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The Size Distribution of Farms and International Productivity Differences

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Abstract

There are striking differences in the size distribution of farms between rich and poor countries. We study the determinants of farm-size across countries and their impact on agricultural and aggregate productivity by developing a quantitative model of agriculture and non-agriculture that features a non-degenerate size distribution of farms. We find that differences in measured aggregate factors such as capital, land, and economy-wide productivity account for 1/4 of the observed differences in farm size and productivity. Farm-level policies that misallocate resources from large-productive to small less-productive farms, are prevalent in poor countries, and have the potential to account for the remaining differences. We assess the quantitative importance of misallocation in two ways. First, we construct a summary measure of farm-size distortions across countries by exploiting within-country variation in crop-specific price distortions with crop farm size. This measure and aggregate factors jointly account for more than 1/2 of the differences in size and productivity. Second, 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 size and productivity.

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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 is measured labor productivity in farming so low in poor countries? 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 these account for 40% of the total number of farms.[2]

(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

[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 (forthcoming), Gollin, Lagakos, and Waugh (2011), Herrendorf and Schoellman (2011), among others.

[2]See Grigg (1966) for an early documentation of differences in farm size across countries and Eastwood, Lipton, and Newell (2010) for some more recent observations and historical trends.

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] In India, Foster and Rosenzweig (2011) show that efficiency rises with farm size.

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.

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

[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. In the current and past U.S. Census of Agriculture, labor productivity increases with farm size at the same time that land productivity falls with size. These patterns are also observed in a wide range of developing countries and time periods (see for instance, Berry and Cline, 1979; Cornia, 1985; and Binswanger, Deininger and Feder, 1995).

Agriculture. The model fits very well the farm-level data. In our theory, for a given distribution of farm-level productivity, higher economy-wide total factor productivity (TFP), capital, or land, results in larger farm sizes since fewer farmers are needed in agriculture to produce food. 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 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?

We focus on farm-level policies that misallocate resources across farms of different sizes, as a potential explanation in generating low farm size and low productivity in poor countries. 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, and 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 input subsidies only 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 (2012) 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 Appendix E.

To get a quantitative handle on the importance of misallocation induced by farm-size distortions, we calibrate size-dependent producer-level taxes in poor countries to match differences in average farm size between rich and poor countries. We find that the model with aggregate factors and producer-level taxes can account for the entire rich-poor gaps in the sectoral share of employment and productivity. Are there empirically observable size-dependent taxes that can generate a quantitatively large drop in both farm size and productivity?

A key component of our analysis is that we provide a quantitative assessment of the importance of misallocation in agriculture using observable policy measures. We do this in two ways. First, we construct a summary measure of farm-size distortions across countries using internationally comparable data on agricultural distortions from the World Bank (see Anderson and Valenzuela, 2008). In particular, we use product-specific price distortions, measured as gaps between the farm-gate price and the international price for each product, after controlling for transportation and distribution costs. The price gaps capture government induced policy distortions such as domestic taxes/subsidies, trade taxes, interventions in the domestic foreign exchange market. A positive gap implies a subsidy for the producer of that product and a negative gap a tax. As is well known, poor countries typically tax agriculture. To obtain a summary measure of size-dependent distortions we exploit the within country variation in crop-specific taxes and their covariance with crop farm size. Combining our empirical measure of farm-size distortions with aggregate factors, the model can account for over 1/2 of the differences in average farm size and agricultural productivity across rich and poor countries. This is a sizeable effect in the context of both the agriculture and the misallocation literatures. We find that the key quantitative effect on productivity is generated through misallocation that depresses average labor productivity in each size category (rather than reallocation across categories with productivities as in the benchmark economy).

Second, 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. 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 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%.

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 (forthcoming), 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. More importantly, we use an empirically observable measure of farm-level distortions and assess its quantitative effect on both size and productivity. In addition, we quantify the effects of specific observable policies that generate misallocation.

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,

[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.

Yang, and Zhu (2008), Caselli (2005), and the related literature. In addition, the particular farm-level policies we study are land policies, and hence specific to agriculture where land is an important factor of production.[5]

The paper proceeds as follows. Section 2 documents 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 and farm-size distortions. Section 6 examines the quantitative effects of land reforms and progressive land taxes. Section 7 discusses the results through the lens of potential amplification mechanisms, time series evidence on farm size and productivity, and a robustness exercise. We conclude in Section 8.

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.[6] 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. We rank countries

[5]Our emphasis in this paper is on the productivity implications of the operational-scale distribution of farms and as a result we abstract from the welfare implications of ownership distribution policies and political economy considerations. See for example Engerman and Sokoloff (2000), Easterly (2001), Adamopoulous (2008), and Galor, Moav, and Vollrath (2009).

[6]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.

according to real GDP per capita and allocate them into quintiles of the income distribution.[7] We summarize our main findings with a special focus on the comparison of the richest and the poorest groups of countries.[8]

2.1 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. 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.[9] While land endowment, geographical location, land quality, and type of agriculture are relevant determinants of farm size across countries and there may be issues of measurement in farm size, the empirical literature has established a strong positive link between farm size and the level of development (see the surveys in Grigg, 1966; and Eastwood, Lipton, and Newell, 2010).[10] Indeed, in the context of the development process and the model we consider in Section 3, it is natural that, holding other factors constant, farm size increases with productivity as

[7]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). The list of countries within each quintile is provided in Appendix C.

[8]The disparity in average real GDP per capita between the richest and poorest 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 Appendix C.

[9]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).

[10]We find large differences in farm size even within narrowly defined crop (wheat, maize, rice) and livestock (cattle, chicken, sheep, pigs) categories between rich and poor countries although the exact magnitude differs by category (e.g., 39-fold difference in rice and maize and 9-fold difference for wheat), see Table 1. Also, while measures of geography may be correlated with farm size, the evidence is not always supportive of a strong link. For example in our sample, there is considerable variation in farm size within climate zones (e.g., tropics-subtropics vs. temperate, according to the Koeppen-Geiger climate zone classification, see Gallup, Sachs and Mellinger, 1999). There is also a weak correlation between average farm size and the mean distance to the nearest coastline or sea navigable river across countries.

a productivity improvement generates a reallocation of labor out of agriculture and increases farm size.[11]

Table 1: Average Farm Size across Countries

Quintile	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.

The above differences in average farm size arise from systematic differences in the size distribution of farms between rich and poor countries. Figure 2 reports the percentage of farms that are small (less than 5 Ha) and large (more than 20 Ha) across income groups. 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%. Histograms, for a finer breakdown of size categories, indicate that the share of farms is decreasing in size in poor countries, whereas the share of farms is increasing in size in rich countries. These facts suggest that small farms constitute the most common form of production unit in poor countries whereas large farms constitute the dominant production unit in rich countries. These patterns are even more striking if we focus on individual countries. For instance, for poor countries such as Ethiopia, Malawi, and Congo, more than 70% of farms are less than 1 Ha in size, whereas in rich countries such as Canada, United States, and United Kingdom, more than 70% of farms are more than 10 Ha in size. Another relevant feature of the data is that in poor countries, small farms account for a disproportionate

[11] This implies that we could expect an increase in average farm size as countries grow over time, holding other factors constant. This is the case in developed countries. See Section 7 for details.

share of land, whereas in rich countries large farms account for most of the land.[12] As we document in Figure 3, in the richest countries almost 70% of land is concentrated in large farms, whereas in poor countries almost 70% of land is concentrated in small farms.

2.2 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 potential 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.

Fact 2: Labor productivity (value added per worker) increases with farm size.[13] The factor difference between the largest and smallest scale of operation reported in the Census is 16-fold. This suggests that the difference in the allocation of farms across sizes between rich and poor countries alone could account for an important portion of the productivity gap in agriculture between these countries. In fact, a simple accounting exercise, where U.S. labor productivity by farm size is aggregated using the size distribution of farms in rich countries, reveals that aggregate agricultural labor productivity would fall by a factor of 4 if instead they had the poor country farm size distribution.[14] However, while this observation represents a useful motivation for the importance of reallocation across farms in poor countries, we note that reallocation across heterogenous farms could generate productivity losses even in the absence of labor productivity differences across farms. To appreciate this point, notice that the baseline framework in the misallocation literature (e.g., Restuccia and Rogerson, 2008) is such that in the absence of distortions, factor demands equalize marginal products across production units, implying that labor productivity differences are also equalized. In this context, misallocation causes measured productivity losses to the extent that factors are

[12]This observation is reminiscent of what Lagakos (2009) reports for retail trade.

