been carried out in many developing countries in the post-war period. Further, it is important to understand the productivity effects of land reforms given that there is a large literature in development economics arguing in favor of such programs on efficiency grounds.[29] Discussions regarding the effect of land redistribution on productivity have been dominated by the ample empirical evidence documenting an inverse relationship between farm size and land productivity. If smaller farms are more productive then redistributing land from large to small farms should increase efficiency in agriculture.[30] However, finding positive productivity effects of land reforms has proven more challenging empirically.[31]

We study the most common type of land reform undertaken in practice which is an explicit limit (ceiling) on the maximum size of any agricultural holding. In Table 8 we have compiled a selected list of countries with available data that have implemented legislation capping farm size since the 1950s. We report the explicit ceiling imposed, the year it was legislated, as well as the average farm size before and after the reform. It is noteworthy that in all the countries we report, average farm size dropped after the imposition of the ceiling. The magnitude of the drop in average farm size should be put in perspective since the tendency is for average farm size to increase over time. However, the ceiling was more restrictive (binding) in some countries than others. We measure the restrictiveness of the ceiling by the ratio of the legislated ceiling to the pre-reform average farm size. This ratio varies from 1.75 in the Philippines to 9 and 14 in Bangladesh and Sri Lanka.

We use the model to study the consequences of a land-reform policy that caps farm size. We introduce the ceiling legislation into the model by imposing a constraint on the maximum size of land

[29] See for example Berry and Cline (1979) and Binswanger, Deininger, and Feder (1995).
[30] See Banerjee (1999) for a review and critical discussion of the land-reform literature.
[31] See for example Besley and Burgess (2000) and Ghatak and Roy (2007) for the case of India.

Table 8: Land Reforms with Explicit Ceilings

Country	Year	AFS	Change in AFS (%)	Land Reform Period	Ceiling on Land Size (Ha)
Bangladesh	1983	0.91			
	1996	0.46	-49.1	1984	8
Ethiopia	1977	1.43			
	1989	0.80	-44.1	1975	10
India	1960	2.70			various by province
	1977	2.00	-25.8	by early 1970s	4-53
Korea	1945	1.11			
	1960	0.87	-21.5	1950	3
Pakistan	1971	5.29			
	1980	4.68	-11.5	1972, 1977	61, 40
Sri Lanka	1962	1.09			
	1982	0.80	-26.2	1972	10-20
Philippines	1981	2.85			
	2002	2.01	-29.6	1988	5

input. In particular, the policy caps land holdings at ℓ_{max}. Then each farmer faces the constraint $\ell \leq \ell_{max}$ when choosing land demand. The farmer now maximizes profits in (3) subject to the size constraint. In equilibrium, profit maximization implies two categories of farmers: unconstrained farmers –those with relatively low ability that would optimally have chosen $\ell(s) \leq \ell_{max}$, and constrained farmers –those with relatively high ability that would have chosen $\ell(s) > \ell_{max}$ in the absence of the size constraint. Let s_{max} be the cut-off level of farmer ability that satisfies the farmer first order condition with respect to ℓ when $\ell = \ell_{max}$,

$$\ell_{max} = \left[\frac{p_a \gamma (1-\theta) A\kappa}{q}\right]^{\frac{1}{1-\gamma}} \left[\theta \left(\frac{\theta}{1-\theta}\frac{q}{r}\right)^{\frac{\rho}{1-\rho}} + (1-\theta)\, s_{max}^{\frac{\rho}{1-\rho}}\right]^{\frac{\gamma-\rho}{\rho(1-\gamma)}} s_{max}^{\frac{\rho}{1-\rho}}.$$

Thus, farmers with $s < s_{max}$ choose $\{l(s), k(s)\}$, given by (4)-(5). Farmers with $s \geq s_{max}$ choose $l(s) = \ell_{max}$, with their optimal k given implicitly by,

$$r = \gamma\theta p_a A\kappa \left[\theta k^{\rho} + (1-\theta)(s\ell_{max})^{\rho}\right]^{\frac{\gamma-\rho}{\rho}} k^{\rho-1}.$$

The market clearing condition for land is,

$$L/N_a = \int_{\underline{s}}^{s_{max}} \ell(s)dF(s) + [1 - F(s_{max})]\, \ell_{max}.$$

Intuitively, the size constraint reduces total demand given prices, leading to a reduction in the price of land to clear the land market and in turn an increase in the demand of land by unconstrained farmers. Thus, the land reform policy leads to a reallocation of resources from high to low productivity farms.

To assess the quantitative effects of the land ceiling policy, we study in more detail the 1988 land reform in the Philippines, known as the Comprehensive Agrarian Reform Program (CARP) or Republic Act 6657. CARP constitutes an interesting case study because it represents a land reform with: (a) a relatively restrictive ceiling, a 1.75 ratio of ceiling to pre-reform average farm size, (b) an extensive coverage, targeting for redistribution all 10.3 million Ha of the country's farmland to 4 million potential household beneficiaries (corresponding to about 80% of the agricultural population) comprising cultivators and landless (Borras, 2003), and (c) a fairly successful redistribution of land since according to a 2005 inventory balance, 81.2% of the total revised targeted land (of 8.1 million Ha) had been distributed (Philippine Department of Agrarian Reform, 2006). The redistribution covered all agricultural lands (private and public) in contrast to the earlier reform of 1972 (Presidential Decree 27), which covered only rice and corn farms. Further, CARP imposed the more restrictive land ownership ceiling of 5 Ha (relative to the 1972 reform which set the ceiling at 7 Ha).[32] The land acquisition took the form of both compulsory acquisition and voluntary-offer-to-sell modes at fair market value. The transferability of the redistributed lands was limited to heirs, the state, and other beneficiaries after 10 years (Saulo-Adriano, 1991). In 1981, the earliest decennial Census of Agriculture prior to the 1988 reform, average farm size was 2.85 Ha. Based on the 2002 Census of Agriculture (by this time most of the redistribution had taken place) the post-reform

[32]In fact the retention limit for landowners was 5 Ha, but the award limit to the beneficiaries was 3 Ha, implying that the ceiling was more restrictive than that implied by the 5 Ha limit alone.

average farm size was 2.01 Ha, implying a drop of 29.6%.

