University of Toronto
Department of Economics

Working Paper 573

Untitled Land, Occupational Choice, and Agricultural Productivity

By Chaoran Chen

December 23, 2016

Untitled Land, Occupational Choice, and Agricultural Productivity

Chaoran Chen*

December 20, 2016

Abstract

The prevalence of untitled land in poor countries helps explain the international agricultural productivity differences. Since untitled land cannot be traded across farmers, it creates land misallocation and distorts individuals' occupational choice between farming and working outside agriculture. I build a two-sector general equilibrium model to quantify the impact of untitled land. I find that economies with higher percentages of untitled land would have lower agricultural productivity; land titling can increase agricultural productivity by up to 82.5%. About 42% of this gain is due to eliminating land misallocation, and the remaining due to eliminating distortions in individuals' occupational choice.

Keywords: Agricultural Productivity, Untitled Land, Misallocation, Occupational Choice.

JEL classification: J24, O13, Q12.

*Department of Economics, University of Toronto, 150 St. George Street, Toronto, Ontario, Canada, M5S 3G7 (Email: chaoran.chen@mail.utoronto.ca). I thank the editor, Richard Rogerson, and two anonymous referees for detailed suggestions. I am grateful to my advisor Diego Restuccia for his continued guidance and support. I have also benefited from the comments of Ashique Habib, Burhanettin Kuruscu, Carolyn Pitchik, Ronald Wolthoff, Xiaodong Zhu, Jiaqi Zou, and various seminar participants. All errors are my own.

1 Introduction

Agricultural productivity is important for understanding international income differences. The international labour productivity differences are much larger in agriculture than in non-agriculture (Caselli, 2005; Restuccia, Yang and Zhu, 2008). Moreover, poor countries tend to have higher employment shares in agriculture. Therefore, it is crucial to understand why agriculture is far less productive in poor countries. A large literature has focused on explaining this agricultural productivity gap, but a substantial portion of the gap remains unexplained. In this paper, I propose a novel explanation: the prevalence of untitled land in poor countries lowers their agricultural productivity.

Untitled land refers to land without legal ownership. This type of land could be owned by the community, the government, or even a king. Farmers cannot trade or rent this land as they do not have land tenure. Empirical studies find that untitled land exists widely in developing countries with poor institutions, yet is almost non-existent in rich countries.

In this paper I quantify how variation in land titling across countries can help explain the agricultural productivity differences. To guide my analysis, I build a general equilibrium model with an agricultural sector and a non-agricultural sector. In this model, an individual chooses to work in one of the two sectors. If she chooses to be a farmer, she operates a farm whose size depends on her farming ability, following Lucas (1978). If she chooses to become a worker, she gets a wage income proportional to her working ability. My model contributes to the literature by introducing untitled land in the economy. I assume that untitled land cannot be rented/traded across farmers, and therefore it can only be used by whomever it is allocated to. In consequence, land is misallocated among farmers. Furthermore, the occupational choice of individuals is distorted, since individuals choosing to work in the non-agricultural sector would have to forfeit their untitled land.

I use this model to quantify how the variation of untitled land across countries would affect their agricultural productivity. I calibrate a benchmark economy with no titled land to the data for a poor country. Then I conduct experiments by titling some of the land in this economy and therefore allowing the titled land to be rented freely across farmers. This experiment shows that economies with higher percentages of titled land would have substantially higher agricultural productivity. In particular, from the benchmark economy, titling all of the land increases agricultural productivity by 82.5%. This productivity gain arises in the model from both eliminating land misallocation and reducing distortions in occupational choice, accounting for 42.1% and 57.9% of the total effects, respectively.

While this model is stylized, it still captures the salient features of poor economies with untitled land. Nevertheless, I discuss several extensions of the model allowing for different setups. These extensions allow for the expropriation risks of structures on untitled land, the informal rental agreements of untitled land, part-time farming, and a frictional capital market. I find that, in general, the main results of the baseline experiment still hold under these extensions.

This paper is related to the macro literature on the international agricultural productivity differences.[1] The most closely related paper is Adamopoulos and Restuccia (2014), which is the first to study the farm size distribution and misallocation in agriculture across countries. My paper builds on their

[1]Please see Gollin, Parente and Rogerson (2002), Gollin, Parente and Rogerson (2004), Gollin, Parente and Rogerson (2007), Restuccia, Yang and Zhu (2008), Adamopoulos (2011), Lagakos and Waugh (2013), Gollin and Rogerson (2014), Donovan (2014), Tombe (2015), and Gottlieb and Grobovšek (2015), among others.

framework but focuses on the role of untitled land as a specific form of land misallocation. I explore the variation of land titling across countries and study how this specific form of land misallocation affects the international agricultural productivity differences. Adamopoulos and Restuccia (2015*b*) focus on another specific form of land misallocation, the ceiling imposed on land holdings during a land reform in the Philippines. They study how the ceiling of land holdings and the redistribution of excess lands affect agricultural productivity over time when the reform was being implemented, in contrast to the cross-country analysis of my paper. Restuccia and Santaeulàlia-Llopis (2015) study factor misallocation in agriculture in a poor country, Malawi. They measure wedges to quantify misallocation and associate these wedges to land market restrictions. I study a specific source of misallocation, untitled land, and quantify the extent to which the empirical variation of untitled land across countries can account for the observed dispersion in agricultural productivity.

My paper is also related to the empirical development literature studying the effect of untitled land at the micro level.[2] To the best of my knowledge, my paper is the first to study the macroeconomic implications of untitled land. My paper also bridges the misallocation literature and the literature studying institutions as a key determinant of economic growth.[3] The lack of land titles is a prominent property rights issue creating misallocation in the agricultural production.

The paper proceeds as follows. Section 2 documents facts on untitled land across countries and shows evidence of the negative impact of untitled land

[2] See Banerjee, Gertler and Ghatak (2002), Banerjee and Iyer (2005), and Goldstein and Udry (2008), among others.

[3] For the misallocation literature, see Restuccia and Rogerson (2008) and Hsieh and Klenow (2009), among others. For the literature studying institutions, see Alchian and Demsetz (1973) and Acemoglu, Johnson and Robinson (2005), among others.

on productivity. Section 3 describes the model. In Section 4, I calibrate the model and perform a quantitative analysis by granting a title to land. Section 5 discusses on different extensions of the model. Section 6 contains concluding remarks.

2 Empirical Evidence

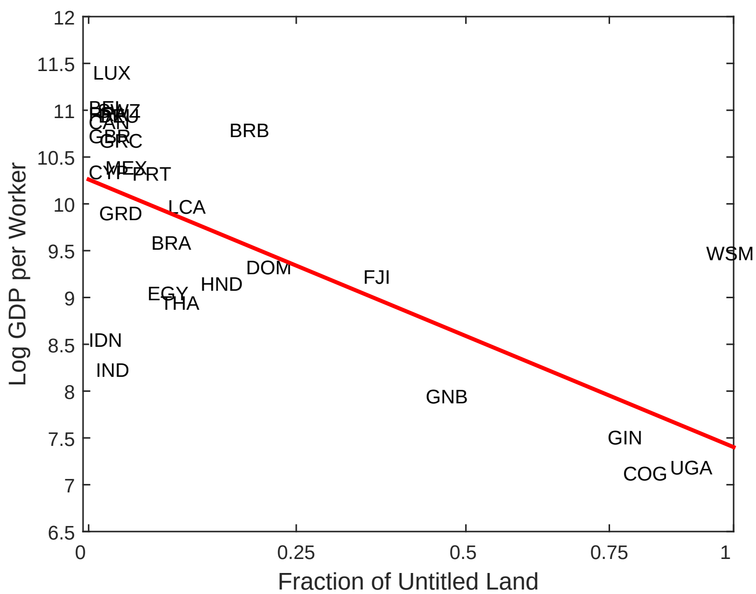
Untitled land refers to land without legal (official) ownership. In developing countries, there are different types of untitled land, including communal land and land with insecure tenure. In this paper, I focus on farmers' ability to trade/rent land to distinguish titled and untitled land.[4]

The extent of land titling differs substantially between rich and poor countries. Internationally-comparable data are available from the Food and Agricultural Organization (FAO). FAO defines land tenure as the relationship between a farmer and land she operates concerning her possibilities to use and control this land. I treat a plot of land as *titled* if it is "owned by the holder or in ownerlike possession" or "rented from others". It follows that, the remaining land, such as "land operated on squatter basis" or "under tribal or traditional communal forms of tenure", shall be considered *untitled*.[5] Based on the above criterion, Figure 1 shows a clear negative relationship between the fraction of untitled land and the gross domestic product (GDP) per worker; countries with high GDP per worker tend to have less untitled land. In partic-

[4]As will be clear in Section 3, inability to trade/rent land generates land market misallocation and distortion in occupational choices in my model.

[5]This classification gives an approximation of how land titling differs across countries. It is noteworthy that "land rented from others" (which I treat as titled) may not necessarily mean that there is formal title of this land. Instead, it may be an informal arrangement which is common in developing countries. Therefore, this measure is likely underestimating the true percentage of untitled land. See Appendix B.1 for a detailed description of the data.

Figure 1: Land Titling and GDP



Notes:
[1] The data for land titling are from Table 3.3 of the *Report on the 1990 World Census of Agriculture*. GDP data of the year 1990 are from *Penn World Table 7.1*.
[2] Both axis are in log scale.

ular, the three richest countries in the sample (Luxembourg, Switzerland, and Germany) all have less than 1% of untitled land, whereas the three poorest countries all have large fractions of untitled land (77.6% in D.R. Congo, 86.8% in Uganda, and 74.7% in Guinea).