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

[14]The details of this counterfactual are provided in separate Appendix D.

reallocated across heterogeneous productive units as is the case in that literature.

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.

In Table 2 we also show that land productivity (value added per unit of land) decreases with farm size. The capital to land ratio also decreases with farm size.[15] 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.

[15] 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.

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).

Technology The non-agricultural good is produced by a stand-in firm with access to a constant returns to scale technology that requires labor and capital as inputs,

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

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,

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

where y_a is output of the farm, ℓ is the amount of land input, and k is the amount of capital.[16] There

[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, 2010). 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.

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 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. The parameter ρ determines the elasticity of substitution between capital and land $1/(1-\rho)$.

Preferences and Endowments The economy is endowed with fixed amounts of total farm land L and capital K.[18] We consider an economy with a stand-in household that has preferences over the two goods according to the following per-period utility function

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

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 $i \in \{a, n\}$. A household is composed of a unit-mass continuum of members.

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 (with productivity normalized to one), household members are ex-post heterogeneous with respect to their productivity in the agricultural sector. Unlike in Lucas (1978), we abstract from selection in the occupational decision by assuming that the productivity of farmers in agriculture is realized after the sectoral allocation decision. The household decides what fraction of its members

[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).

[18] We abstract from capital accumulation in order to focus on the productivity effects resulting from the reallocation of resources across farms of different productivity.

work in the agricultural sector, drawing their farmer managerial ability from a known time-invariant distribution with cdf $F(s)$ and pdf $f(s)$, with support in $S = [\underline{s}, \overline{s}]$. This assumption implies that the distribution of farmer's ability will be the same in all countries and hence we are abstracting from a potential selection channel into agriculture.[19] The selection channel into agriculture has been studied in a more elaborate model of worker heterogeneity in Lagakos and Waugh (forthcoming) and is shown to amplify the role of both aggregate factors as well as misallocation in agriculture. Since this selection channel and other potential amplification mechanisms are well understood in the literature, we abstract from them in this paper in order to focus on the role of farm-level policies in generating misallocation and productivity gaps in agriculture in poor countries.[20]

Definition of Equilibrium We focus on a competitive equilibrium of the model. 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 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,

$$\max_{K_n, N_n} \{AK_n^{\alpha} N_n^{1-\alpha} - rK_n - wN_n\}. \tag{2}$$

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

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

The stand-in household maximizes utility in (1) by choosing household consumption and the allo-

[19]The measure one assumption implies that we abstract from issues of risk sharing as the stand-in household acts under certainty with respect to the ability distribution.

[20]There are many other relevant amplification mechanisms such as human capital accumulation, accumulation of managerial skills, investment in firm's productivity, among others.

cation of labor given prices subject to the following budget constraint:

$$p_a \cdot c_a + c_n = (1 - N_a)w + N_a \int_S \pi(s)\, dF(s) + qL + rK \equiv I, \tag{4}$$

where p_a is the relative price of agricultural goods (the non-agricultural good is the numeraire whose price is normalized to 1) and I is income of the household.

A *competitive equilibrium* is a set of allocations for: the household $\{c_a, c_n, N_a\}$, firm in the non-agricultural sector $\{K_n, N_n\}$, and farmers $\{[\ell(s), k(s), y_a(s)]_S\}$, and a set of prices $\{p_a, q, r, w\}$ such that: (*i*) given prices, the allocations of the household solve the household's problem (i.e., maximize utility in (1) subject to the budget constraint in (4)); (*ii*) given prices, the allocations of firms in non-agriculture and farmer solve their problems in (2) and (3); and (*iii*) markets clear: for labor $N_a + N_n = 1$; for capital $K_a + K_n = K$, where $K_a = N_a \int_S k(s) dF(s)$; for land, $L = N_a \int_S \ell(s) dF(s)$; and for agricultural and non-agricultural goods, $c_a = N_a \int_S y_a(s) dF(s)$ and $c_n = Y_n$.

The characterization of equilibrium is provided in Appendix B. Here we focus on the conditions that are less standard. The first order conditions for land and capital from the farmer maximization problem imply that the optimal capital-land ratio depends on the farmer ability s,

$$\frac{k}{\ell} = \left[\frac{\theta}{1-\theta}\frac{q}{r}\right]^{\frac{1}{1-\rho}} s^{-\frac{\rho}{1-\rho}}. \tag{5}$$

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. The optimal scale of operation of a farm is determined by the managerial ability of the farmer. The 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 first order condition of the household with respect to the share of household members working in agriculture implies,

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

This no-arbitrage condition states that the household allocates its members across sectors until the net return from non-agriculture is equal to the profits in agriculture.

A Simplified Economy We illustrate the key properties of the model though a simple example whereby we abstract from capital in the economy, i.e., $\theta = \alpha = 0$. We also assume that $\phi = 0$ so that $\bar{a}$ is not only a subsistence term for food but also a satiation point, in which case, the household only consumes $\bar{a}$ units of the agricultural good. With these assumptions there is a closed-form solution of the model which implies that the total agricultural output in the economy is equal to $Y_a = A\kappa L^{\gamma}[E(s)N_a]^{1-\gamma}$ where $E(s) = \int_S s^{\gamma/1-\gamma} dF(s)$ is average ability. Since consumption of the agricultural good is equal to subsistence, $c_a = \bar{a}$, then using the resource constraint in agriculture we can solve for the share of labor in agriculture,

$$N_a = \left[\frac{\bar{a}}{A\kappa L^{\gamma} E(s)^{1-\gamma}}\right]^{\frac{1}{1-\gamma}}.$$

The share of employment in agriculture is high when economy-wide productivity A is low, when agriculture-specific productivity κ is low, when the land endowment L is low, and when the efficiency of farmers $E(s)$ is low. By assumption in our model we abstract from potential differences in farmer's ability across countries. In our quantitative analysis we also maintain κ constant across economies. But misallocation of factors across farmers with different abilities operates through a reduction in measured productivity and acts in a similar fashion as a reduction in κ. Since average farm size is the ratio of land to employment in agriculture, the same objects that drive a high share of employment in agriculture also reduce the average farm size, with land endowment having both a direct and indirect effect on this statistic. As a result, average farm size differences are potentially driven by aggregate factors such as economy-wide productivity and land endowment as well as distortions that misallocate resources across farmers with different productivity. Assessing the contribution of these factors in accounting for farm size and productivity differences across countries is the focus of our quantitative analysis in Section 5.

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, 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 Ha. 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 Valentinyi and Herrendorf

(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 Valentinyi and Herrendorf, 2008), and (3) a disparity in the capital to land ratio between the minimum and maximum farm sizes of 84.8. Note that the target on the capital to land ratio across farm sizes 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,

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

so that a given distribution of abilities maps into differences in capital to land ratios depending on ρ. Since differences in capital to land drive differences in labor productivity (and yields) across farm sizes, this parameter may be important for our results. One concern with the target on capital to land ratios may be that the observed disparity across farms reflects a compositional bias due to: (a) large farms producing different agricultural goods (e.g., ranching) than small farms and (b) the set of goods in U.S. agriculture may not reflect the set of goods produced in poor countries. To address these issues, we calculate the capital-land ratio for selected agricultural goods (NAICS categories in the U.S. Census of Agriculture).[21] These goods are representative of the production in the farm-size distribution in the United States and tend to be produced by both rich and poor countries: grains, vegetables, fruit, nuts, sheep, goats, pigs, eggs and poultry.[22] The average disparity between the minimum and maximum scale of operation over these categories is 83.6, which is very close to our target of 84.8 for the total average. The overall pattern is also similar for the average disparity between other size categories. We note that the calibrated value for ρ implies an elasticity of substitution between capital and land of 1.32 which is very close to Binswanger's (1974) estimate of 1.22 using U.S. state-level data. In addition, we conduct sensitivity analysis with respect to ρ in

[21]We thank the U.S. Department of Agriculture for providing unpublished specially-tabulated data on capital and land by NAICS category to perform this comparison.

[22]Note that these categories exclude ranching, feedlots, tobacco, cotton, sugarcane, among others, which may be conducive to more large-scale production and may not be produced by most poor nations.