To implement the land reform in our model we consider an economy that is endowed with the aggregate factors (land per capita, capital-output ratio, economy-wide productivity) of the Philippines at the time of the reform, 1988. To replicate the sectoral structure of the Philippines in 1988, without assuming any other farm-size distortions, we also choose the agriculture-specific productivity parameter κ to reproduce a pre-reform share of employment in agriculture of 45.1%.[33] This calibration yields a disparity in aggregate output per worker between the benchmark economy and 1988 Philippines of 7.2, which is close to the 6.9 disparity between 1990 U.S. and 1988 Philippines observed in the data. The implied pre-reform average farm size of this economy is 2.80 Ha, which is close to the 2.85 Ha observed in the Philippines before the reform.

Next, we examine the effect of imposing a land ceiling with a restrictiveness ratio of 1.75 on the economy resembling the Philippines in 1988. We compare the model results to the actual changes in the key variables of interest that were observed in the Philippines after the reform, 1988-2000. Note, that in the data over this period there were other changes taking place alongside the land reform that impact farm size, agricultural and aggregate productivity: a drop in land per capita, capital accumulation, and economy-wide productivity growth. To put the effects of the land reform in perspective, when comparing model to data we also take into account the observed changes in the aggregate factors. In order to decompose the overall effect on farm size and productivity arising from each factor we proceed as follows. First, we examine what would be the effects if the land reform, with a restrictiveness ratio of 1.75, was the only factor occurring in 1988 Philippines. Second, in addition to the size ceiling we feed into the model the drop in land per capita observed in

[33]The disparities in aggregate factors between the benchmark economy and 1988 Philippines that we calculate are: 3.3 in land per capita, 1.38 in capital-output ratio, and 4.2 in non-agricultural productivity. Matching the agricultural employment share requires $\kappa = 1/3.9$. Data sources: number of farms and total land in farms are from the World Census of Agriculture; real GDP per worker, real GDP per capita, and total population are from PWT6.3; the capital-output ratio for 1988 is from Easterly and Levine (2001), while the 2000 value is calculated using the perpetual inventory method and investment data from PWT6.3 with a depreciation rate of 6%; value added in agriculture in constant 1985 prices and persons employed in agriculture are from the Groningen Growth and Development Centre 10-sector database.

the Philippines over 1988-2000 (-26.9%). Third, in addition we take into account the changes in the capital-output ratio and non-agricultural productivity observed in the Philippines over 1988-2000 (3.8% and 9.9% respectively). The model results from these three experiments are presented in turn in the first three columns of Table 9. The fourth column presents the actual changes in the variables of interest observed in the Philippine data over 1988-2000.

The first column of Table 9 shows that imposing the ceiling alone produces: a reduction in average farm size by 7.0%, a reduction in agricultural labor productivity by 7.0%, an increase in the share of employment in agriculture by over 3 percentage points (from 45.1% to 48.5%), and a reduction in aggregate labor productivity by 5.8%. These effects are all in the anticipated direction. A binding ceiling prohibits farms over the legislated maximum to exist bringing down average size. This causes a misallocation of resources away from large productive farms and a drop in agricultural productivity. Lower productivity requires a larger share of employment in agriculture to meet subsistence needs. Since a larger weight is placed on an activity with lower productivity, aggregate labor productivity drops as a result. The change in agricultural productivity produced by the model is quantitatively consistent with the drop observed in the Philippines immediately after the reform, over 1989-1993 (-7.0% in the model vs. -8.1% in the data). The drop in average farm size is not as pronounced as in the data (-7.0% vs. -29.6%) because of the induced general equilibrium effects on the price of land from the imposition of the ceiling.

In the second column in Table 9 we impose not only the size cap but also the reduction in land per capita over 1988-2000. The additional effects on productivity and the employment structure are relatively small. However, there is a considerable drop in average farm size relative to the case with the ceiling alone (-32.1% vs. -7.0%). Intuitively, the fall in the supply of land, other things equal, raises the relative price of land, inducing all farmers to reduce their farm size. In the third column, we add the observed increases in non-agricultural productivity and the capital-output ratio over 1988-2000. Qualitatively, the positive changes in these aggregate factors alone would tend

Table 9: Philippine Land Reform – Changes 1988-2000

	Ceiling	$+\Delta L$	$+\Delta(\frac{K}{Y}, A)$	Data
% Change in AFS	-7.0	-32.1	-23.2	-29.6
% Change in $\frac{Y_a}{N_a}$	-7.0	-7.2	5.2	9.5
% Change in $\frac{Y_n}{N_n}$	0.0	0.0	9.9	9.9
N_a (%)	48.5	48.6	43.0	37.6
% Change in $\frac{Y}{N}$	-5.8	-6.0	13.4	16.4
Share of Farms < 1 Ha (%)	32.6	48.8	42.7	40.1
Share of Land < 1 Ha (%)	5.7	10.0	8.2	8.6

to increase average farm size, reduce the share of labor in agriculture, and increase agricultural and aggregate labor productivity. Quantitatively, combining these forces with the reform and the change in land per capita, the model accounts for the salient features of the Philippine's experience over 1988-2000. The model not only produces more realistic changes in average farm size and productivity, but also accounts well for the fraction of farms and the share of land under 1 Ha.

In summary: (1) land reforms imposing ceilings on land size reduce not only farm size but also productivity, (2) land per capita is an important determinant of average farm size but not productivity, and (3) increases in aggregate factors such as capital accumulation and economy-wide productivity, can mask the negative size and productivity effects of land ceilings when assessed using time-series evidence.