Other works also describe the land market institutions in the developing world. For example, Doss et al. (2015) estimate the percentage of untitled land across six African countries: Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda.[6] In Malawi, one of the poorest countries in the world, only 1.5%

[6]They use data from *Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA)*. They classify agricultural land as “owned” or “accessed”. I only consider the “owned” land. A piece of land is treated as titled in my paper if it is “documented”. Undocumented land is treated as untitled. The “accessed” land pieces are most likely untitled, since they are mainly granted by local leaders. Nevertheless, I exclude these accessed

of sampled land is titled. This number is 9.8% in Niger, 12% in Tanzania, 21% in Uganda, and 50% in Ethiopia.[7] Feder and Onchan (1987) survey land in three provinces of Thailand, and find that 689 of 1409 land plots are untitled. Goldstein and Udry (2008) study untitled land in south Ghana, where a chief allocates land across villagers, rather than allow the land to be traded in the market. This allocation of land is inefficient because it is based on nepotism and not villagers' ability. Furthermore, if farmers do not use their allocated land, they are likely to lose it.

Farmers may rent untitled land informally, but informal arrangements can be costly and highly inefficient. For example, Deininger, Ali and Alemu (2008) find that in Ethiopia, where the property rights are not secure, most farmers tend to rent out their land to their relatives and friends, rather than the most productive villagers.

Extensive empirical micro-level works have identified that untitled land impedes economic development of poor countries. For example, Banerjee, Gertler and Ghatak (2002) study a government-implemented tenancy reform in West Bengal, India. They take a quasi-experimental approach to control for selection and identify that secure tenure has a positive effect on agricultural productivity. Banerjee and Iyer (2005) explore a variation in land tenure security across India arising from colonial institutions. They find lower agricultural productivity in areas where property rights of land historically belonged to landlords instead of the cultivators themselves. Galiani and Schargrodsky (2010) exploit a natural experiment of land titling in Argentina and conclude that land titling can be an important tool for poverty reduction. These micro studies, at both the household and regional levels, show that land titling

pieces to be conservative, since the title is not explicitly stated.

[7] Nigeria has a different documentation system and I exclude it here.

increases agricultural productivity.

Guided by these micro-level works, my paper studies the macroeconomic implications of land titling by focusing on two impacts of untitled land. First, untitled land cannot be traded/rented, resulting in misallocation in the land market. This channel is supported by empirical findings that land rentals improve agricultural productivity (Restuccia and Santaeulàlia-Llopis, 2015). Second, as suggested by several recent studies (Do and Iyer, 2008; de Janvry et al., 2015), I model how untitled land distorts farmers' occupational choices. Furthermore, I also explore expropriation risks as an extension of my model.

3 A Model with Untitled Land

My two-sector general equilibrium model builds on Adamopoulos and Restuccia (2014) with two extensions. First, I introduce untitled land in the economy. Second, I allow individuals to choose their occupation between the two sectors following Lagakos and Waugh (2013).

The model is static. There are two sectors in the economy: agriculture and non-agriculture. Goods produced by both sectors are for consumption only. I normalize the price of the non-agricultural good to 1, and let the price of the agricultural good be p.

A measure 1 of heterogeneous individuals can choose to be either a farmer in the agricultural sector or a worker in the non-agricultural sector. Each individual is endowed with a pair of abilities $\mathbf{z} = (z_a, z_n)$ drawn from a joint distribution $H(\mathbf{z})$, where z_a and z_n denote her farming and working abilities, respectively. Moreover, individuals receive a heterogeneous endowment of untitled land holdings. Once abilities and endowments are realized, individuals make their occupational choice.

3.1 Technologies

The non-agricultural good is produced by a representative firm with a Cobb-Douglas technology which takes capital k_n and labour n_n as inputs:

$$y_n = An_n^{1-\alpha_n} k_n^{\alpha_n},$$

where A is the economy-wide total factor productivity (TFP) and α_n is the capital share in non-agriculture.

The agricultural good is produced by home-operated farms according to the following production function, which takes capital k_a and land l as inputs:

$$y_a = A\kappa z_a[\omega k_a^{\eta} + (1-\omega)(z_a l)^{\eta}]^{\frac{\gamma}{\eta}}. \tag{1}$$

Here κ is agriculture-specific productivity, z_a is the farmer's ability of operating the farm, η is the elasticity between capital and land inputs, and $\gamma \in (0, 1)$ governs the return to scale. The labour input of a farm is assumed to be inelastic and therefore normalized to 1.[8] Farmers' abilities are assumed to be land-augmenting.[9]

3.2 Preferences and Endowments

Individuals have preferences over the consumption of the agricultural good (c_a) and the non-agricultural good (c_n). The preferences are described by the

[8]I assume farmers employ their family members for labour and do not hire any labour from the labour market, following Adamopoulos and Restuccia (2014). Table 3.5 of the *Report on the 1990 World Census of Agriculture* shows that, among the 55 countries reported, each farm on average uses 5.26 household member workers, and only 0.2 outside-hired workers who work more than 6 months per year.

[9]This assumption is required for fitting the yield curve observed in the data: yield (land productivity) tends to decrease with farm size. See a detailed discussion on this assumption in Adamopoulos and Restuccia (2014).

following non-homothetic utility function:

$$u(\mathbf{c}) = \phi \log(c_a - \bar{c}) + (1 - \phi) \log c_n. \tag{2}$$

Here $\bar{c}$ measures the individuals' subsistence level of consumption, and ϕ is the weight that individuals assign to agricultural goods.

The economy is endowed with K units of capital, which is perfectly mobile between sectors. Firms and farms rent capital for production. The endowment of capital is evenly distributed among individuals, who all earn the same capital return.[10]

The land endowment is L units. There are two kinds of land in the economy: titled land and untitled land, which are perfect substitutes in production. Titled land is also evenly distributed among individuals and can be rented at the market rate. Farmers also own some untitled land, which cannot be rented in the market. As a result, the size distribution of untitled land is exogenous. Farmers do not pay anything for the untitled land they are using. Let θ denote the percentage of land in the economy that is untitled.[11]

3.3 The Profit Maximization Problems

A farmer with productivity z_a and untitled land holdings $\bar{l}$ solves the following profit maximization problem:

$$\max_{k_a, l} \quad pA\kappa z_a[\omega k_a^\eta + (1 - \omega)(z_a l)^\eta]^{\frac{\gamma}{\eta}} - rk_a - C(l, \bar{l}),$$

[10]Given preferences in the form of Equation (2), the ownership structures of capital and land do not affect the equilibrium provided that they can be rented. Therefore, for simplicity, I assume individuals hold equal shares of capital and titled land.

[11]In some poor countries, even titled land may not be traded due to other frictions in land market. In this case, that type of titled land can be treated as untitled in my analysis, as I focus on farmers' ability to trade/rent land to distinguish titled and untitled land. It is also possible that some untitled land could be rented informally. I study this informal rental as an extension to the model in Section 5.2.

where r is the interest rate and $C(l,\bar{l})$ is the cost function of land. This cost function takes the form of $C(l,\bar{l}) = 0$ if $l \leqslant \bar{l}$, and $C(l,\bar{l}) = q(l-\bar{l})$ if $l > \bar{l}$, where q is the rental rate of titled land. This cost function means that a farmer with $\bar{l}$ units of untitled land could use any amount of land up to $\bar{l}$ units at no cost. Lemma 1 in Appendix A shows that it is optimal to choose the land input $l \geqslant \bar{l}$. This is to say, it is optimal for a farmer to use all of her untitled land.[12] The farmer then obtains not only the residuals of operating the farm, but also the land income share from her untitled land. This extra income from land distorts the occupational choice, which I discuss in Section 3.6.

The profit maximization problem of the representative firm in the non-agricultural sector is given by

$$\max_{k_n,n_n} \quad Ak_n^{\alpha_n} n_n^{1-\alpha_n} - rk_n - \tilde{w}n_n,$$

where k_n and n_n denote capital and efficient labour inputs respectively, at costs of interest rate r and wage $\tilde{w}$. Note that labour input is defined in efficient labour units. Assume workers supply one unit of time inelastically to the labour market. A worker with productivity z_n has z_n units of efficient labour, and obtains wage payment of $w(z_n) = z_n\tilde{w}$. Factor demands are given by

$$r_n = A\alpha_n\Big(\frac{k_n}{n_n}\Big)^{\alpha_n-1}; \qquad \tilde{w} = A(1-\alpha_n)\Big(\frac{k_n}{n_n}\Big)^{\alpha_n}.$$

3.4 Utility Maximization and Occupational Choice

An individual can choose to be either a farmer in the agricultural sector or a worker in the non-agricultural sector. If she chooses to be a farmer, she obtains her profit of operating her farm $\pi(z_a,\bar{l})$; if she chooses to be a worker, she

[12]In principle, the farmer could choose to use a portion of her untitled land and give up the extra, but this would not maximize her profit, as Lemma 1 shows.

receives her wage payment $w(z_n)$.[13] Moreover, working in the non-agricultural sector is subject to a labour income tax of rate ξ. As a result, workers receive post-tax labour income of $(1-\xi)w(z_n)$. This tax captures the labour mobility barrier between sectors, which I will discuss in detail in the calibration. A similar setup is also adopted in Adamopoulos and Restuccia (2014).

Given prices, the tax rate, and the wage rate, an individual makes her occupational choice based on her ability in both sectors, as well as her untitled land holdings. Since her utility is strictly increasing in income, she chooses the occupation that yields a higher income. Let dummy variable D denote the occupational choice of an individual: $D = 1$ when an individual chooses to be a farmer. Therefore, $D \in \arg\max\{(1-D)(1-\xi)w(z_n) + D\pi(z_a, \bar{l})\}$.

Individuals choose their occupations after abilities and untitled land holdings are realized. Individuals who choose to be workers will have to give up their untitled land. I assume that untitled land surrendered by workers is proportionally transferred to farmers based on these farmers' initial untitled land holdings. For example, if Farmer 1 initially has twice as much untitled land as Farmer 2, then Farmer 1 will receive twice as much transferred land as Farmer 2. It follows that, the ex post distribution of untitled land is simply a rescaling of the ex ante distribution among those who choose to become farmers. When choosing their occupations, individuals have rational expectation on the employment share of agriculture, and can therefore deduce the amount of reallocated land they will receive if they choose to be farmers.