Section 7 and find that our results are not critically affected for reasonable ranges of this parameter. The resulting calibrated parameter values are $\overline{a} = 0.035$, $\rho = 0.24$, and $\theta = 0.89$. 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. We choose 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.[23]

Finally, we note that the labor productivity ratio (i.e., the value of labor productivity in agriculture to non-agriculture) in the benchmark economy is $(1-\alpha)/(1-\gamma)$. Given our calibrated values for these parameters, the implied ratio is larger than one. It is well-known that the labor productivity ratio in the data for the United States is around 0.5 although there is a debate whether this gap represents barriers to labor mobility or simply measurement problems (see Herrendorf and Shoellman, 2012). The labor productivity ratio is only relevant for our calibration because it affects the units of agricultural labor productivity and as a result the units used to compute aggregate labor productivity across the experiments for poor countries. For this reason, we introduce a barrier to labor mobility between agriculture and non-agriculture in units of output of the non-agricultural good that is kept constant throughout our analysis across countries. The barrier has a one-to-one mapping to the equilibrium price of the agricultural good so we select the barrier so that the labor productivity ratio is 0.5. We note that if instead we treat the labor productivity gap as a measurement gap, the main departure from our calibration would be a larger $\bar{a}$ to reproduce the given target of employment in agriculture. This alternative calibration would amplify the cross-country implications on productivity emphasized in Section 5.

The model parameters along with their targets and calibrated values are provided in Table 3. 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. It also matches the capital to land ratios across farm sizes even though the calibration only targets the disparity between the largest and smallest size categories (see Figure

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

4). The model also matches well other statistics that were not objects of the calibration targets. For instance, the model generates a reasonable distribution of land across farm sizes by reproducing for example the observation that about 80% of the land is in farms over 20 Ha in size (see Figure 5, Panel A). The model is consistent with the positive relationship between farm size and labor productivity (value added per worker) observed in the data (see Figure 5, Panel B) as well as the well-known negative relationship between value added per hectare and size (see Figure 5, Panel C). These features make the model suitable for the quantitative analysis in the next section.

Table 3: Parameterization

Parameter		Value	Target
Technology:	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
Preferences:	$\overline{a}$	0.035	Current employment share in agriculture
	ϕ	0.010	Long-run employment share in agriculture
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

5 Quantitative Analysis

We use the calibrated model as a framework for understanding cross-country differences in the size 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.[24]

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

5.1 Aggregate Factors

We have shown that, in the context of our model, variations in aggregate factors affect the size and productivity of farms in the agricultural sector. In this section, we examine the quantitative effect of measurable aggregate factors such as land L, capital K, and economy-wide productivity A on 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 on the share of employment in agriculture (N_a), average farm size (AFS), agricultural labor productivity, and aggregate labor productivity are reported in Table 4, along with statistics for the benchmark economy.[25]

Table 4: Effects of Aggregate Factors

	Benchmark Economy	+ Land Differences	+ (TFP, Capital) Differences
Employment in Agriculture N_a (%)	2.5	2.6	16.6
Average Farm Size (AFS)	-	1.3	8.6
Labor Prod. in Agriculture (Y_a/N_a)	-	1	11.2
Aggregate Labor Productivity (Y/N)	-	1	7.6

Note: Average farm size, labor productivity in agriculture and aggregate labor productivity are reported as the ratio between the benchmark economy and the poor economy. Land differences represent the difference in arable land per capita between the rich and poor countries which is 1.3 fold. TFP and capital-to-output differences represent a factor of 2.5 and 2.9 between rich and poor countries.

We measure land endowments as arable land per capita in the data consistently with our model.[26] While richer countries have higher arable land per capita than poorer countries, this disparity is only 1.3-fold.[27] Not surprisingly then the model implies small disparities in the variables of interest

[25] 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.

[26] 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.

[27] 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 United States and poor countries (2.96-fold), but also between the US and rich countries

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 and N_a is close between the two economies, average farm size differs essentially by the disparity in 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 so 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. 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. We note that aggregate factors can yield a large share of farms under 5 Ha (58.1% in the model versus 93.6% in the data) explaining the sizeable impact of aggregate factors on average farm size.

Geography and Land Quality Another potentially important aggregate factor that can affect agricultural productivity is land quality. Studying the importance of land quality quantitatively involves two issues: (a) to obtain good measures of land quality differences across rich and poor countries; (b) to map these differences into efficiency units of land that go into the production function of agriculture. This is similar to the issue of mapping education (average years of schooling)

(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.

into human capital in development accounting. Traditional measures of land quality include the percentage of agricultural land classified as arable or cropland, or the percentage of arable land or cropland that is irrigated. These measures however are subject to the criticism that they can be affected by economic or other factors, and do not control for inherent soil or climate characteristics.

The FAO in collaboration with the International Institute for Applied Systems Analysis (IIASA) has developed a system, known as the Global Agro-ecological Zones (GAEZ - 2000), which classifies land in terms of its suitability potential for agricultural production. The classification is based on an intricate combination of information on soil (e.g., depth, fertility, drainage, texture, chemical composition), terrain (e.g., slope, elevation), and climate (e.g., moisture, temperature) characteristics. The classification of world land surface is established at a very fine grid-cell level, which allows aggregation at the country and regional level. We use country-level information which classifies a country's land according to the extent of soil, terrain, and climate constraints for rain-fed agricultural production. Constraints are classified according to none, moderate, severe for each characteristic. Using this information we calculate a country's endowment of suitable land per capita for various degrees of constraints, for each of the countries in our rich and poor sample. If we focus on the best quality land within each country (the land that has no soil, terrain, or climate constraints) then the ratio of the average rich to average poor is 1.1. This result does not imply that there are no important differences in "good" quality land across countries, what we find is that the differences are not systematically related to the level of development. For example, Norway is similar to Malawi (low end) in terms of unconstrained land per capita, while the U.S. is similar to Lesotho (high end). Including additional classes of land (of moderate soil and terrain and moderate climate constraints) and using different weighting schemes we find a rich-poor ratio of suitable land per capita that ranges from 0.5 to 1.6.

Another measure of land quality is constructed by Wiebe (2003). He constructs a land quality index which utilizes soil (e.g., slope, depth, salinity) and climate (e.g., temperature and percipitation data) properties to classify a country's cropland (a much more narrow concept of land, already used for agricultural production). The index ranges from 3 to 11, where a higher number reflects a higher land quality class. While this index varies across the countries in our sample, it does not vary systematically with income. The ratio between the averages for the poor and rich countries is 1.1. Wiebe, Soule, Narrod, and Brenman (2000), use the same underlying data to construct a complementary measure of land quality: the share of country's cropland that is not limited by major soil or climate constraints to agricultural production (cropland in the highest three land quality classes). This measure is a fraction and ranges from 0 to 1. They include this measure in a regression to study the effect of land quality on agricultural labor productivity. They find that good soils and climate are associated with a 13% increase in agricultural productivity relative to poor soil and climate.

The above discussion suggests that while there are important differences in land quality across countries, these do not vary substantially between rich and poor countries. A remaining question is: what is the quantitative impact of the observed differences in land quality across countries? While we think that the question merits a separate in-depth analysis, we nevertheless use the estimated effect of land quality on agricultural productivity in Wiebe, Soule, Narrod, and Brenman (2000), to feed in differences in land quality we report above. In the context of our model, we find that while aggregate factors without land quality generate a rich-poor disparity in agricultural productivity of 11.2, including land quality differences of 1.1, generate a disparity of 11.7. Considering the range of land quality differences from GAEZ, 0.5-1.6, yields a disparity in agricultural productivity of 9.9 to 12.5. This preliminary analysis suggests that while the effect of land quality is quantitatively non-trivial, it is unlikely to explain most of the remaining differences in agricultural productivity, and in fact may mitigate rather than amplify the overall contribution of aggregate factors.

Rich Countries While aggregate factors alone cannot account for the bulk of the differences in agriculture between rich and poor countries, we note that aggregate factors explain the bulk of differences in size and productivity among developed countries, even for developed countries with large and small average farm sizes such as Canada and Netherlands. Table 5 shows the results of the model with aggregate factors differences for all countries in the top quintile of the income distribution. While there are some country cases that require individual analysis such as Norway and Japan, the simple aggregate factors we consider in the model are capable of generating closely agricultural employment shares, average farm size and agricultural and aggregate labor productivity. As a summary, aggregate factors account on average for more than 60 percent of the farm size and productivity data for rich countries.