6.2 Progressive Land Taxes

The next farm size policy that we consider is a progressive land tax whereby the tax rate on land input rises with the size of the farm. Progressive land taxes are pervasive in developing countries such as Zimbabwe, Pakistan, Brazil, Namibia, among many others. Progressive land taxes are motivated on the basis of intensifying land use, discouraging speculative landholding, inducing redistributive market transfer of land, and diffusing social and political tensions around land (see Childress et al., 2009). While there is some evidence in favor of progressive land taxes discouraging under utilization of land there is not much rigorous evaluation of the productivity and farm size effects of such taxes.

We use our model to assess the quantitative impact of progressive land taxation. We assume there is some threshold level of land $\widehat{\ell}$ such that farmers face a tax rate of τ_L for $\ell \leq \widehat{\ell}$ and a tax rate of τ_H for $\ell > \widehat{\ell}$. Thus, a farmer wanting to expand land input use beyond $\widehat{\ell}$ faces a cost $q\left(1+\tau_L\right)\widehat{\ell}+q\left(1+\tau_H\right)(\ell-\widehat{\ell})$. Then the problem of a farmer in the agricultural sector is,

$$\max_{\ell,k}\left\{p_a A\kappa\left[\theta k^{\rho}+(1-\theta)\left(s\ell\right)^{\rho}\right]^{\frac{\gamma}{\rho}}-rk-q(1+\tau_H)\ell+q(\tau_H-\tau_L)\widehat{\ell}\right\}.$$

Profit maximization implies that there are three types of farms: low ability farmers that fall in the low tax bracket and choose $\ell(s;\tau_L,\tau_H,\widehat{\ell})<\widehat{\ell}$, high ability farmers with $\ell(s;\tau_L,\tau_H,\widehat{\ell})>\widehat{\ell}$ that face a higher marginal cost because they pay tax τ_H on the excess units of land, and the group for which $\ell(s;\tau_L,\tau_H,\widehat{\ell})=\widehat{\ell}$. This implies that for a given $\widehat{\ell}$ there are two thresholds (s_L,s_H) that satisfy,

$$\widehat{\ell}=\left[\frac{p_a\gamma\left(1-\theta\right)A\kappa}{q(1+\tau_i)}\right]^{\frac{1}{1-\gamma}}\left[\theta\left(\frac{\theta}{1-\theta}\frac{q(1+\tau_i)}{r}\right)^{\frac{\rho}{1-\rho}}+\left(1-\theta\right)s_i^{\frac{\rho}{1-\rho}}\right]^{\frac{\gamma-\rho}{\rho(1-\gamma)}}s_i^{\frac{\rho}{1-\rho}},\quad\forall i\in\{L,H\}.$$

Then the low ability farmers facing the low tax are those with $s\in[\underline{s},s_L)$, the intermediate group includes those with $s\in[s_L,s_H]$, and the highest ability farmers facing the high cost of land those with $s\in(s_H,\overline{s}]$. Note that farmers in the $[s_L,s_H]$ choose $\ell=\widehat{\ell}$ and their optimal choice of k is given by,

$$r=\gamma\theta p_a A\kappa\left[\theta k^{\rho}+(1-\theta)\left(s\widehat{\ell}\right)^{\rho}\right]^{\frac{\gamma-\rho}{\rho}}k^{\rho-1}.$$

The optimal choices of (ℓ,k) for the low and high ability farmer groups are given by equations (4) and (5) with the rental prices of land $q(1+\tau_L)$ and $q(1+\tau_H)$.

We study quantitatively the 1970s land revenue system in Pakistan. The West Pakistan Land Revenue Act of 1967 required all farmers to pay a (provincial) land tax. According to the 1967 Act, while tax rates were classified by soil type for a village or group of villages (Khan and Khan, 1998), they were not differentiated across farms on the basis of size. A 1976 amendment to this Act, known as the West Pakistan Land Revenue Act 1976, introduced steep progressivity in the land tax system. According to the 1976 Act all irrigated land holdings of up to 5 Ha were exempted from paying a land tax. Among the non-exempt farmers, those with holdings between 5-10 Ha paid the same rates as before, while farmers with holdings between 10-20 Ha were subject to a 50% rate increase, and farmers with over 20 Ha were subject to a 100% increase relative to the previous rates.[34] Neither the original 1967 Act nor its 1976 Amendment contain specific tax rates. However, according to the 1967 Act the land tax rate could not exceed 25% of "net assets" (calculated as the value of gross product minus "ordinary" expenses of cultivation, which include mainly intermediate inputs).[35] In the Census (1971/73) prior to the 1976 progressive land tax policy, average farm size was 5.29 Ha. By the 1989 Census average farm size had dropped to 3.78 Ha, a reduction of 28.7%.

We examine the quantitative effects of imposing a progressive land tax policy in our model. We consider an economy that resembles Pakistan at the time of the 1976 Amendment in terms of land taxes, aggregate factors, and sectoral structure. We assume a pre-reform average tax rate that is uniform across farms of all sizes. Given that no explicit tax rate is provided in the 1967 Act, we side with the conservative choice of choosing a tax rate in value added that is half of the maximum allowed in the 1967 Act. Hence, we select a land tax of 12.5% of value added in farming. With an 18% land income share, the implied uniform land tax rate is $\tau = 0.694$. We calculate aggregate factors and reproduce the agricultural employment share in 1976 Pakistan following the same approach as in the land-reform experiment.[36] This calibration yields a disparity in aggregate

[34] See Sections 4-5 of the 1976 Act (North-West Frontier Province Amendment), available at: http://www.khyberpakhtunkhwa.gov.pk/Gov/files/v8_0019.htm.

[35] See Chapter 1 (4) of the 1967 Act at: http://www.khyberpakhtunkhwa.gov.pk/Gov/files/v6_0015.htm.