3.5 Equilibrium

I focus on the competitive equilibrium of the model, which is defined as follows.

[13] Functions such as profit $\pi(z_a, \bar{l})$ also depend on aggregate variables $(p, q, r, \tilde{w})$. To simplify notation, I omit them whenever possible.

Definition 1. *Denote the individual state variables $\{z_a, z_n, \bar{l}\}$ as s. A competitive equilibrium is a set of prices $\{p, q, r, \tilde{w}\}$, a set of farmers' consumption bundles $\{c_a(s), c_n(s)\}$ $\forall s$, a set of workers' consumption bundles $\{\tilde{c}_a(s), \tilde{c}_n(s)\}$ $\forall s$, a set of farmers' factor demands and outputs $\{k_a(s), l(s), y_a(s)\}$ $\forall s$, a dummy indicating occupational choices $D(s)$ $\forall s$, and a set of factor demands and output of the representative firm $\{k_n, n_n, y_n\}$, such that*

1. *Given prices, farmers and workers maximize their utility subject to their budget constraint. $\{c_a(s), c_n(s)\}$ $\forall s$ solve the farmers' problem, and $\{\tilde{c}_a(s), \tilde{c}_n(s)\}$ $\forall s$ solve the workers' problem.*

2. *Given prices, factor demands and output $\{k_n, n_n, y_n\}$ are profit maximizing for the representative firm, and $\{k_a(s), l(s), y_a(s)\}$ $\forall s$ are profit maximizing for farmers.*

3. *Markets clear:*

   (i) Labour market: N_a and $1 - N_a$ are measures of farmers and workers respectively. The labour market clearing condition for the non-agricultural sector is $\int_s z_n(1 - D(s))F(ds) = n_n$ where F is the cumulative distribution function of state s over individuals.

   (ii) Capital market:

$$K = \int_s k_a(s)D(s)F(ds) + k_n.$$

   (iii) Non-agricultural good:

$$\int_s c_n(s)D(s)F(ds) + \int_s \tilde{c}_n(s)(1 - D(s))F(ds) = y_n.$$

(iv) Agricultural good:

$$\int_s c_a(s)D(s)F(ds) + \int_s \tilde{c}_a(s)(1-D(s))F(ds) = \int_s y_a(s)D(s)F(ds).$$

(v) Titled land market: denote θ as the ratio of untitled land over all land. Then

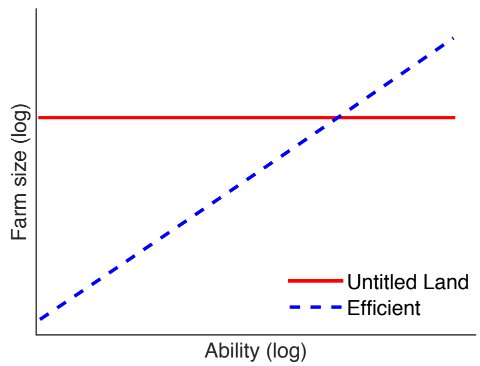
$$(1-\theta)L = \int_s (l(s) - \bar{l}(s))D(s)F(ds).$$

3.6 Characterization of the Model

In this section, I give a numerical example to describe how untitled land affects agricultural productivity through two channels: land misallocation and distortions in occupational choice. I compare two economies: one where all land is untitled and another where all land is titled. To simplify this comparison, I further assume farmers have equal amounts of untitled land in this example.

Untitled land creates misallocation in the land market. Figure 2 plots farmers' operational scales over their ability. In the economy without untitled land (the dashed line), operational scales are increasing in farmers' ability, independent of their land endowments. The equilibrium implies that marginal product of land is equalized across farmers. However, in an economy with 100% untitled land uniformly distributed across farmers (the solid line), the operational scales are constant across farmers. Even though low ability farmers have untitled land holdings larger than their optimal scales, they cannot rent out extra untitled land. Consequently, their marginal products of land will be lower than that of other farmers. Conversely, despite the fact that high ability farmers have untitled land holdings smaller than their optimal scales, they cannot rent land from other farmers as there is no titled land for rent in the market. Therefore, their marginal product of land will be higher than

Figure 2: Land Misallocation

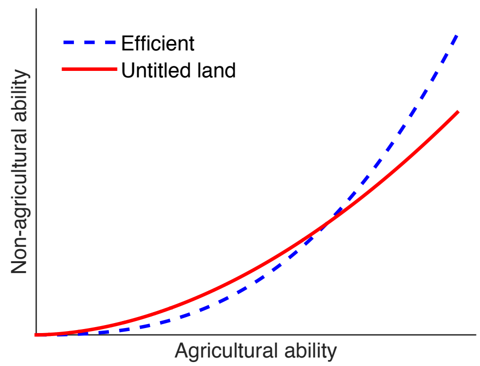


Notes:
[1] The dashed line shows the farm size distribution across farmers in an economy without untitled land; the solid line shows the farm size distribution in an economy where no land is titled.
[2] Farms are sorted by farmers' ability.

other farmers. This dispersion in the marginal product of land across farmers indicates land misallocation.

Untitled land also distorts the occupational choice of individuals. Figure 3 shows the occupational choice problem of individuals. An individual with abilities $(\tilde{z}_a, \tilde{z}_n)$ on the curve is indifferent between farming and working. The dashed line represents the indifference curve in the economy with 100% titled land, and the solid line represents the one in the economy with 100% untitled land. In the latter case, more low ability individuals become farmers, as the solid line is above the dashed line at the lower left corner. This is because individuals do not pay for their usage of untitled land, and are therefore implicitly subsidized. Low ability individuals (located at the lower left corner) tend to have low income in both sectors, so this subsidy is attractive to them. If they choose to become workers, they would lose their untitled land and, with it, this implicit subsidy. Consequently, the occupational choice of low ability

Figure 3: Distortions in Occupational Choice



Notes:
[1] An individual with abilities $(\tilde{z}_a, \tilde{z}_n)$ on the curve is indifferent between being a farmer and a worker. The dashed line is the indifference curve in the benchmark economy without untitled land; the solid line is the one in an economy where no land is titled.
[2] Individuals above (below) the curve strictly prefer being a worker (farmer).

individuals is distorted in favour of farming. In contrast, fewer high ability individuals become farmers in the economy with untitled land. As discussed before, the prevalence of untitled land reduces the supply of land available for rent. If high ability farmers cannot expand their farm size to their optimal scales, farming becomes the less attractive alternative.[14] As more low ability individuals and fewer high ability individuals choose to become farmers in an economy with untitled land, the average ability of farmers is reduced. This phenomenon is confirmed in my baseline experiment in Section 4.2.

[14] Note that this distortion in occupational choice is different from the self-selection mechanism studied in Lagakos and Waugh (2013). In their framework, the ability ratio $\frac{z_a}{z_n}$ is a sufficient statistic for occupational choice. All individuals who have the same ability ratio will be affected in the same direction by this self-selection mechanism. In my model, however, the distortion in occupational choice affects high and low ability individuals differently, regardless of their ability ratio.

4 Quantitative Analysis

4.1 Calibration

As untitled land is an issue mainly for poor countries, I calibrate my model to reflect salient features of poor countries, as opposed to Adamopoulos and Restuccia (2014) and Lagakos and Waugh (2013), who calibrate their benchmark economy to the United States. My basic strategy is to consider a poor economy with 100% untitled land ($\theta = 1$) and calibrate it to the empirical moments of a poor country. I choose Malawi for my calibration as it has almost no titled land and is thus very relevant to my study. However, the calibrated parameter values of my model are comparable to the related literature, and therefore the calibrated economy reflects general features of poor countries with untitled land and is not limited to Malawi only.

The calibration process includes determining parameter values governing the ability distributions, technologies, preferences, and untitled land holdings. I start by describing the assumptions on the functional forms. I then list the parameters to be calibrated, and discuss what moments I use to infer these parameters.

4.1.1 Functional Forms

I first describe my assumptions on the functional forms of the ability distribution and the distribution of untitled land holdings. Note that I use some data moments from the study of Restuccia and Santaeulàlia-Llopis (2015) to guide my choice of these functional forms and the associated parameter values.[15]

[15] For a detailed description of the data, see Restuccia and Santaeulàlia-Llopis (2015), who use micro data on Malawi from the Integrated Surveys on Agriculture (ISA) to quantify misallocation in agriculture. I thank Diego Restuccia and Raül Santaeulàlia-Llopis for providing additional moments and statistics from their data.

Ability distribution.—I assume that the joint distribution of the two-dimensional ability $\mathbf{z} = (z_a, z_n)$ takes the following functional form:

$$H(z_a, z_n) = C_p[\Phi_a(z_a), \Phi_n(z_n)],$$

where

$$\Phi_a(z_a) = 1 - e^{-z_a^{\zeta_a}}, \quad \Phi_n(z_n) = 1 - e^{-z_n^{\zeta_n}},$$

and

$$C_p(u, v) = -\frac{1}{\rho} \log \left[1 + \frac{(e^{-\rho u} - 1)(e^{-\rho v} - 1)}{e^{-\rho} - 1}\right].$$

Ability z_a and z_n follow Weibull distributions with cumulative distribution functions Φ_a and Φ_n, which have dispersion parameters ζ_a and ζ_n. C_p is a Frank copula with correlation coefficient ρ. I choose the ability distribution to be Weibull in order to generate a negative skewness of (log) farm output in the calibrated economy to match observed data.[16] There are three parameters associated with the ability distribution: ζ_a and ζ_n govern the dispersion of ability, and ρ determines the correlation between the two dimensions of ability.