Table 5: Effects of Aggregate Factors in Rich Countries

	N_a(%)		AFS		Y_a/N_a		Y/N	
	Model	Data	Model	Data	Model	Data	Model	Data
Belgium	2.92	1.86	19.2	16.1	1.31	1.16	1.06	1.05
Netherlands	3.28	3.32	11.1	17	1.56	1.16	1.19	1.18
Germany	3.17	3.46	21.2	32.8	1.49	2.73	1.25	1.27
France	2.71	5.46	80.5	31.5	1.15	1.90	1.07	1.10
Japan	3.31	6.26	5.9	1.2	1.59	14.8	1.23	1.29
Canada	2.74	3.12	336	242	1.17	1.41	1.30	1.31
Denmark	3.17	4.6	77.7	37.8	1.49	1.49	1.36	1.37
Austria	2.81	5.93	42.9	26.4	1.23	2.89	1.08	1.11
Norway	2.79	5.26	41.1	10	1.21	4.74	1.09	1.13
Switzerland	2.74	3.85	12.3	11.8	1.17	2.73	1.02	1.04
Luxembourg	2.26	1.74	22.3	36.2	0.82	1.16	0.73	0.73
Rich (Q5)	2.77	4.08	61.9	42.1	1.19	1.88	1.09	1.11
Poor (Q1)	16.6	65.0	8.6	34	11.2	46.7	7.6	19.2

Note: N_a is the share of employment in agriculture, AFS is average farm size, and Y_a/N_a and Y/N are labor productivity in agriculture and aggregate labor productivity reported as the ratio between the benchmark economy and each country.

We conclude that while aggregate factors account for a large portion of the differences in size and productivity among rich countries, they only account for 1/4 of the differences between rich and poor countries. Hence, other factors that are specific to the agricultural sector must be affecting not only farm size but also agricultural productivity.

5.2 Farm-Size Distortions

A possible explanation for 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. There is substantial evidence on farm-size distortions in developing countries. 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.[28] 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."[29] In Appendix E 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 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 for fertilizer and seed that are either directly targeted at smallholders or disproportionately benefited them (e.g., Kenya,

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

[29]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.

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.

But the fact that we can produce a long list of policies and institutions that affect the allocation of factors across heterogenous farmers does not immediately imply that these restrictions are quantitatively important in explaining the low average size of farms and low productivity in agriculture in poor countries. To assess the quantitative importance of misallocation, we follow the approach in Restuccia and Rogerson (2008), by introducing farm-size distortions in the model as generic output taxes on individual farmers, $\tau_s \geq 0$.[30] These taxes are idiosyncratic to individual farmers and are meant to englobe the variety of policies and institutions affecting farm size. We implement these idiosyncratic taxes by positing a generic tax function that specifies the output tax rate as a function of the productivity of the farmer as follows:

$$\tau_s = P(s) = 1 - \frac{1}{\exp(\psi s)},$$

where $P(.)$ is the policy function, $\psi > 0$ is a parameter and s is the productivity of the farmer. For values of farmer's productivity greater than zero, the shape of this tax function is such that for low levels of farmer productivity the tax rate is very low and then increases approaching one for large values of farmer's productivity. The specific functional form of this tax schedule is motivated by the empirical evidence discussed earlier and further documented in appendix E, and summarizes in a parsimonious way the set of farm-level policies in developing countries that virtually exempt small farms from effective taxation, while imposing maximum effective taxes on large farms. The nearly 100% effective tax rates implied by the function for the very high ability farmers capture restrictions, taxes, and outright prohibitions, that effectively curtail production of large farms. The steep progressivity of tax rates implied by the function is also consistent with the evidence on actual

[30]The government balances the budget by rebating tax receipts lump-sum to the stand-in household.

taxes and other policies which change in a stark way across ranges of farm-size. We discipline the parameter ψ by selecting it to match the disparity in average farm size between rich and poor countries (34-fold) starting from an economy that features aggregate factors of poor countries. Hence, the question we are asking with this experiment is whether there is a tax schedule $P(s)$ that can generate sufficient misallocation as to reproduce the average farm size in poor countries relative to rich countries, and if so, what the productivity implications for poor countries are.

The results of this experiment are in Table 6. Farm-size distortions, while chosen to match only differences in average farm size, reproduce other pertinent features of poor countries (compare columns 2 and 3 in Table 6). In particular, our model with aggregate factors and idiosyncratic taxes can entirely match the employment share in agriculture in poor countries (65.2% in the model vs. 65% in the data) and agricultural and aggregate labor productivities (factor differences of 46.5 and 17 in the model vs. 46.7 and 19.2 in the data).

Before we move on to discuss the empirical discipline of the tax schedule, we discuss two implications. First, as is standard in the class of two sector models we build on, lower productivity of agricultural goods in poor countries translates into a higher relative price of agriculture. The relative price of agriculture in the model with generic farm-size distortions is 8.4 times that of the relative price in the benchmark economy. In the data, the relative price of agricultural goods in poor countries relative to the United States is a factor of 7. We note however that while the implications of the model on relative prices are not far from the data, there is less testable content in these observations than what may appear. The reason is that in the context of the calibrated model, aggregate price distortions have a first order impact on prices and only second order impact on allocations (an extreme case is the case where $\phi = 0$, implying that allocations in agriculture are independent of prices). Second, in the model, most of the drop in labor productivity in agriculture in poor countries is driven by the misallocation of factors across heterogenous farmers. To see that we note that applying the share of farms by size in the farm-size distortions economy to the labor productivity across farm sizes in the benchmark economy implies a drop in productivity of only a factor of 2.7.[31] This is less than 6% of the 46-fold drop in agricultural productivity in the farm-size distortions experiment.

Table 6: Effects of Farm-Size Distortions

	Aggregate Factors	+Farm-Size Distortions	Data
Employment in Agriculture N_a (%)	16.6	65.2	65.0
Average Farm Size (AFS)	8.6	34	34
Labor Prod. in Agriculture ($\frac{Y_a}{N_a}$)	11.2	46.5	46.7
Aggregate Labor Productivity ($\frac{Y}{N}$)	7.6	17.0	19.2

Note: Average farm size, labor productivity in agriculture and aggregate labor productivity are reported as the ratio between the benchmark economy and the poor economy. Farm-size distortions represent the model with aggregate factors and farm-size distortions given by the tax function $P(s) = 1 - 1/\exp(\psi s)$ where $\psi = 406$ is calibrated to match the average farm size of poor countries.

A Measure of Agricultural Distortions While these taxes reflect the type of farm-size distortions documented in Appendix E (high taxes on large farms, and low taxes on small farms), in the previous experiment we restricted them to match average farm size in poor countries. Are there empirically observable farm-size distortions that can generate a quantitatively large drop in both farm size and productivity? This is a tall order, especially when put in perspective through the lens of the broad literature on misallocation and productivity (see for instance Restuccia and Rogerson, 2013). Our approach is to exploit crop-level distortions and their relationship to typical operational farm size to obtain a summary measure of farm-size distortions.

In particular, we use internationally comparable data on agricultural distortions, available from the World Bank through the "Distortions to Agricultural Incentives" (DAI) project, and the associated database (for details see, Anderson and Valenzuela, 2008).[32] The DAI database uses detailed price and output data, by product, to measure government induced policy distortions faced by farmers in

[31] This compares to a drop in productivity of a factor of 4 in the accounting in Appendix D.

[32] This database extends earlier efforts to document agricultural distortions (Krueger, Schiff, and Valdes, 1988) to a larger set of countries (77 in total), a longer period of time (1955-2007), and a more comprehensive set of distortionary measures.

a wide range of countries. The measure of agricultural distortions we focus on, known as the nominal rate of assistance (NRA), is the gap by which government policy raises the return to farmers above what it would be without government intervention. In essence, if positive, the NRA for a product is a subsidy to the farmers of that product, and if negative, a tax. The NRA is meant to capture domestic direct taxes and subsidies to farmers, trade taxes (e.g., import tariffs, export subsidies), and government intervention in the foreign exchange market (e.g., multi-tier exchange rate regimes). The NRA for a covered product is calculated as the percentage by which the domestic farm-gate price is above the international price of a similar product. If the product is not traded then it only includes the domestic taxes/subsidies. Further, these measures are net of transportation and distribution costs. The DAI database also constructs an NRA for total agriculture as the sum of an output weighted average of the covered product-NRA, an estimate on the rate of protection for non-covered farm products, and non-product specific assistance.