[36] The implied disparities in aggregate factors between the benchmark economy and 1976 Pakistan are: 1.6 in land per capita, 2.49 in capital-output ratio, and 9.5 in non-agricultural productivity. We choose $\kappa = 1/1.9$ to

output per worker between the benchmark economy and 1976 Pakistan of 17.8 (compared to the 14.3 disparity between 1990 U.S. and 1976 Pakistan in the data). The implied pre-reform average farm size of this economy is 4.91 Ha, which is close to 5.29 Ha observed in Pakistan before the reforms.

To implement the progressive land tax policy, we set the threshold $\widehat{\ell}$ at 5 Ha in line with the 1976 Amendment. Given that farms smaller than the threshold are exempt from the land tax after 1976 we set $\tau_L = 0$. For all farms above the threshold we assume an average land tax rate that is 50% higher than the pre-reform uniform tax rate, $\tau_H = 1.04$ (which averages the three tax rates in the more gradual progressivity of the 1976 Amendment). We compare the results produced by the model after the policy reform to the actual changes in the key variables of interest over 1976-1985. To put the effects of the land tax policy in context, when comparing model to data in Table 10, we also take into account in turn the observed changes in the aggregate factors over 1976-1985: a decrease of 29.9% in land per capita, a decrease of 13.3% in the capital-output ratio, and an increase of 23.2% in non-agricultural productivity.

The first column of Table 10 reports the results of implementing the progressive land tax policy alone: a reduction in average farm size by 3.1%, a reduction in agricultural labor productivity by 3.2%, an increase in the share of employment in agriculture by less than 2 percentage points, and a reduction in aggregate labor productivity by 3.3%. In the second column we allow not only for the progressive land policy but also for the reduction in land per capita. Average farm size now falls considerably more than under the policy reform alone (31.1% vs. 3.1%). Also, in contrast to the land ceiling policy, the additional effects on productivity and the employment structure are non-trivial: the share of employment in agriculture increases a further 3 percentage points, while

reproduce a pre-reform share of employment in agriculture of 53.9%. Data sources: number of farms and total land in farms are from the World Census of Agriculture; real GDP per worker, real GDP per capita, and total population are from PWT6.3; the capital-output ratio is from Easterly and Levine (2001); the economically active population for agriculture and the total economy are from the International Labour Organization; value added in agriculture and GDP at constant factor cost are from the Handbook of Statistics on Pakistan Economy 2010 (State Bank of Pakistan).

Table 10: Progressive Land Taxation in Pakistan – Changes 1976-1985

	Progressive Tax	$+\Delta L$	$+\ \Delta(\frac{K}{Y}, A)$	Data
% Change in AFS	-3.1	-31.1	-11.0	-28.7
% Change in $\frac{Y_a}{N_a}$	-3.2	-8.2	19.3	11.8
% Change in $\frac{Y_n}{N_n}$	0.0	0.0	23.2	23.2
N_a (%)	55.6	58.6	45.4	48.7
% Change in $\frac{Y}{N}$	-3.3	-8.9	40.1	36.3
Share of Farms < 1 Ha (%)	81.5	86.3	82.7	80.9
Share of Land < 1 Ha (%)	36.4	48.3	39.6	38.8

agricultural and aggregate productivity drop by over 2.5 times more than under the progressive policy alone.

In the third column of Table 10 we incorporate the increase in economy-wide productivity and the decrease in the capital-output ratio. Combining these changes with the policy reform and the change in land per capita, the model captures the observed changes in the key variables of interest with the exception of average farm size which ends up falling less than in the data. The increase in economy-wide productivity increases average farm size, agricultural and aggregate productivity, and reduces the share of employment in agriculture, whereas the decrease in the capital-output ratio has the opposite implications. The stellar increase in non-agricultural productivity in Pakistan over 1976-1985 dominates, masking the negative productivity effects of the progressive land tax policy.

To summarize: (1) introducing progressive land taxes (as compared to a uniform land tax rate) reduces both farm size and productivity, (2) decreases in land per capita amplify the negative effects on size and productivity of progressive land taxes, and (3) as in the case of the land ceiling, increases in aggregate factors can mask the effects of the tax policy on size and productivity.

7 Conclusions

We have documented substantial differences in average farm size and the entire distributions of farms by size and land area across countries. Agricultural production in rich countries is characterized by large farms, whereas in poor countries by small farms. Differences in the type of agricultural goods produced or differences in geography cannot explain away these differences. Since large farms have higher labor productivity than small farms we ask, how important are farm size differences in understanding agricultural and aggregate productivity gaps across countries?

We developed a tractable quantitative framework to organize our understanding of the factors impacting farm size and productivity across countries. Our theory features a non-degenerate distribution of farm sizes, which we calibrate to U.S. farm-level observations. We first used our framework to assess the importance of aggregate factors (land, capital accumulation, and economy-wide productivity). We found that measured aggregate factors account for only 1/4 of the observed differences in farm size and productivity. We argued that among the possible explanations, farm-level policies that misallocate resources from large to small farms have the most potential to account for the remaining differences. We documented that such farm-level policies are prevalent in poor countries.

We studied two specific farms-size policies that are prevalent in developing countries: land reforms that cap the size of farms and progressive land taxes. We assessed the quantitative implications of each policy by emphasizing the institutional detail of two case studies, land reform in the Philippines and land tax reform in Pakistan. We found that each policy alone can generate non-trivial size and productivity effects but that these effects can be masked by the evolution of aggregate factors in the time-series data.

We conclude that understanding farm-size differences may provide a key stepping stone towards understanding the large differences in agricultural labor productivity and consequently aggregate labor productivity between rich and poor countries. As a result, it would be interesting to study the size and productivity effects of land policies for particular developing countries over time using micro data. Such an analysis could shed light on the importance of changes in size within farms as compared to reallocation across sizes, controlling for farm location. It would also be of interest to examine the importance of aggregate factors and policy in understanding the substantial changes in farm size and productivity historically in today's developed countries such as Canada and the United States. We leave these relevant extensions of our work for future research.