Untitled land distribution.—I choose the distribution of untitled land across farmers to match the land distribution described by Restuccia and Santaeulàlia-Llopis (2015). In particular, Restuccia and Santaeulàlia-Llopis (2015) find that (log) untitled land holdings and (log) farmer's ability have a weak linear positive correlation. Guided by these findings, I assume the following functional form of untitled land across farmers:

$$\log \bar{l}^i = \beta_0 + \beta_1 \log z_a^i + \varepsilon^i,$$

[16]Note that the lognormal distribution generates a roughly zero skewness of log farm output in the equilibrium and the Fréchet distribution generate a positive skewness, both of which contradict with the data. As a result, these distributions are not chosen.

where $\bar{l}^i$ and z_a^i denote the untitled land holdings and ability of farmer i, and ε is a random variable following a normal distribution with a standard deviation of σ_ε. β_1 and σ_ε jointly determine the dispersion of untitled land and its correlation with farming ability. β_0 is a scale parameter to be determined in equilibrium.

4.1.2 Parameters and Moments

In total there are 16 parameters to be calibrated: six technology parameters ($\{A, \kappa, \alpha_n, \eta, \gamma, \omega\}$), two preferences parameters ($\{\bar{c}, \phi\}$), three parameters governing the ability distribution ($\{\zeta_a, \zeta_n, \rho\}$), two endowment parameters ($\{K, L\}$), two parameters governing the distribution of untitled land ($\{\beta_1, \sigma_\varepsilon\}$), and one parameter of tax (ξ). Eight of them ($\{A, \kappa, \alpha_n, \eta, \gamma, \phi, \rho, L\}$) are either normalized or assigned values that are common to existing work. The remaining eight are jointly determined by requiring the model moments to exactly match eight data moments.[17] I now discuss how the values of these parameters are determined.

Technologies: $\{A, \kappa, \alpha_n, \eta, \gamma, \omega\}$.—The first four parameters are directly assigned values common to existing work. The economy-wide productivity A and the agriculture-specific productivity κ are both normalized to one. In the non-agricultural sector, I set $\alpha_n = 0.33$ to match the capital share of 0.33. In the agricultural sector, I set η, which determines the elasticity of substitution between capital and land in agriculture, to 0.24, such that the elasticity between capital and land is 1.32, following Binswanger (1974) and Adamopoulos and Restuccia (2014).

The last two parameters, γ and ω, determine the factor shares in agri-

[17] Appendix B.2 describes in detail my data source of the moments used in this calibration.

culture. There is some consensus that the labour share in agriculture should be around one half for most countries (Gollin, Lagakos and Waugh, 2014*b*). Therefore, I follow Adamopoulos and Restuccia (2014) and set $\gamma = 0.54$ to target a labour share of 0.46, which falls in the acceptable range. The remaining 0.54 is the sum of capital and land shares. In the U.S., the land share is 0.18, which is only half of the capital share (Valentinyi and Herrendorf, 2008). However, this ratio may not apply to poor countries. For instance, Haley (1991) find that in Sub-Saharan Africa, the land share is roughly three quarters of the capital share; Restuccia and Santaeulàlia-Llopis (2015) estimate the land share to be even larger from survey data of Malawi: about two times that of the capital share. I choose the midpoint between Valentinyi and Herrendorf (2008) and Restuccia and Santaeulàlia-Llopis (2015), and assign 0.27 to land share and 0.27 to capital share. Since a higher land share would make the negative impact of land misallocation larger, I do not use the higher land share from Restuccia and Santaeulàlia-Llopis (2015) to be conservative. A land share of 0.27 requires $\omega = 0.57$. As factor shares are important to the quantitative analysis, I also report the results when the factor shares are assigned to be consistent with either Valentinyi and Herrendorf (2008) or Restuccia and Santaeulàlia-Llopis (2015) in Appendix C.1.

Preferences: $\{\phi, \bar{c}\}$.—I follow the literature and set $\phi = 0.005$ by assuming a long-run agricultural employment share of 0.5%. The level of subsistence consumption $\bar{c}$ is set to 0.68 to match the current agricultural employment share of 64.1% in Malawi. Note that $\bar{c} > 0$ implies that the income elasticity of the agricultural good is smaller than one, which is consistent with the well-known stylized fact that poorer countries in general have larger agricultural employment shares.

Endowments: $\{K, L\}$.—I choose the capital endowment K to match the capital-output ratio of Malawi. There is a large literature documenting the distorted price of investment in poor countries (Jones, 1994; Restuccia and Urrutia, 2001). Therefore, I calculate the capital-output ratio following Caselli (2005) and using the internationally comparable data from Penn World Table 6.3, which adjusts the price of capital using price data from the World Bank's International Comparison Program. This yields a capital-output ratio of 1.01 in Malawi, which requires $K = 0.72$ in the calibration. I set the aggregate land endowment L to be 0.53 such that the average farm size is 0.83 hectare to match the Malawi data.[18]

Ability distribution: $\{\zeta_a, \zeta_n, \rho\}$.—Parameters ζ_a and ζ_n govern the dispersion of ability. I choose $\zeta_a = 1.28$ such that, given the distribution of untitled land holdings, the model generates a variance of (log) farm output of 1.54, as found in the data of Restuccia and Santaeulàlia-Llopis (2015). I choose $\zeta_n = 0.92$ to match a Gini coefficient of 0.48 for workers' income in Malawi's non-agricultural sector. The correlation parameter ρ is difficult to determine using our data. I follow Lagakos and Waugh (2013) and set $\rho = 2.24$ to match the Spearman's rank correlation of 0.35 between the two dimensional abilities. This choice of correlation is comparable to the literature: for instance, Adamopoulos et al. (2016) also find a similar correlation from panel data on China. Nevertheless, I do perform robustness checks on different values of ρ in Appendix C.2, and my results are not sensitive to this parameter.

The distribution of untitled land: $\{\beta_1, \sigma_\varepsilon\}$.—I choose these two parameters to match two moments in the data of Restuccia and Santaeulàlia-Llopis (2015):

[18] The measure of agricultural employment is 0.641 and the land endowment is 0.53, implying the average farm size to be $0.53/0.641 = 0.83$.

Table 1: Calibration: Targets and Results

Category and Parameter		Value	Target
Technology	A	1	Normalization
	κ	1	Normalization
	ω	0.57	Agricultural capital share
	η	0.24	Elasticity between capital and land
	γ	0.54	Agricultural labour share
	α_n	0.33	Non-agricultural capital share
Preference	$\bar{c}$	0.68	Current agricultural employment share
	ϕ	0.005	Long-run agricultural employment share
Endowments	L	0.53	Average farm size
	K	0.72	Capital-output ratio
Ability	ζ_a	1.28	Variance of farm output in agriculture
	ζ_n	0.92	Gini coefficient in non-agriculture
	ρ	2.24	Spearman correlation of 0.35
Untitled land	σ_ε	0.78	Dispersion of land holdings
	β_1	0.22	Correlation between land and ability
Barrier	ξ	0.90	Labour productivity between sectors

the dispersion of (log) untitled land holdings among farmers is 0.77 and the correlation between farmer's ability and untitled land holdings is 0.12. These moments result in parameter values of $\beta_1 = 0.22$ and $\sigma_\varepsilon = 0.78$.

Barrier: $\{\xi\}$.—The agricultural employment share is 64.1% in Malawi, while the agricultural value added share is only 30.8%. This means that labour productivity in the non-agricultural sector is around four times that of the agricultural sector. This is consistent with Gollin, Lagakos and Waugh (2014*b*), who find an "agricultural productivity gap" especially for many poor countries. To capture this nominal labour productivity gap in my model, I introduce a barrier to labour mobility between sectors in my model: recall that a worker in the non-agricultural sector is subject to labour income tax $\xi \in (0, 1)$ such that her post-tax income is $(1 - \xi)w$. I set the tax rate ξ to be 0.90 such that the labour productivity in non-agriculture is also four times of that in agriculture.[19] By matching this between-sector productivity gap, the value added share in agriculture is therefore also matched. It is important to match the agricultural value added share in order to correctly quantify the impact of untitled land on the non-agricultural sector and the aggregated labour productivity. Finally, I note that I keep this tax rate ξ to be unchanged in the quantitative analysis.

Table 1 summarizes the value of all 16 parameters as well as the targeted moments. Recall that eight parameters $\{A, \kappa, \alpha_n, \eta, \gamma, \phi, \rho, L\}$ are either normalized or assigned values directly, while the remaining eight parameters are jointly determined by requiring eight equilibrium model moments to match eight data moments exactly. For convenience, I will refer to this calibrated economy as my benchmark economy hereafter.

4.2 Baseline Experiment

4.2.1 Land Titling in the Benchmark Economy

Given the above setup, I study how agricultural productivity would change if all the untitled land were to be titled. In the latter case, farmers can now rent their land frictionlessly in a competitive land market. As a result, the operational scales of farmers will no longer coincide with their land endowments. Note that everything else remains unchanged in this experiment, including the endowment of capital and the barrier to labour mobility.

[19] A tax rate of 0.90 means that the marginal individual's labour productivity in agriculture is around 10% of that in non-agriculture; the average labour productivity, however, only differs by 4.0 folds between sectors.

Table 2 summarizes the results of this experiment. Eliminating untitled land only changes the aggregate agricultural output slightly, as demand for the agricultural good is mainly for subsistence consumption and is thus inelastic. Eliminating untitled land, however, increases the agricultural labour productivity drastically (82.5%). This productivity gain comes from the two channels described in Section 3.6: the elimination of land misallocation, and the reduction of the distortions of occupational choice. As a result of this increased productivity, less resources are required to produce the agricultural good. Notably, agricultural employment share drops from 64.1% to 35.4%, and the fraction of capital allocated to agriculture drops from 26.7% to 14.2%.[20]

After eliminating untitled land, the median farmer's ability increases by 38.2%. This is mainly because occupational choice is no longer distorted, as discussed in Section 3.6. It is also due to standard self-selection in the general equilibrium: as agricultural employment share decreases, only individuals with relatively higher agricultural ability stay in agriculture (Lagakos and Waugh, 2013; Young, 2014). Since individuals' agricultural ability and non-agricultural ability are positively correlated in my calibration, the median farmer's ability increases at the cost of a decrease of the median worker's ability (20.0%).