A well known fact that has emerged from the World Bank's DAI project is that on average poor countries tax agriculture (while rich countries tend to subsidize it). This observation is based on the aggregate agriculture NRA, which is typically used as an empirical summary measure of distortions in the literature. For the countries in our sample, the ratio of the average gross tax rate (negative NRA) in poor countries relative to rich countries is a factor of 2.6. However, what is critical in generating misallocation in the model is not necesarily the average tax rate but how taxes vary across producers with different productivity (size). While this information is not readily available in the DAI database, we use the variation of agricultural distortions across covered products within countries and how they correlate with typical operational size. To this end we exploit a well-known relationship between types of product in agriculture and associated farm size (e.g., farm size is larger for sugar and rice farms than for maize and vegetable farms). Holding the product-size relationship constant to that in the United States, we examine how relative taxes in poor countries vary with size. In Figure 6, we plot for each crop, the average tax rate across poor countries relative to the United States, against U.S. crop average farm size ordered from lowest to highest. Taxes are systematically related to the product operational scale in the U.S., that is, products produced on a larger scale are taxed more heavily in poor countries relative to the products produced on a smaller scale (correlation of 0.6). Hence, not only is there large dispersion in taxes in poor countries (standard deviation of taxes of 0.33), but there is also a large correlation between taxes and size.

To the best of our knowledge we are the first to utilize the data set on product level distortions from the World Bank and relate them to farm size and productivity. We note that this observable measure of distortions is not encompassing of all the distortions that we document in Appendix E, as it captures only explicit distortions that operate on the price, but nevertheless it represents a concrete and direct measure of distortions in agriculture in poor countries.

What share of the observed variation between rich and poor countries in farm size and productivity can these measurable farm-size distortions account for? To provide an empirical assessment of the cross-country variation in farm-size distortions, as captured by the above data, we generalize our tax function to allow for different means and correlation between size and productivity. In particular, we posit,

$$\tau_s = P(s) = 1 - \frac{\psi_0}{\exp(\psi_1 s)}.$$

We note that the previous function $P(s)$ is embedded here with $\psi_0 = 1$ and $\psi_1 = \psi$. We calibrate ψ_0 and ψ_1 to minimize the distance between the model and the data for three moments from the tax rates we presented above: (a) a mean gross tax rate that is 2.6 of the gross tax rate in the benchmark economy; (b) a standard deviation of taxes of 0.33; and (c) a correlation between tax rates and size of 0.6.[33] In the first column of Table 7 we present the results from feeding in the model the aggregate factors and the empirically disciplined tax function. The model produces considerable changes in the key variables of interest relative to the aggregate factors only case: the share of employment in agriculture increases to 33.8% from 16.6%, the average farm size disparity rises from 8.6 to 17.6, and the agricultural productivity gap rises from 11.2 to 23.9. Overall, the model with the empirical farm-size distortions is able to generate 50% of the variation in the allocation of employment, average farm size, and productivity between rich and poor countries, with about half

[33]The calibrated parameter values match the target moments very well (within 2 decimal places).

of this accounted for by aggregate factors. Given that our empirical measure of distortions does not capture all the distortions in agriculture in poor countries, we think this is substantial variation generated by these observable policies. The 24-fold drop in agricultural productivity is sizeable, especially compared to the quantitative effects often found in the general misallocation literature. Moreover, as we discuss in section 7, there are many mechanisms considered in the literature that are absent in the model that are known to amplify the effects of distortionary policies on outcomes.

Table 7: Effects of Empirical Measure of Farm-Size Distortions

	Farm-Size Distortions	Flat Tax	Data
Employment in Agriculture N_a (%)	33.8	15.9	65.0
Average Farm Size (AFS)	17.6	8.3	34
Labor Prod. in Agriculture ($\frac{Y_a}{N_a}$)	23.9	11.2	46.7
Aggregate Labor Productivity ($\frac{Y}{N}$)	9.5	7.6	19.2

Note: Average farm size, labor productivity in agriculture and aggregate labor productivity are reported as the ratio between the benchmark economy and the poor economy. Farm-size distortions represent the model with aggregate factors and empirical farm-size distortions from NRA data (with $\psi_0 = 0.73$ and $\psi_1 = 4.9$). Flat Tax represents an economy with aggregate factors and a common tax to all farms equal to the mean in the empirical farm-size distortions.

The covariance of taxes with farm size is key in generating misallocation and the substantial effects on average farm size and productivity. To illustrate this point we conduct another experiment, where all farmers are taxed at a flat rate equal to the average tax rate in the experiment with the empirical measure of distortions. The results of the experiment with aggregate factors and the flat tax rate are presented in the second column of Table 7. Introducing an aggregate tax has virtually no effect on size and productivity relative to the case of only aggregate factors. The systematic correlation to farm-level productivity is what generates misallocation and consequently size and productivity effects.

Our empirical measure of farm-size distortions has two key desirable attributes: it is a summary measure of agricultural policies that are size-dependent, and it is available for a wide cross-section of countries. Next, we complement this analysis with specific-observable policies that distort size in a stark way in two case studies in developing countries.

6 Specific Farm-Size Policies

We study the quantitative effects of two concrete farm-size policies, land reforms and progressive land taxes, in two case studies. We focus on the institutional detail of the policy change in each country and examine the size and productivity effects.

6.1 Land Reforms

Land reforms are 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.

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. We introduce the ceiling legislation into the model by imposing a constraint on land input demand by farmers ($\ell \leq \ell_{max}$). In equilibrium, profit maximization implies two categories of farmers: unconstrained farmers –those with relatively low ability that would optimally have chosen land input below the ceiling, and constrained farmers –those with relatively high ability that would have chosen land input above the ceiling in the absence of the size constraint. In Appendix B we briefly provide the key conditions that change relative to the benchmark model. In this version of the model, 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 the 1988 land reform in the Philippines, known as the Comprehensive Agrarian Reform Program (CARP). CARP constitutes an interesting case study because it represents a land reform with a relatively restrictive ceiling (a 1.75 ratio of ceiling to pre-reform average farm size), an extensive coverage in terms of land and beneficiaries, a fairly successful redistribution with most of the targeted land having been redistributed by early 2000s (Philippine Department of Agrarian Reform, 2006). The redistribution covered all agricultural lands (private and public). CARP imposed a ceiling of 5 Ha on land ownership. Land was acquired on both a compulsory and a voluntary-offer-to-sell basis 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 the post-reform 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 in 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%.[34] We then impose a land ceiling with a restrictiveness ratio of 1.75 on this economy. The first column of Table 8 shows that the ceiling produces an increase in the share of employment in agriculture of over 3 percentage points, a reduction in average farm size of 7.0%, a reduction in agricultural labor productivity of 7.0%, and a reduction in aggregate labor productivity of 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 and productive

[34]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 $\kappa = 1/3.9$. The data sources are provided in Appendix A.

farms causing a drop in agricultural productivity. The drop 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).

In evaluating the impact of land reforms which often take time for the associated redistribution of land to take place, many studies rely on the time series evidence for the period following the reform. In the context of our model, the evolution of aggregate variables can mask the impact of the reform on size and productivity. In fact, while the land reform has a substantial negative effect on agricultural productivity in the model, the data for the Philippines show an increase in agricultural productivity for the period 1988-2000. We introduce the relevant changes in aggregate factors for the Philippines between 1988-2000: (a) a reduction in land per capita of -26.9% and (b) an increase in the capital-output ratio and non-agricultural productivity of 3.8% and 9.9%. Table 8 introduces these factors into the economy after the land reform. Quantitatively, combining these forces with the reform, the model accounts for the salient features of the Philippines' experience over 1988-2000.

Table 8: Philippine Land Reform – Changes 1988-2000

	Ceiling	$+\Delta L$	$+\Delta(\frac{K}{Y}, A)$	Data
N_a (%)	48.5	48.6	43.0	37.6
AFS (%Δ)	-7.0	-32.1	-23.2	-29.6
$\frac{Y_a}{N_a}$ (%Δ)	-7.0	-7.2	5.2	9.5
$\frac{Y}{N}$ (%Δ)	-5.8	-6.0	13.4	16.4

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 (see column 2 in Table 8), 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. 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 $\ell > \widehat{\ell}$. The characterization of the farmer problem is provided in Appendix B.