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A Data Description

Report on the 1990 World Census of Agriculture The report is compiled by the Food and Agricultural Organization (FAO) of the United Nations. The variables we use from this report are: number and area of holdings classified by size (Table 4.1); average size of agricultural holding for total (Table 3.1), wheat (Table 3.7), rice (Table 3.8), maize (Table 3.9); average persons per holding (Table 3.5); livestock per farm for cattle (3.10), chicken (Table 3.11), sheep (Table 3.12), goats (Table 3.13), pigs (Table 3.14).

Penn World Table PWTv6.2: The variables we use are real GDP per capita ($RGDPCH$), real GDP per worker ($RGDPWOK$), and population (POP). PWTv5.6: We use the 1990 values for capital stock per worker ($KAPW$) and real GDP per worker ($RGDPW$) to calculate the capital-output ratio variable. For Nepal the 1990 capital-output ratio is not available, and thus we use the 1985 value.

Food and Agricultural Organization (FAO) of the United Nations Rao (1993) uses data from the FAO production accounts to construct comparable measures of agricultural output and agricultural price indices for a set of 103 countries, using a methodology similar to the PWT. The variables we use are: population (Table 5.8), economically active population engaged in agriculture (Table 5.9), total arable land (Table 5.10.1), agricultural final output (Table 5.4), share of non-agricultural intermediate inputs in final output (Appendix 3). The intermediate inputs share is available only for 1985.

Countries By Quintile 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, Canada, Denmark, Austria, Norway, U.S.A, Switzerland, Luxembourg.

2007 U.S. Census of Agriculture The U.S. Census of Agriculture contains detailed information on inputs and outputs by farm size (measured in acres).[37] We calculate value added per acre and value added per worker for each size category as value added over the amount of land and farm workers respectively. Value added in dollars is calculated as the difference between gross output (measured as sales) and intermediate inputs. Intermediate inputs include seed, feed, fertilizer and other chemicals, gasoline and other fuels, utilities, supplies, repairs and maintenance. Farm workers include operators and hired labor. Given that operators work on average more hours per year in every size category, we adjust hired workers by their relative average hour contribution, to obtain a full-time farmer equivalent measure of labor input. We calculate average annual hours for hired labor, by farm category, from the expenditures on hired labor in the U.S. Census and a 2007 wage rate per hour of $10.23 (from the 2007 Farm Labor Survey of the USDA). We obtain average hours of work per farm operator by class size from Ahearn and Hamrick (2007), based on data from the 2006 Agricultural Resource Management Survey (ARMS) of the USDA. Capital is calculated as the market value of machinery and equipment (trucks, tractors, combines etc.).

Data on Rich and Poor Countries The disparities in the statistics of interest, between the the richest ($Q5$) and poorest ($Q1$) countries, are provided in Table A.1.

Table A.1: Rich-Poor Disparities in the Data

	Rich (Q5)	Poor (Q1)
Real GDP Per Capita	1	1/21.1
Real GDP Per Worker	1	1/19.2
Capital-Output Ratio	1	1/2.9
Arable Land Per Capita	1	1/1.3
Non-Agricultural Real GDP Per Worker	1	1/6.8
Agricultural Real GDP Per Worker	1	1/46.7
Relative Productivity Agriculture/Non-Agriculture	1	1/6.9
Share of Employment in Agriculture (%)	3.8	65
Average Farm Size	1	1/34
Size Distribution (%):		
Farms $<$ 5 Ha	31.7	93.6
Farms $>$ 20 Ha	38.3	0.2
Share of Land (%)		
Farms $<$ 5 Ha	10.0	68.1
Farms $>$ 20 Ha	68.7	3.4

[37]The farm size categories, measured in acres in the U.S. Census are: '1-9,' '10-49,' '50-69,' '70-99,' '100-139,' '140-179,' '180-219,' '220-259,' '260-499,''500-999,' '1,000-1,999,' '2,000+'.