There are also spillover effects to the non-agricultural sector. With land titling, the aggregate output of the non-agricultural sector increases by 38.8%, since more labour and capital can now be allocated to the non-agricultural sector. This is consistent with the traditional wisdom that improving agricultural productivity does not necessarily increase the output in agriculture, but triggers growth in the non-agricultural sector (Gollin, Parente and Rogerson,

[20]Note that the fractions of capital and value added in agriculture are lower than that of labour, mainly because of the labour mobility barrier (ξ) which generates the gap of value added per labour and capital-labour ratio between the two sectors.

Table 2: Eliminating Untitled Land

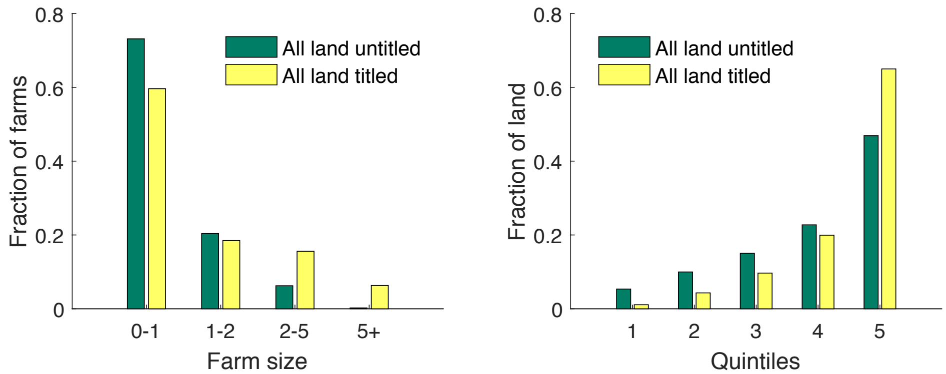
	Benchmark (Normalized to 1)	All Land Titled
Agriculture:		
Aggregate Output (Y_a)	1	1.01
Labour Productivity (Y_a/N_a)	1	1.82
Employment Share (N_a/N)	64.1%	35.4%
Capital Usage Share (K_a/K)	26.7%	14.2%
Value Added Share ($pY_a/(pY_a + Y_n)$)	30.8%	19.6%
Non-Agriculture:		
Aggregate Output (Y_n)	1	1.39
Labour Productivity (Y_n/N_n)	1	0.77
Real GDP ($\bar{p}Y_a + Y_n$)	1	1.27
Median Individual's Ability:		
Farmer	1	1.38
Worker	1	0.80

Note:
[1] The first column (the benchmark economy) refers to the economy where no land is titled. The second column refers to the economy where all land is titled, while everything else remains unchanged.
[2] All variables, except for agricultural share of employment, capital, and value added, are normalized to 1 in the benchmark economy.
[3] Real GDP is computed with the price fixed at the benchmark level ($\bar{p}$).

2007). Labour productivity of non-agriculture, however, decreases by 22.8%. This is because the number of workers increases by around 80% after land titling, so both the median worker's ability and the capital-labour ratio decrease in the non-agricultural sector. The economy-wide GDP, which is also GDP per capita as $N = 1$, increases by 27.1%. Note that this GDP should be interpreted as *real* GDP, since it is computed with the price fixed at the benchmark level with 100% untitled land. *Nominal* GDP, computed using the new price after land titling, increases less than real GDP, as the agricultural good is cheaper after land titling when its productivity is higher.

Note that capital stock is kept invariant in this experiment. It follows that,

Figure 4: The Size Distribution of Farms



Note: In the right panel I show the fraction of farms falling into different size classes. In the left panel I sort farms into quintiles according to their size and then plot the fraction of land operated by farms of each quintile.

as nominal GDP increases by 19.5%, the capital-output ratio decreases from 1.01 to 0.85. If the capital-output ratio is kept to be constant to capture the capital accumulation effect, then gains from land titling would be even larger: agricultural labour productivity would increase by 98.8%, instead of the 82.5% in my baseline experiment; real GDP would also increase by 40.0% instead of 27.1%.

Land titling drastically affects the size distribution of farms. First, as fewer individuals choose to become farmers after land titling, the average farm size increases from 0.83 hectare to 1.50 hectares. The magnitude of change is exactly the same as the agricultural employment share, since the land endowment is fixed. The left panel of Figure 4 confirms this pattern: the fraction of farms larger than 2 hectares increases drastically after land titling. Second, the inequality of farm size is higher among farmers. The right panel of Figure 4 shows the size distribution of farms before and after land titling. After land titling, the largest 20% of farms account for 65% of total land, which is a large increase from the 47% in the benchmark economy, while the land share of the smallest 20% of farms shrinks from 5% to barely 1%. This difference is intuitive, as the distribution of untitled land in the benchmark economy, as in many poor countries, is more egalitarian, while efficient land distribution tends to allocate more land to a small fraction of talented farmers.

As discussed in Section 3.6, the 82.5% agricultural productivity gain can be decomposed into two channels: the benefits from eliminating (1) land misallocation and (2) distortions in occupational choice. To quantify the contribution of each component, I first estimate the impact of eliminating land misallocation by implementing land titling while keeping occupational choice constant. Note that, at this stage, I do not impose the agricultural good market clearing condition. Land titling is found to increase agricultural productivity by a factor of 1.288. Therefore, eliminating misallocation explains $\log(1.288)/\log(1.825) = 42.1\%$ of total productivity gain, and the remaining 57.9% can be explained by eliminating distortions in occupational choice.

4.2.2 Cross-Country Analysis

Recall from Section 2 that the extent of land titling varies across countries, and is systematically correlated with their GDP per worker: poor countries tend to have more untitled land than rich countries. To study the effect of land titling in an economy with less than 100% untitled land, I now allow the fraction of untitled land (θ) in my model to take on a value between 0 and 1, where θ closer to 1 represents more untitled land in the economy. This experiment helps us to understand how variation in land titling can explain international differences in agricultural productivity.

Figure 5: The Impact of Untitled Land

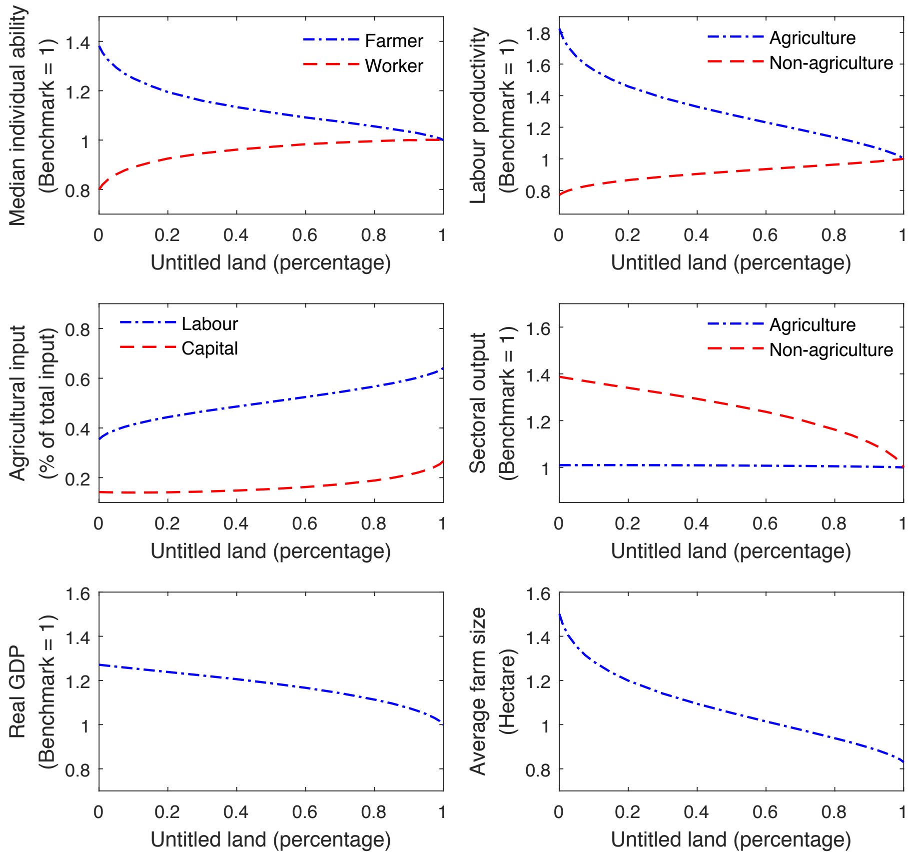


Figure 5 shows the results for different values of θ. The upper-left panel shows that as the fraction of untitled land increases, median farmer ability decreases while median worker ability increases. This is because occupational choice is distorted by untitled land as discussed before. Note that the slope of the curves are steepest near 0 percent untitled land. This result is quite intuitive. As discussed previously, low ability individuals are more sensitive to the implicit subsidy from untitled land. Therefore, as the fraction of untitled land increases, low ability individuals will be the first to respond to it by changing their occupation to farming, followed by high ability individuals. As there are considerably more low ability individuals than high ability ones, median abilities change faster when θ is small.

Agricultural labour productivity decreases with the fraction of untitled land, as shown in the upper right panel. A typical Sub-Saharan country with about 80% untitled land can increase its agricultural productivity by about 50% through land titling. This curve is also steepest near 0 percent untitled land, since median farmer ability changes fastest there. Agricultural labour productivity also changes rapidly near 100% untitled land, as land misallocation is the most severe here. Non-agricultural labour productivity increases with θ, for the same reason discussed in Section 4.2.1.

The aggregate output in the agricultural sector changes minimally with θ, since demand for the agricultural good is relatively inelastic. Since agricultural productivity decreases with θ, more resources need to be allocated to the agricultural sector to produce the inelastic demand. The middle left panel shows that, as the fraction of untitled land increases, agricultural employment share and percentage of capital in agriculture both increase. It follows that, labour and capital allocated to the non-agricultural sector decreases with θ. Therefore, the aggregate output in the non-agricultural sector also decreases with θ (middle right panel). Its slope is largest around $\theta = 1$, in the same pattern as the allocation of labour and capital inputs between sectors of the middle left panel.