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.[35] 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 produce minus "ordinary" expenses of cultivation, which include mainly intermediate inputs).[36] 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

[35] 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`.

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

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. We calculate aggregate factors and reproduce the agricultural employment share in 1976 Pakistan following the same approach as in the land reform application.[37]

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 τ_H that is 50% higher than the pre-reform uniform tax rate (the average of 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.

The first column of Table 9 reports the results of implementing the progressive land tax policy. The model generates an increase in the share of employment in agriculture of less than 2 percentage points, a reduction in average farm size of 3.1%, a reduction in agricultural labor productivity of 3.2%, and a reduction in aggregate labor productivity of 3.3%.

Table 9: Progressive Land Taxation in Pakistan – Changes 1976-1985

	Progressive Tax	$+\Delta L$	$+\Delta(\frac{K}{Y}, A)$	Data
N_a (%)	55.6	58.6	45.4	48.7
AFS (%Δ)	-3.1	-31.1	-11.0	-28.7
$\frac{Y_a}{N_a}$ (%Δ)	-3.2	-8.2	19.3	11.8
$\frac{Y}{N}$ (%Δ)	-3.3	-8.9	40.1	36.3

We also incorporate changes in aggregate factors over 1976-1985: a reduction in land per capita of 29.9%, an increase in non-agricultural productivity of 23.2%, and a decrease in the capital-output ratio of 13.3%. Combining these changes with the policy reform in the model, the results capture

[37]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 reproduce a pre-reform share of employment in agriculture of 53.9%. The data sources are provided in Appendix A.

the observed changes in the key variables of interest with the exception of the average farm size which ends up falling less than in the data. Because the increase in non-agricultural productivity was particularly stellar in Pakistan over 1976-1985, it dominates the opposing effects of the capital-output ratio, masking the negative productivity effects of the progressive land tax.

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

7 Discussion

In this section we discuss three issues: potential amplification mechanisms; the experiences of today's developed economies through the lens of our model; and robustness on the elasticity between capital and land.

7.1 Amplification Channels

The effects of farm-size distortions in our model may be limited by the fact that we abstract from mechanisms that could amplify their effects. For instance, land reforms effectively reallocate land across farmers but this reallocation in the model does not affect the average ability of farmers in production. In practice, land reforms not only redistribute factors of production across farmers, but also can potentially create a selection effect by encouraging low-productivity producers to become farmers. Similarly, distortions to farming activity, especially distortions that disproportionately affect the return of high-productivity producers, discourage investments in productivity improvement and, as a result, negatively affect the distribution of farmer's ability. In both of these examples, the productivity impact of distortions is amplified by distorted decisions – occupational choice and productivity investment – that are absent in the model. There are several amplification channels that have been considered in the literature.[38]

In the context of a model of agriculture and development, selection effects have been explored by Lagakos and Waugh (forthcoming) where individuals are heterogenous in their ability to produce in the agricultural and non-agricultural sectors. Exogenous economy-wide or agriculture-specific productivity differences across countries create selection whereby the average ability of workers in agriculture falls when the level of productivity is lower. An interesting finding in Lagakos and Waugh is that differences in exogenous productivity are amplified substantially by this selection channel. When economy-wide productivity and agriculture-specific productivity are reduced exogenously to match pertinent features of poor countries, then agricultural productivity differences are amplified by a factor of 1.5 (see their Table 6). To put this number in perspective, note that if we take the results of the empirical measure of distortions, the implied factor difference in agricultural productivity would increase from 23.9 to 35.9, much closer to the data (46.7-fold difference).

7.2 Evidence across Time

We have analyzed the factors leading to farm size differences across countries at a point in time. There are also considerable changes in farm size over time for individual countries. For instance, developed countries such as Canada and the United States have seen tremendous increases in average farm size over the last century. In Canada, average farm size increased 7-fold from 1871 to 2006 whereas in the United States it increased 4-fold from 1880 to 1997.[39] Despite the fact that the model was constructed to address differences across countries, can it shed light on the time series experiences of today's developed economies?

[38] In the context of the misallocation literature see Restuccia and Rogerson (2013) and the references therein.

[39] At the same time, several developing countries have experienced substantial drops in average farm size (see for example Eastwood, Lipton, and Newell, 2010). The disparity in average farm size between rich and poor countries has more than doubled from 1960 to 1990, implying that the average farm size of developing countries has not kept pace with that of rich countries. Our case studies on specific farm-level policies in Section 6 can shed light on the divergence of farm size across countries.

As a first pass, we explore the importance of aggregate factors in accounting for time series data by focusing on the historical experience of the United States. Average farm size increased by a factor of 3 from 1929 to 1990 (the period for which we have the all the data to perform the analysis). At the same time, while the amount of land in farms was roughly constant during this time period, the increase in population produced a decrease in land per capita (land per worker) of more than 60%. Labor productivity in non-agriculture increased by a factor of 3 while the capital to labor ratio was roughly constant. Unlike in the cross-country analysis, when we look at changes over time for individual countries we cannot abstract from changes in labor productivity in agriculture (captured by increases in the agricultural specific parameter κ). The reasons is that it is well-known than labor productivity growth (and total factor productivity) has been faster in agriculture than non-agriculture and that this process is critical in understanding the reallocation of labor out of agriculture (see for example Jorgenson, 1995). This is the case not only in the United States but virtually in every country in the cross-country data (see for instance Duarte and Restuccia, 2010). In fact, the data for the US indicates that the increase in labor productivity in agriculture from 1929 to 1990 was 18 fold (vs the 3-fold increase in non-agriculture).[40] When we feed in the values for land per capita, economy-wide productivity, capital, and agriculture-specific productivity to match the observations on land per capita, capital accumulation, and labor productivity growth across sectors, we find that the model roughly reproduces the reallocation of labor, a share of employment in agriculture of 26% vs 22% in the data, and the entire increase in average farm size we have observed for the United States. We take this to suggest that the model has the potential to account for the behavior of the U.S. over time.

[40]It would be interesting to assess the importance of labor reallocation across farms over time in explaining agricultural labor productivity growth, similar to the work on the manufacturing sector which indicates that the reallocation process across plants explains about half the productivity growth in that industry, e.g. Baily, et al. (1992) and Foster et al. (2008).

7.3 Robustness

We evaluate the robustness of our results to variations in the elasticity of substitution between capital and land ρ. Recall that when ρ approaches 0, capital and land enter the production function of agriculture as a Cobb-Douglas term. In this case, capital to land ratios are equalized across farms and this in turn implies that labor productivity across farms varies much more than in the data for the United States. Alternatively, when ρ approaches 1, capital and land are perfect substitutes in agricultural production and this implies that labor productivity is equalized across farms. Our calibration of ρ was disciplined by the ratio of capital to land between the smallest and largest farm size categories reported in the U.S. data and therefore implicitly restricts the pattern of labor productivity across farms sizes.

To assess the importance of this elasticity for our results (and the importance of the empirical observations used to restrict it) we compute the experiment of generic farm-size distortions for alternative values of ρ. In each case we only recalibrate the value of the aggregate capital stock so that the capital to output ratio is as observed between rich and poor countries. Table 10 reports the results for the share of employment in agriculture, average farm size, and agricultural and labor productivity. The results show that less substitution between capital and land would actually amplify the results of the model. The evidence from direct estimates of production functions as well as the observed differences in labor productivity across farms in poor and rich countries suggest that extreme values for ρ are not supported but then the results are fairly robust to values of ρ in the range between 0.1 and 0.4.

8 Conclusions

There are substantial differences in farm size across countries. Agricultural production in rich countries is characterized by large farms, whereas in poor countries by small farms. We developed a

Table 10: Robustness Results with Generic Farm-Size Distortions

	ρ				
	0.01	0.1	0.24	0.4	0.95
Employment in Agriculture N_a (%)	75.5	70.4	65.2	61.7	55.1
Average Farm Size (AFS)	39.3	36.3	34	32.1	28.7
Labor Prod. in Agriculture ($\frac{Y_a}{N_a}$)	53.9	50.2	46.9	43.9	39.2
Aggregate Labor Productivity ($\frac{Y}{N}$)	23.0	19.6	17.0	15.6	13.5

Note: Average farm size, labor productivity in agriculture and aggregate labor productivity are reported as the ratio between the benchmark economy and the poor economy. Farm-size distortions represent the model with aggregate factors and generic farm-size distortions. Results reported for each value of ρ in each case only adjusting the aggregate capital stock K to match the disparity in capital to output ratios in the experiments.

tractable quantitative framework to organize our understanding of the factors impacting farm size and productivity across countries. Our focus has been on two sets of factors: (a) aggregate factors (land, capital accumulation, and economy-wide productivity), and (b) farm-level policies in poor countries that misallocate resources from large-productive to small-unproductive farms.