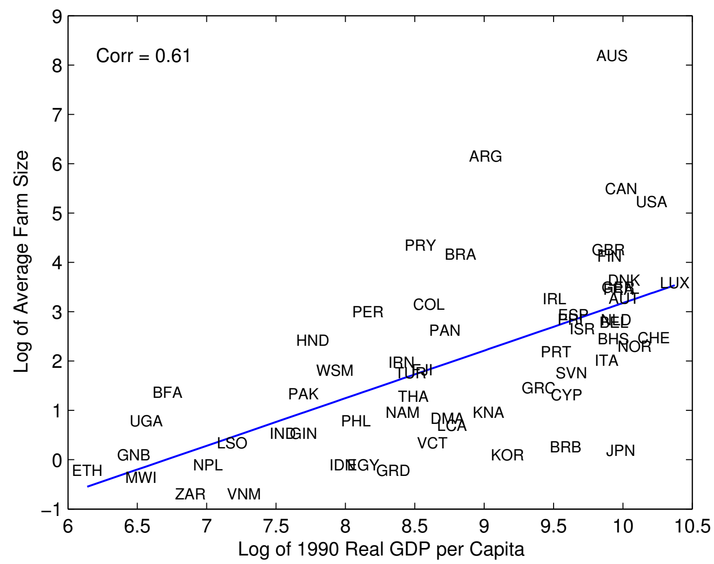

Figure 1: Average Farm Size across Countries

Panel A: Latitude of Centroid

Panel B: Land in Tropics/Subtropics

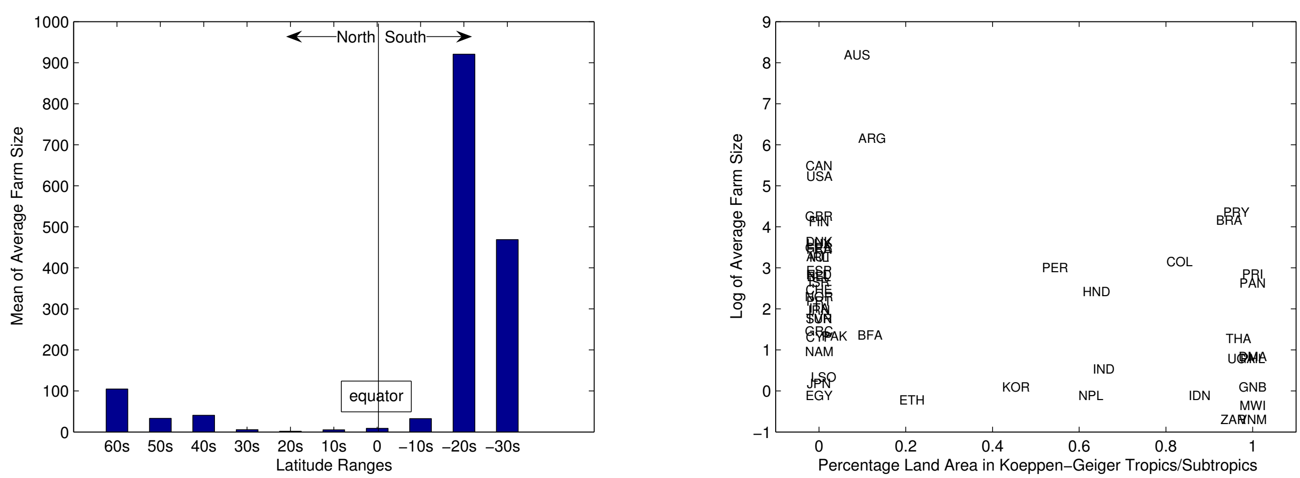

Figure 2: Average Farm Size and Geography

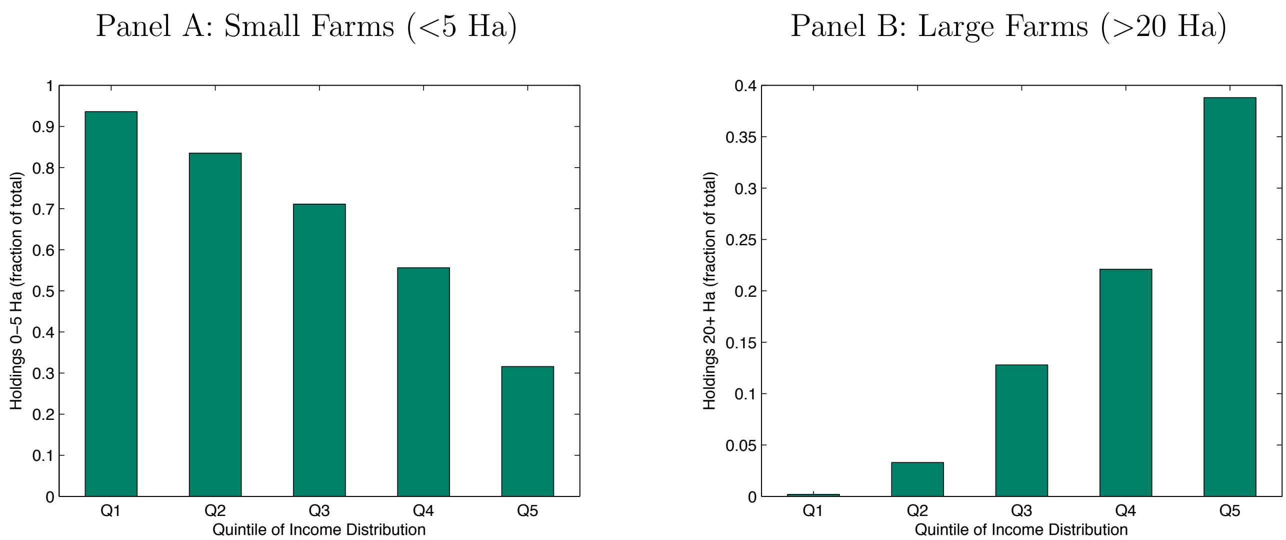

Figure 3: Share of Small and Large Farms across Countries