Real GDP is computed with price fixed at the case of 100% untitled land. Since agricultural output is fairly stable while non-agricultural output decreases with θ, real GDP also decreases with θ (bottom left panel). Recall that the population is normalized to one, hence real GDP coincides with real GDP per capita.

The bottom right panel shows that average farm size decreases with θ. Again, since the land endowment is fixed, the average farm size changes in a pattern exactly opposite to that of agricultural employment share.

To conclude, a larger fraction of untitled land tends to decrease agricultural labour productivity as well as median farmer ability. It also increases agricultural employment share and reduces average farm size.

5 Discussion

In this section, I extend my model to allow for 1) land improvement and expropriation risk of capital, 2) informal rentals of untitled land, 3) part-time farming, and 4) a frictional capital market. Recall the baseline experiment which finds that, in an economy with 100% untitled land, land titling increases agricultural productivity by 82.5%. Let us now re-consider this experiment with these four extensions. I find that the benefits of land titling under these extensions are similar to those of the baseline experiment. I also discuss the relevance of land quality differences across countries, and between titled and untitled land.

5.1 Land Development and Expropriation Risk

Empirical studies have found that the presence of untitled land reduces farmers' incentive to invest, in particular in long term projects associated with land development, as they would be concerned about expropriation risk. For example, Feder and Onchan (1987) compare titled and untitled land plots in Thailand, and conclude that titled plots has a significantly higher probability of being improved by bunding or clearance of stumps. Banerjee and Iyer (2005) study Indian data and find that in regions where land tenure is historically more secure, proportion of irrigated area is 7.7 percentages higher, compared to regions where land tenure is less secure. To capture the idea that farmers are concerned about expropriation on untitled land, I extend my model to incorporate land development as a form of investment and expropriation risk on agricultural capital.

Farmers can invest in structures (denoted as k_s), such as irrigation and grading, to improve their land. Hence, I assume these structures enter the production function as land augmenting: the *efficient* land unit is $k_s^{\alpha_s} l^{1-\alpha_s}$. A farmer can invest asymmetrically in structures across their titled and untitled land. The total efficient land unit of a farm is given by $\tilde{l} = k_{st}^{\alpha_s} l_t^{1-\alpha_s} + k_{su}^{\alpha_s} \bar{l}^{1-\alpha_s}$, where l_t and $\bar{l}$ are titled and untitled land, while k_{st} and k_{su} are structures situated on titled and untitled land, respectively.[21] Again we maintain the assumption that the *efficient* unit of titled and untitled land are perfect substitutes in production. The production technology is now given by $y = A\kappa z_a[\omega k_e^\eta + (1-\omega)(z_a\tilde{l})^\eta]^{\frac{\gamma}{\eta}}$, where k_e is equipment input (compared to land-enhancing structures), which can be used as a common resource across both titled and untitled land plots on the farm.

Farming on untitled land is subject to an exogenous expropriation risk. Farmers risk losing the portion of their structures situated on untitled land (k_{su}). That is, they can still keep the portion of structures on their titled land (k_{st}) as well as all of their equipment (k_e) and output (y).[22] Therefore, the risk of capital loss in expropriation increases the expected cost of capital in

[21] Note that separating the land of a farm into two components — titled and untitled land is without loss of generality, since the land augmenting technology is constant return to scale.

[22] Goldstein and Udry (2008) find that untitled land is more likely to be expropriated during fallow seasons when farmers are not cultivating anything on the land. Hence, I assume farmers keep all of their output and equipment under expropriation.

structures on untitled land. The profit maximization problem is now

$$\max_{k_e, k_{st}, k_{su}, l_t \geqslant 0} \quad py - r(k_e + k_{st} + k_{su}) - \phi_{\exp} p_k k_{su} - c(l, \bar{l}),$$

where $\phi_{\exp}$ is the probability of expropriation and p_k is the price of the capital good relative to the numeraire in my model (the non-agricultural good). Farmers know the probability of expropriation and maximize their *expected* profit. Individuals make their occupational choice based on how this expected profit compares to workers' wage.

I re-calibrate the model to include this expropriation risk. The details can be found in Appendix D. Parameters existing in my benchmark model are calibrated to match the same moments. There are three more parameters in this calibration: $p_k, \alpha_s, \phi_{\exp}$. I choose $p_k = 3.94$ as it is Malawi's local price of investment relative to consumption from the Penn World Table. I set $\alpha_s = 0.53$ so that the structures of land development account for 40.1% of agricultural capital stock, as FAO reports for Malawi. Data on expropriation risk are not directly available for Malawi. I target the expropriation risk $\phi_{\exp} = 6.7\%$, implying that expropriation happens on average once every 15 years, roughly consistent with what Goldstein and Udry (2008) find for Ghana, another poor country in Sub-Saharan Africa.[23] Given that data on expropriation risk are quite limited, I also show how the results respond to changes in the expropriation risk in my quantitative analysis. The calibrated model generates investment on land development comparable to the literature. For example, Goldstein and Udry (2008) estimate that when expropriation risk

[23] Goldstein and Udry (2008) find that there is virturally no expropriation risk when a plot of land is being cultivated, but the risk increases to 20% - 40% annually when the land is left fallowed. On average, farmers have held their plots for a period between 5 to 16 years when they are surveyed. Hence, my choice of expropriation risk at once every 15 years falls in the right range and is conservative.

Table 3: The Impact of Expropriation Risk

	Labour productivity Y_a/N_a	Equipment K_e	Structures $K_{st}+K_{su}$	Structures on titled land $K_{st}/(K_{st}+K_{su})$
All land titled (normalized to 1)	1	1	1	100%
No land titled:				
$\phi_{\exp}=0$	0.67	1.47	1.24	0%
$\phi_{\exp}=6.7\%$	0.62	2.22	0.87	0%
$\phi_{\exp}=20\%$	0.58	3.41	0.58	0%
80% untitled land:				
$\phi_{\exp}=0$	0.74	1.17	1.08	39%
$\phi_{\exp}=6.7\%$	0.72	1.47	0.97	60%
$\phi_{\exp}=20\%$	0.70	1.77	1.03	87%

Note: All variables, except for the fraction of structures on titled land, are normalized to 1 in the case where all land is titled.

increases from around 6% to 10%, the period of fallow, as a form of land improvement, decreases by 12%. My model predicts that with the same increase of expropriation risk, investment in structures, or land improvement, will drop by 15.9%, similar to their estimation.[24]

Table 3 summarizes the results. Given expropriation risk $\phi_{\exp}=6.7\%$, land titling in an economy with no titled land can increase agricultural productivity by 60%(=1/0.62). Introducing land development and expropriation risk has two effects. First, allowing for land development alleviates land misallocation: productive farmers who cannot expand their farm size physically can now invest in land development. Occupational choice is also less distorted for the same reason. Second, the risk of expropriation introduces capital misallocation. To see this, consider again the case where all land is untitled. When the

[24]See Goldstein and Udry (2008) Table 9 for the category of "male, plot from same abusua". In this comparison, I use my model's prediction in the economy with 100% untitled land, which corresponds to the case of Southern Ghana studied by Goldstein and Udry (2008).

expropriation risk increases, farmers invest more in equipment, which cannot be expropriated, as a substitute for structures. These two forces work in opposite directions, and therefore the efficiency gain of land titling remains similar to my baseline experiment.

It is also interesting to study intermediate cases where some land is untitled. I consider an economy with 80% untitled land as this is the empirically relevant case: expropriation mainly happens in the poorest countries with large fractions of untitled land. With expropriation risk, farmers allocate structures asymmetrically between titled and untitled land (see bottom of Table 3). As the risk of expropriation increases, farmers over-invest in titled land and under-invest in untitled land. For example, without expropriation risk, farmers allocate 39% of structures to titled land, while this number increases to 87% when expropriation risk increases to 20%.[25] With more structures on titled land and less on untitled land, the total structures in an economy will not be monotone in expropriation risk.

This experiment can also quantify how agricultural productivity responds to changes in the expropriation risk. In an economy with 100% untitled land, agricultural productivity drops by 13.2% when the risk of expropriation increases from zero to 20%. In an economy with 80% untitled land, however, agricultural productivity drops by only 4.9% with the same amount of increase in expropriation risk, since expropriation risk does not affect titled land, which will have more structures and higher yield.

[25] Note that without expropriation risk, farmers whose farms consist both titled and untitled land will allocate structures symmetrically, but farmers whose farms consist only untitled land can invest less on structures. As a result, in the aggregate economy, structures are still allocated asymmetrically between titled and untitled land.

5.2 Informal Rentals

Farmers may participate in informal arrangements to facilitate untitled land reallocation: a low ability farmer with extra untitled land may rent out her land informally to a high ability farmer, which can potentially reduce land misallocation. However, in practice, informal rental arrangements may not be efficient. This is because, in real life, farmers in poor countries generally prefer renting their land to relatives and close friends rather than more productive individuals to reduce the risk of losing the land. For example, Deininger, Ali and Alemu (2008) look at Ethiopia, where land tenure is insecure. There, they find that around 90% of land rentals happen within relatives and friends.