A key feature of our analysis is that we quantitatively assess the extent of misallocation in agriculture in poor countries using observable policy measures. We do this in two ways. First, for a cross-section of countries we introduce an empirical summary measure of farm-size distortions by exploiting the variation in crop-level price distortions within countries. We find that our model with aggregate factors and our empirical measure of distortions can account for half of the gaps in farm size and productivity between rich and poor countries. From this just under half is accounted by aggregate factors alone. Second, we study two specific policies that generate misallocation in two case studies. The first is a land reform that caps size in the Philippines, and the second is a progressive land tax 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. Our analysis has abstracted from several institutions and policies that are important in practice in determining the allocation of land across farms in poor countries. For instance, as prevalent as land ceilings are, they are distinct from episodes of massive redistribution of land that effectively replace experienced more able farmers and large-scale operations with inexperienced farmers and government organized small-scale farms. These drastic redistributions of land coupled with imperfections in land markets (e.g., limited property rights and lack of land titles) are likely to be an important obstacle to size and productivity in poor countries (see for instance Bardhan and Udry, 1999 and Goldstein and Udry, 2008). A related issue is to explicitly consider amplification channels such as selection into agriculture and how this may interact with institutions and policies in poor countries. We also think that exploring the time series observations across countries with a dynamic model can be useful in shedding light on several issues raised in this paper. For example, 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 issues for future research.

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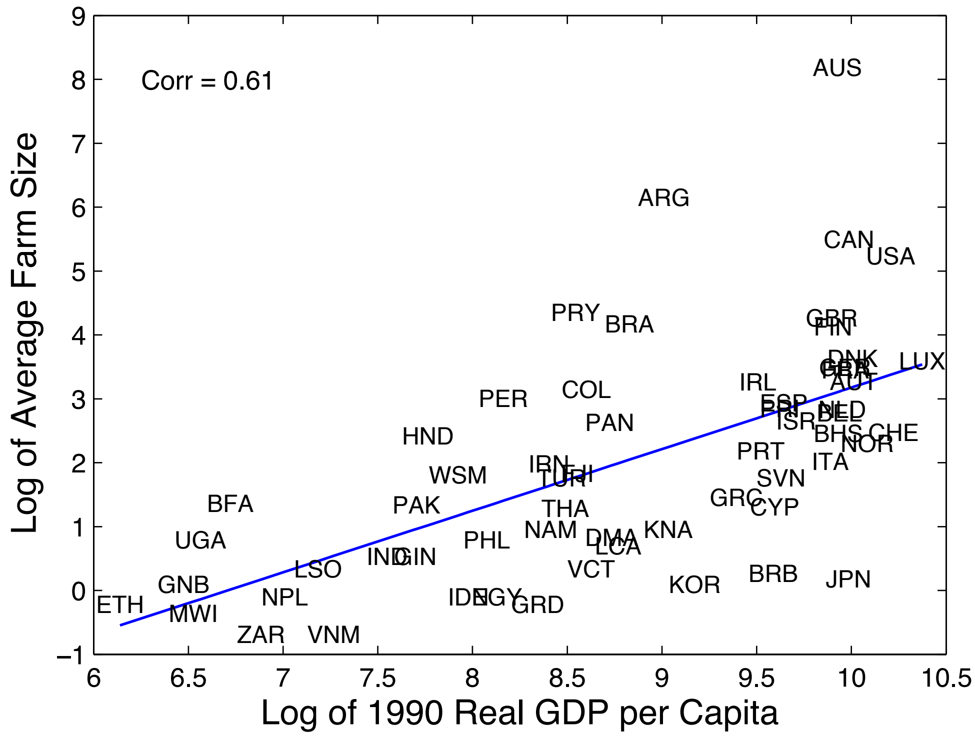


Figure 1: Average Farm Size across Countries

Panel A: Small Farms (<5 Ha)

Panel B: Large Farms (>20 Ha)

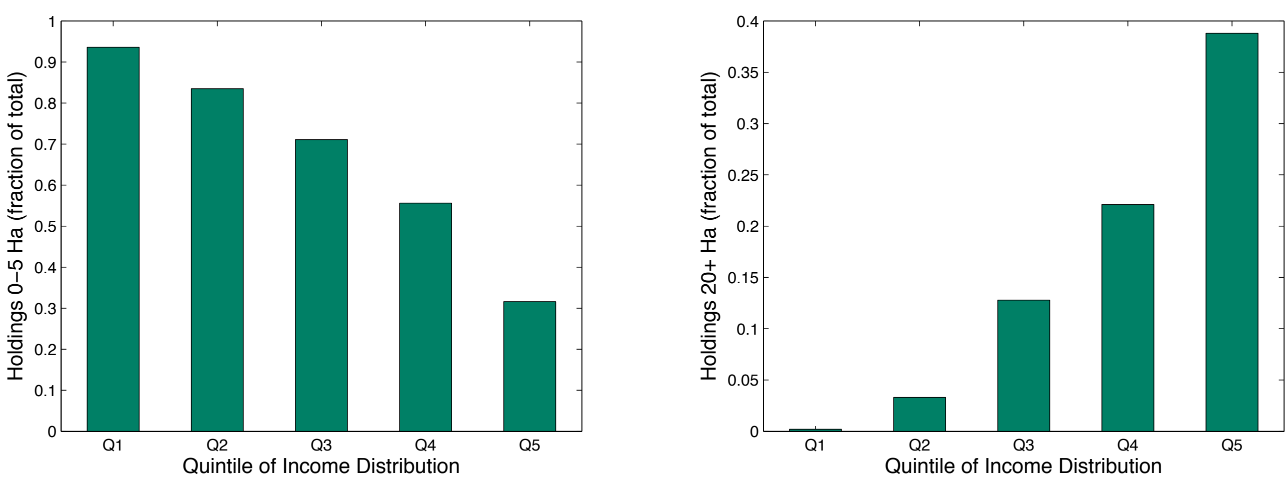


Figure 2: Share of Small and Large Farms across Countries

Panel A: Small Farms (<5 Ha) Panel B: Large Farms (>20 Ha)