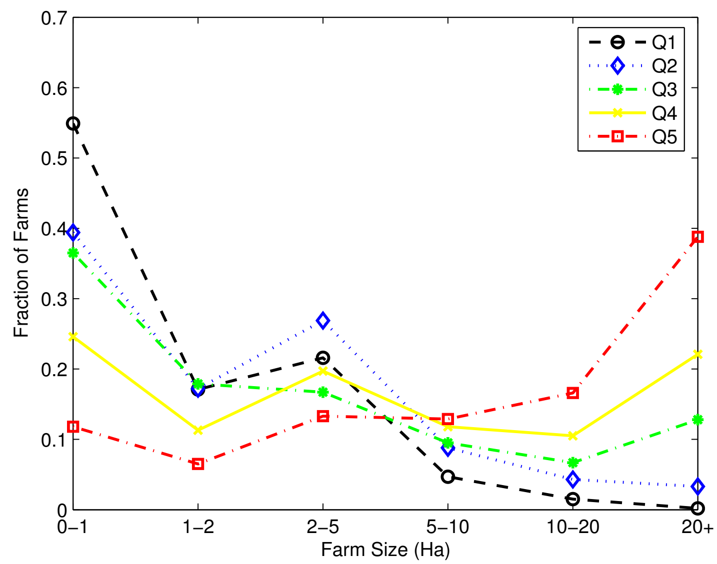

Figure 4: Share of Farms by Size across Income Groups

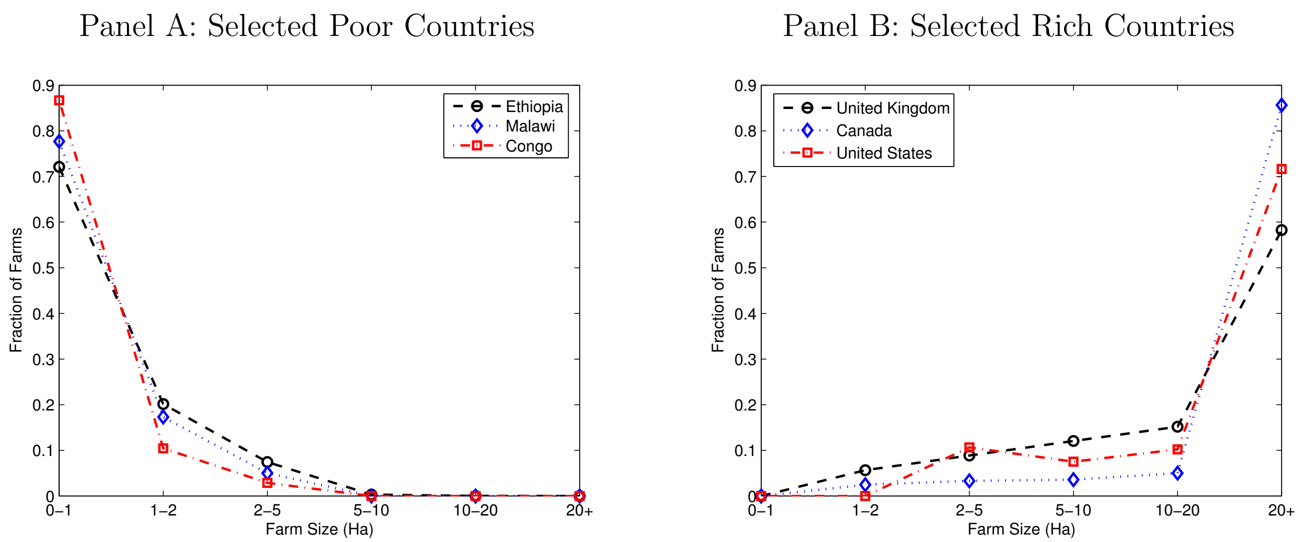

Figure 5: Share of Farms by Size

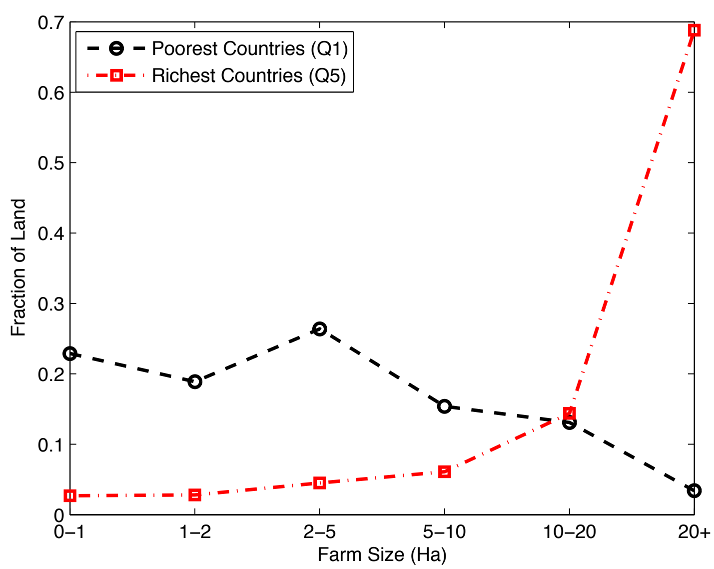

Figure 6: Share of Land in Farms by Size

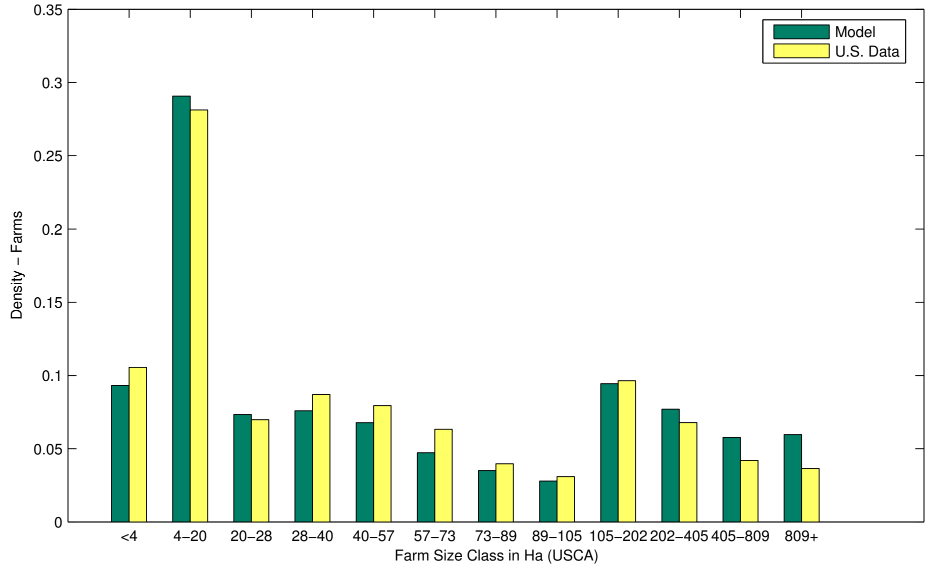

Figure 7: Share of Farms by Size