Nevertheless, I extend my model to incorporate informal rentals, allowing individuals to rent their untitled land efficiently (rather than only within friends). Renting out untitled land is generally more costly, since there does not exist a formal market to facilitate transactions. I therefore assume farmers who rent out untitled land l obtain rental income $(1 - c_1)ql$, where ql is the full land rental income at the market rate, and c_1 is the proportional cost of informal rentals. Moreover, workers no longer need to forfeit their untitled land endowment; they can also choose to rent it out and acquire land rental income of $(1 - c_1)ql - c_2$, where c_2 is an additional fixed cost specific to workers: intuitively, since workers are not devoted to agricultural production, their cost of land rentals should be higher than farmers and I use c_2 to denote this additional cost.[26]

Consider again the benchmark economy with 100% untitled land, now allowing for untitled land to be rented informally subject to these costs. As

[26] This additional fixed cost c_2 is technically necessary. Untitled land does not affect a worker's wage income; without this fixed cost c_2, every worker will rent out all their untitled land, which is contrary to the fact that in the data only a small portion of the land is rented informally.

discussed in Restuccia and Santaeulàlia-Llopis (2015), only 7.4% of untitled land is rented informally in Malawi since informal rentals are generally very costly. The data, however, do not distinguish between the fractions of this land rented out by farmers and workers. Since farmers can rent out land at a lower cost compared to workers, I consider the following two scenarios. 1) All 7.4% of land is rented out by farmers, while workers do not rent out land ($c_2 = \inf$). In this case, I set $c_1 = 0.95$ to match the 7.4% of rented land. 2) Half of the 7.4% of land is rented out by farmers and the remaining by workers. This case requires $c_1 = 0.97$ and $c_2 = 0.02$.

Compared to the benchmark economy where untitled land cannot be rented, agricultural labour productivity is 4.7% higher in Scenario 1 and 5.6% higher in Scenario 2. Labour productivity is slightly higher in Scenario 2, since workers are allowed to rent out some land and the distortion in occupational choice is a bit lower. Overall, the impact of allowing for informal rentals is therefore quite small, since only a small proportion of untitled land is reallocated.

Note that allowing for 7.4% of untitled land to be rented informally is not equivalent to having 7.4% of titled land in the economy: the latter improves agricultural productivity by 6.6% compared to the benchmark economy of no informal rentals. Therefore, land titling is more efficient than allowing land to be rented informally. This is because titled land can be rented at the market rate, while informal rentals of untitled land have associated costs, and therefore informal rentals cannot fully alleviate distortions in occupational choice.

To conclude, it is true that informal land rentals have the potential to improve land allocation efficiency. However, the resulting agricultural productivity gain is not found to be substantial. In practice, these benefits are further limited, as individuals tend to rent to friends or family and not necessarily the most productive farmers.

5.3 Part-time Farming

Individuals may farm seasonally and spend the remaining time working in the non-agricultural sector. To capture this phenomenon, I extend my model to include part-time farming by allowing individuals to choose their occupation continuously.

I assume an individual can choose to spend t units of her time farming and the remaining $1 - t$ units of time working in the non-agricultural sector. It follows that, she is a full-time farmer (worker) if $t = 1$ ($t = 0$), and she is a part-time farmer if $t \in (0, 1)$. A part-time farmer produces $y^p(t)$ units of agricultural good, where $y^p(t) = A\kappa z_a t^{1-\gamma}[\omega k^\eta + (1-\omega)(z_a l)^\eta]^{\frac{\gamma}{\eta}}$. The profit maximization problem of her farm is $\max_{k,l}\{py^p(t) - trk - C(l, \bar{l})\}$, where trk is her capital cost: as a part-time farmer, she only hires capital for a fraction t of time and therefore only pays a fraction t of the regular capital cost rk.[27] She also earns $(1-t)^{1-\alpha_n} w(z_n)$ units of wage income from the non-agricultural sector. In addition to this, part-time farming incurs a fixed cost c^p of the non-agricultural good (the numeraire). This fixed cost captures inconveniences associated with part-time farming, such as commuting costs. Both full-time and part-time farmers keep their untitled land holdings.

I re-calibrate the model extended with part-time farming; details are provided in Appendix D. I choose the fixed cost $c^p = 0.0067$ such that 28.1% of individuals work on a part-time basis to match the Malawi data. (Appendix B.2 provides a detailed description of this moment.) This is to say, 28.1% individuals choose $t \neq \{0, 1\}$. It follows that 62.1% of individuals are full-time farmers and 9.8% are full-time workers. Then I implement land titling by allowing land to be rented among both full-time and part-time farmers. Land

[27] Note that I assume capital flows frictionlessly between the agricultural sector and non-agricultural over the seasons.

titling has two impacts on the economy. First, it substantially reduces the fraction of part-time farmers from 28.0% to 17.7%. This is because, after land titling, individuals who prefer to be workers do not need to farm part-time to keep their untitled land holdings. Second, land titling increases agricultural productivity by 57.7%, which is lower than the 82.5% from the baseline experiment. This is intuitive, as allowing for part-time farming alleviates distortions in occupational choice. We can also see this from the following decomposition exercise: if we also decompose the 57.7% of efficiency gain into the two aforementioned channels as in Section 4.2.1, then we find that eliminating distortions in occupational choice now only account for 43.7% of the efficiency gain, compared to the baseline experiment where we find that occupational choice channel accounts for more than half (57.9%) of the efficiency gain.

5.4 Frictional Capital Market

In the baseline experiment, I assume that the capital market is frictionless to keep my analysis clean. In this extension, I assess how frictions in the capital market can affect the efficiency gain of land titling.

Restuccia and Santaeulàlia-Llopis (2015) document substantial capital misallocation in Malawi. To match these frictions in the capital market, I add to my model capital wedges (τ_k) that take the following functional form: $\log \tau_k^i = \beta_2 + \beta_3 \log(z_a^i) + \beta_4 \log(\bar{l}^i) + \varepsilon_k^i$, where ε_k follows a normal distribution with a standard deviation of σ_{ε_k}. I choose this functional form since capital wedges estimated from the data are positively correlated with farmer's ability and negatively correlated with untitled land holdings. I re-calibrate my entire model; in particular, I choose the three parameters of capital wedges $\beta_3 = 1.14$, $\beta_4 = -0.37$, and $\sigma_{\varepsilon_k} = 0.62$ to jointly match three moments from

Restuccia and Santaeulàlia-Llopis (2015): the standard deviation of (log) capital is 1.20, its correlation with (log) ability is -0.01, and its correlation with (log) land holdings is 0.51. The details of this calibration are in Appendix D. Note that I keep capital wedges to be constant in the quantitative analysis.

Next, I implement land titling in this economy by allowing land to be rented among farmers. Land titling increases agricultural productivity by 131.1% (versus the 82.5% of the baseline experiment). The efficiency gain of land titling is larger in magnitude when the capital market is frictional, because land titling interacts with capital misallocation, largely through the channel of occupational choice. In this experiment with frictional capital market, land titling increases median farmer ability by 66.1%, almost doubled compared to the 38.1% increase in the baseline experiment. The economic intuition is as follows. Capital wedges also distort occupational choice: an individual who should be a farmer in the first best case may choose to be a worker if she is constraint in capital input (with a high τ_k). This distortion is more severe if land is untitled, when farmers cannot adjust their land input to substitute for the misallocated capital in the production. Therefore, with regard to occupational choice, land titling not only eliminates distortions arising from untitled land, but also alleviates those distortions from capital wedges, which are highly correlated with ability (0.84 in our sample).

Land titling and capital wedges also interact through misallocation. Land titling eliminates land misallocation, and also allow farmers to rent land to partially undo capital misallocation. We can isolate the pure misallocation effect to better understand this interaction. Holding occupational choice constant, land titling increases agricultural productivity by 46.3% when the capital market is frictional. This is more than the 37.8% gain when all parameter values stay the same but the capital market is frictionless. It is also confirmed by the fact that, after land titling, the equilibrium allocation of land reflects capital wedges: the Spearman's rank correlation between land allocation and capital wedges is 0.79.

5.5 Land Quality

Land quality affects agricultural productivity. While a detailed analysis of the importance of land quality is beyond the scope of this paper, I summarize the best available evidence in this section in support of abstracting from land quality differences in my analysis.

First, although land productivity differs across countries (Gollin, Lagakos and Waugh, 2014*a*), it may not necessarily be the case that land quality differs systematically across these countries. Adamopoulos and Restuccia (2015*a*) use high-resolution micro-geography data from the Global Agro-Ecological Zones project (GAEZ) to study the difference in land productivity and land quality across countries. They measure land quality using soil quality, climate conditions, and terrain topography. Despite large differences in land productivity across countries, they find, however, that rich and poor countries have similar potential yields, which means the land quality is not systematically related to a country's GDP per capita. This evidence suggests that low land productivity in poor countries may not be due to poor land quality. Importantly, the results of my analysis show that land productivity differences can arise naturally from land market institutions such as untitled land, without any assumption on land quality.

Second, while land quality differs across farmers, the available evidence indicates that these differences only explain a small portion of the dispersion in their output. Restuccia and Santaeulàlia-Llopis (2015) use survey data from Malawi and measure land quality difference across farmers through 11 dimensions, including the land's elevation, slope, erosion, soil quality, nutrient availability, and oxygen availability. Then they perform a variance decomposition on agricultural output of farmers. They find that land quality explains less than 5% of the output dispersion of farmers, and more importantly, land quality is idiosyncratic and not systematically related to farmers' ability. Another concern is that untitled land may be of lower quality than titled land. In most poor countries where there is virtually no titled land, this concern does not apply. In other countries where titled land and untitled land coexist, land titling is often exogenous, arising from historical reasons, independent of land quality (for example, see Banerjee and Iyer (2005)). Even if there is some difference in land quality between untitled and titled land, evidence in Restuccia and Santaeulàlia-Llopis (2015) suggests that its impact may be limited.

6 Conclusion

The prevalence of untitled land in poor countries contributes substantially to their low agricultural productivity. Untitled land not only creates land misallocation, but also distorts individuals' occupational choices. Quantitatively, I find that land titling can increase agricultural productivity by up to 82.5%, depending on the extent of land titling in a country. About 42% of this gain is due to eliminating land misallocation, and the remaining comes from eliminating distortions in occupational choice. In terms of policy analysis, the key is to build a social mechanism that is able to eliminate untitled land in poor countries, which can pose dire socioeconomic challenges for the government. I will leave the internalization of these costs in the transition path for future research.