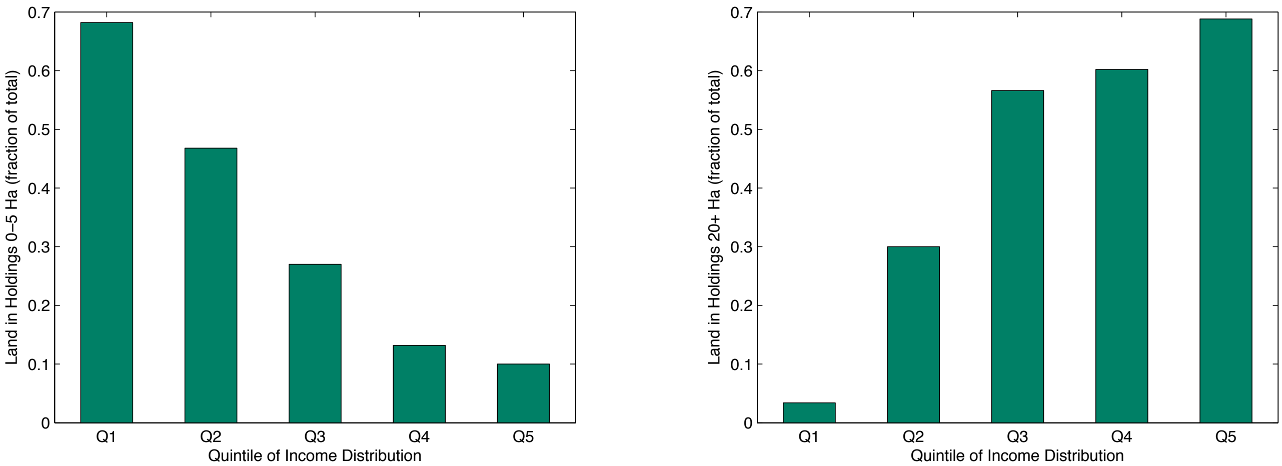


Figure 3: Share of Land in Small and Large Farms across Countries

Panel A: Size Distribution Panel B: Capital-Land Ratio

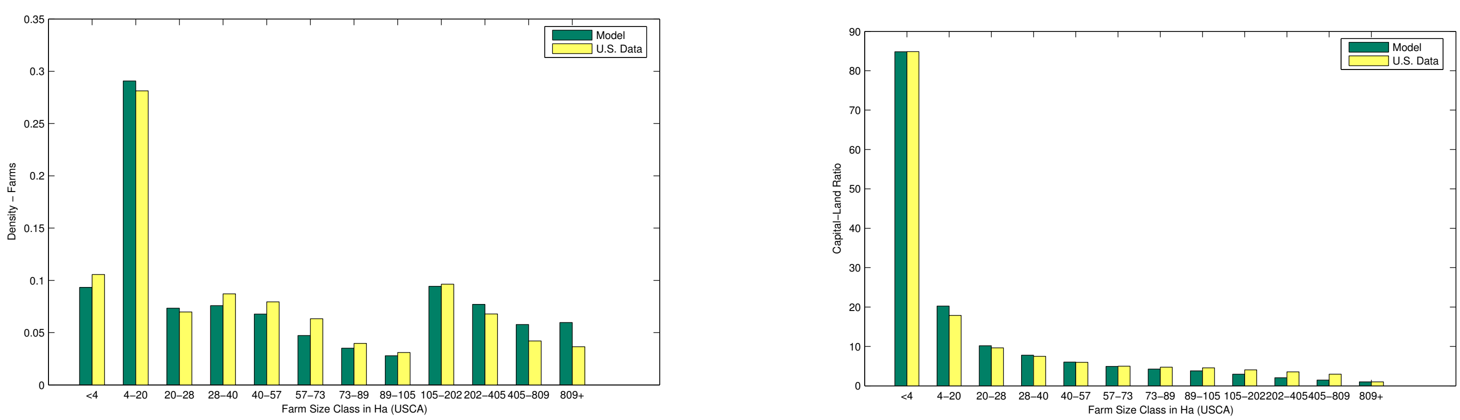
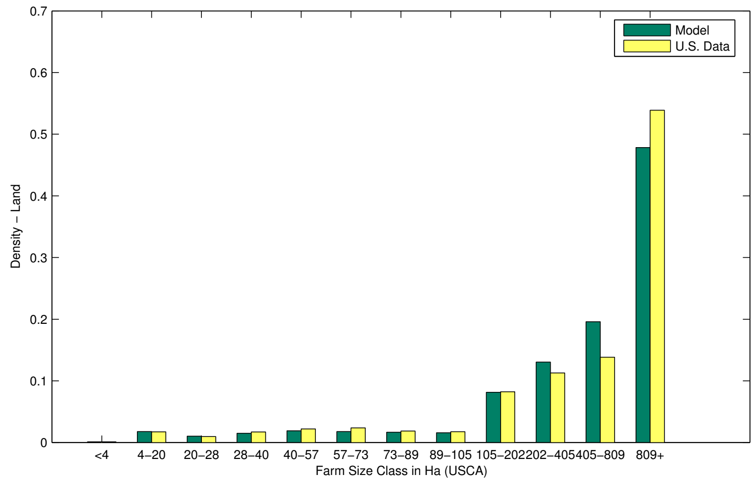
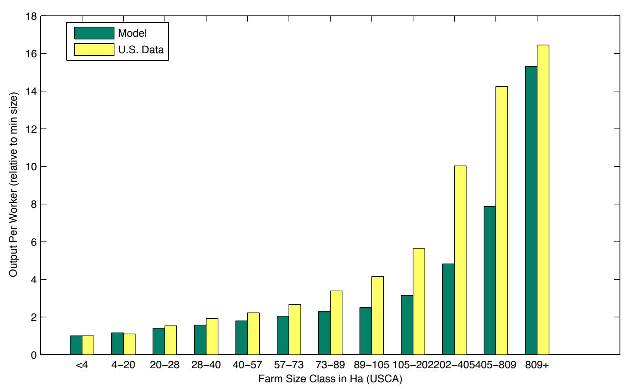


Figure 4: Calibrated Variables by Farm Size

Panel A: Land Distribution



Panel B: Output per Worker



Panel C: Output per Hectare

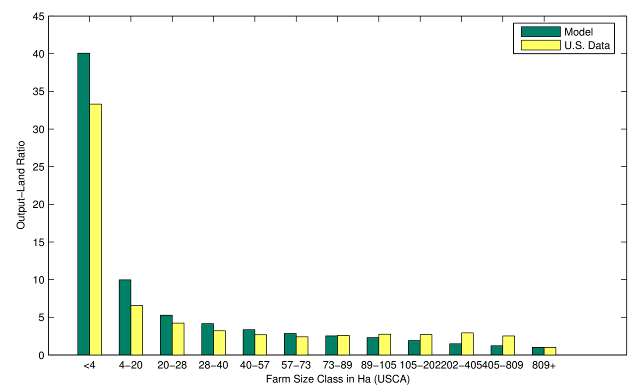


Figure 5: Other Variables by Farm Size

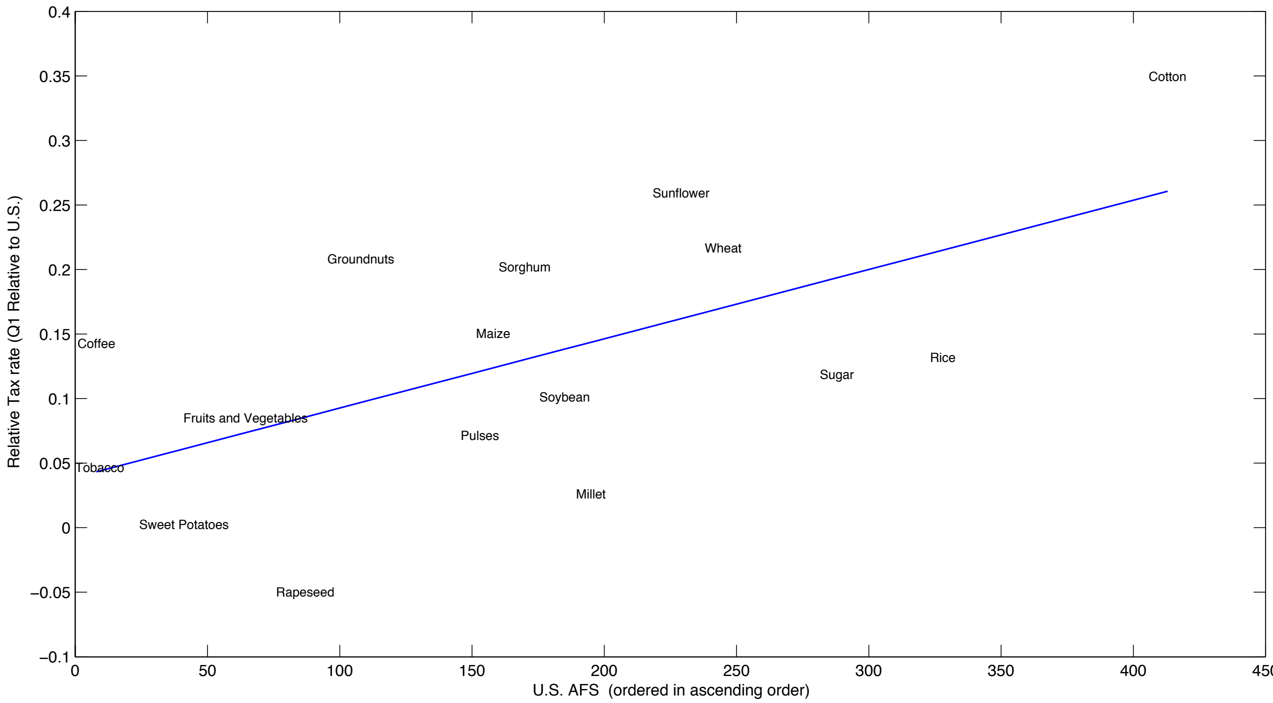


Figure 6: Empirical Farm-Size Distortions