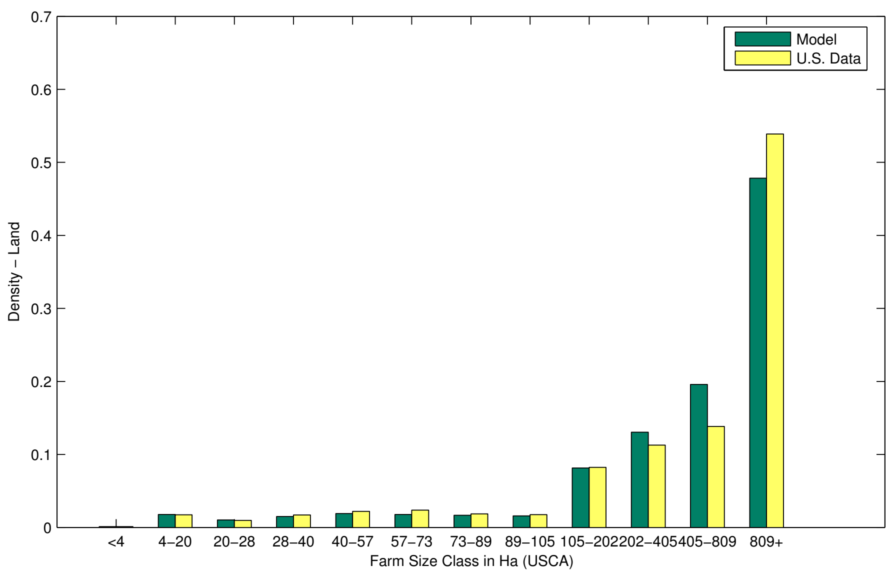

Figure 8: Share of Land in Farms by Size

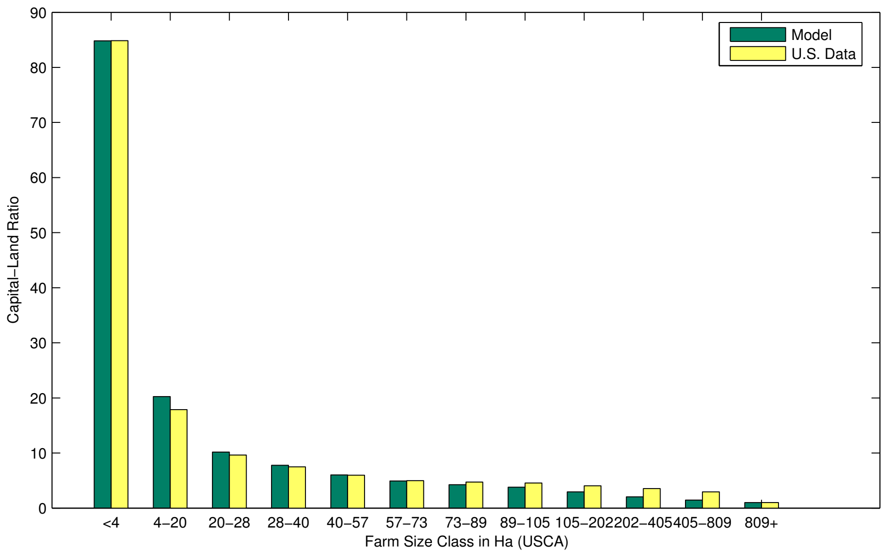

Figure 9: Capital to Land Ratio by Farm Size

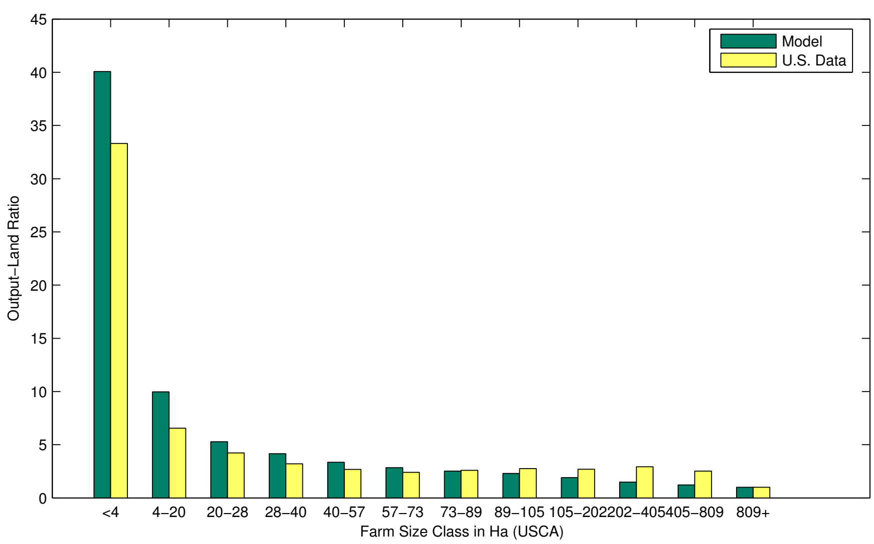

Figure 10: Output per Hectare by Farm Size

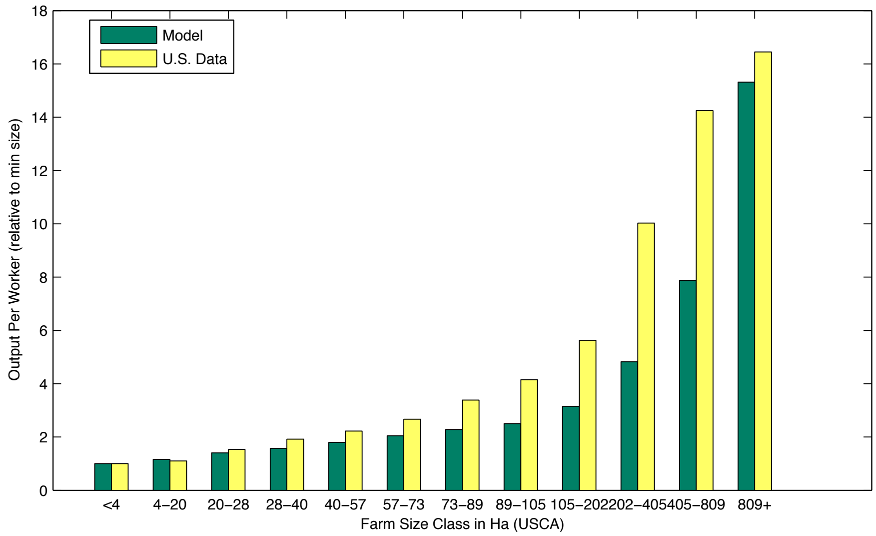

Figure 11: Output per Worker by Farm Size