References

Acemoglu, Daron, Simon Johnson, and James A. Robinson. 2005. "Institutions as a Fundamental Cause of Long-Run Growth." *Handbook of Economic Growth*, 1(A): 385–472.

Adamopoulos, Tasso. 2011. "Transportation Costs, Agricultural Productivity, and Cross-Country Income Differences." *International Economic Review*, 52(2): 489–521.

Adamopoulos, Tasso, and Diego Restuccia. 2014. "The Size Distribution of Farms and International Productivity Differences." *American Economic Review*, 104(6): 1667–1697.

Adamopoulos, Tasso, and Diego Restuccia. 2015*a*. "Geography and Agricultural Productivity: Cross-Country Evidence from Micro Plot-Level Data." *University of Toronto Working Paper.*

Adamopoulos, Tasso, and Diego Restuccia. 2015*b*. "Land Reform and Productivity: A Quantitative Analysis with Micro Data." *University of Toronto Working Paper.*

Adamopoulos, Tasso, Loren Brandt, Jessica Leight, and Diego Restuccia. 2016. "Misallocation, Selection and Productivity: A Quantitative Analysis with Panel Data from China." *Working Paper.*

Alchian, Armen A., and Harold Demsetz. 1973. "The Property Right Paradigm." *Journal of Economic History*, 33(1): 16–27.

Banerjee, Abhijit, and Lakshmi Iyer. 2005. "History, Institutions, and Economic Performance: The Legacy of Colonial Land Tenure Systems in India." *American Economic Review*, 95(4): 1190–1213.

Banerjee, Abhijit V., Paul J. Gertler, and Maitreesh Ghatak. 2002. "Empowerment and Efciency: Tenancy Reform in West Bengal." *Journal of Political Economy*, 110(2): 239–280.

Binswanger, Hans P. 1974. "The Measurement of Technical Change Biases with Many Factors of Production." *American Economic Review*, 64(6): 964–976.

Caselli, Francesco. 2005. "Accounting for Cross-Country Income Differences." *Handbook of Economic Growth*, 1: 679 – 741.

Deininger, Klaus, Daniel Ayalew Ali, and Tekie Alemu. 2008. "Assessing the Functioning of Land Rental Markets in Ethiopia." *Economic Development and Cultural Change*, 57(1): 67–100.

de Janvry, Alain, Kyle Emerick, Marco Gonzales-Navarro, and Elisabeth Sadoulet. 2015. "Delinking Land Rights from Land Use: Certification and Migration in Mexico." *American Economic Review*, 105(10): 3125–3149.

Donovan, Kevin. 2014. "Agricultural Risk, Intermediate Inputs, and Cross-Country Productivity Differences." *University of Notre Dame Working Paper.*

Do, Quy-Toan, and Lakshmi Iyer. 2008. "Land Titling and Rural Transition in Vietnam." *Economic Development and Cultural Change*, 56(3): 531–579.

Doss, Cheryl, Chiara Kovarik, Amber Peterman, Agnes R. Quisumbing, and Mara van den Bold. 2015. "Gender Inequalities in Ownership and Control of Land in Africa: Myth and Reality." *Agricultural Economics*, 46(3): 403–434.

Feder, Gershon, and Tongroj Onchan. 1987. "Land Ownership Security and Farm Investment in Thailand." *American Journal of Agricultural Economics*, 69(2): 311–320.

Galiani, Sebastian, and Ernesto Schargrodsky. 2010. "Property Rights for the Poor: Effects of Land Titling." *Journal of Public Economics*, 94(9-10): 700–729.

Goldstein, Markus, and Christopher Udry. 2008. "The Profits of Power: Land Rights and Agricultural Investment in Ghana." *Journal of Political Economy*, 116(6): 981–1022.

Gollin, Douglas, and Richard Rogerson. 2014. "Productivity, Transport Costs and Subsistence Agriculture." *Journal of Development Economics*, 107: 38–48.

Gollin, Douglas, David Lagakos, and Michael E. Waugh. 2014*a*. "Agricultural Productivity Differences across Countries." *American Economic Review: Papers and Proceedings*, 104(5): 165–170.

Gollin, Douglas, David Lagakos, and Michael E. Waugh. 2014*b*. "The Agricultural Productivity Gap." *Quarterly Journal of Economics*, 129(2): 939–993.

Gollin, Douglas, Stephen L. Parente, and Richard Rogerson. 2002. "The Role of Agriculture in Development." *American Economic Review: Papers and Proceedings*, 92(2): 160–164.

Gollin, Douglas, Stephen L. Parente, and Richard Rogerson. 2004. "Farm Work, Home Work and International Productivity Differences." *Review of Economic Dynamics*, 7(4): 827–850.

Gollin, Douglas, Stephen L. Parente, and Richard Rogerson. 2007. "The Food Problem and the Evolution of International Income Levels." *Journal of Monetary Economics*, 54(4): 1230–1255.

Gottlieb, Charles, and Jan Grobovšek. 2015. "Communal Land and Agricultural Productivity." *University of Edinburgh Working Paper.*

Haley, Stephen L. 1991. "Capital Accumulation and the Growth of Aggregate Agricultural Production." *Agricultural Economics*, 6(2): 129 – 157.

Hsieh, Chang-Tai, and Peter J. Klenow. 2009. "Misallocation and Manufacturing TFP in China and India." *Quarterly Journal of Economics*, 124(4): 1403–1448.

Jones, Charles I. 1994. "Economic Growth and the Relative Price of Capital." *Journal of Monetary Economics*, 34(3): 359 – 382.

Lagakos, David, and Michael E. Waugh. 2013. "Selection, Agriculture, and Cross-Country Productivity Differences." *American Economic Review*, 103(2): 948–980.

Lucas, Jr., Robert E. 1978. "On the Size Distribution of Business Firms." *Bell Journal of Economics*, 9(2): 508–523.

Restuccia, Diego, and Carlos Urrutia. 2001. "Relative Prices and Investment Rates." *Journal of Monetary Economics*, 47(1): 93 – 121.

Restuccia, Diego, and Raül Santaeulàlia-Llopis. 2015. "Land Misallocation and Productivity." *University of Toronto Working Paper.*

Restuccia, Diego, and Richard Rogerson. 2008. "Policy Distortions and Aggregate Productivity with Heterogeneous Establishments." *Review of Economic Dynamics*, 11(4): 707–720.

Restuccia, Diego, Dennis Tao Yang, and Xiaodong Zhu. 2008. "Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis." *Journal of Monetary Economics*, 55(2): 234–250.

Tombe, Trevor. 2015. "The Missing Food Problem: Trade, Agriculture, and International Productivity Differences." *American Economic Journal: Macroeconomics*, 7(3): 226–258.

Valentinyi, Ákos, and Berthold Herrendorf. 2008. "Measuring Factor Income Shares at the Sectoral Level." *Review of Economic Dynamics*, 11(4): 820–835.

Young, Alwyn. 2014. "Structural Transformation, the Mismeasurement of Productivity Growth, and the Cost Disease of Services." *American Economic Review*, 104(11): 3635–67.

Appendix A Land Demand of Farms

In Section 3.3 I mentioned that a farmer with untitled land $\bar{l}$ will use all her untitled land to maximize her profit. The following lemma formally states this result.

Lemma 1. *A farmer with ability z_a and untitled land holdings $\bar{l}$ maximizes her profit by choosing $l(z_a, \bar{l}) \geqslant \bar{l}$.*

Proof. Suppose not. Then I will show it leads to a contradiction.

Consider a farmer with ability z_a and untitled land holdings $\bar{l}$. Her profit function is given by $\pi(z_a, k, l, \bar{l}) = py(z_a, k, l) - rk - C(l, \bar{l})$. Suppose k^* and $l^* < \bar{l}$ maximize her profit, with output $y(z_a, k^*, l^*)$ and profit $\pi(z_a, k^*, l^*, \bar{l})$. There exists an $\varepsilon > 0$ such that $l^* + \varepsilon < \bar{l}$ and $y(z_a, k^*, l^* + \varepsilon) > y(z_a, k^*, l^*)$. Since the land cost remains unchanged when $l < \bar{l}$, i.e., $C(l^*, \bar{l}) = C(l^* + \varepsilon, \bar{l})$, we have

$$\pi(z_a, k^*, l^* + \varepsilon, \bar{l}) = py(z_a, k^*, l^* + \varepsilon) - rk^* - C(l^* + \varepsilon, \bar{l})$$
$$= py(z_a, k^*, l^* + \varepsilon) - rk^* - C(l^*, \bar{l}) > py(z_a, k^*, l^*) - rk^* - C(l^*, \bar{l}) = \pi(z_a, k^*, l^*, \bar{l})$$

This inequality contradicts with the condition that k^* and l^* maximize her profit. Therefore, profit maximization requires $l \geqslant \bar{l}$. □

Therefore, although farmers have the option to partially give up their untitled land, they will always use all of it without giving up any.

Appendix B Data

B.1 World Census of Agriculture

Food and Agricultural Organization (FAO) does this census and provides comparable data across countries. I use the 1990 Census. The data I use are from Table 3.3 (Area of holdings by tenure of land operated). These data are used to plot Figure 1 in my paper.

There is a key difference between Table 3.2 and Table 3.3 in the FAO report. Land holdings may be classified as as operated under one single form of tenure or under more than one form of tenure. In Table 3.2, only those holdings operated under one form of tenure are further classified by various tenure forms. In Table 3.3, all land, despite the number of form of tenure, is classified by individual tenure forms. Therefore, I choose Table 3.3 to display, as it gives a more complete picture of land titling situations.[28]

B.2 Malawi Data

I thank Diego Restuccia and Raül Santaeulàlia-Llopis for providing additional moments and statistics from their data. In this section, I first briefly discuss their data and the moments used in the calibration. Restuccia and Santaeulàlia-Llopis (2015) provide information on farmers' inputs and outputs. Using this information I can calculate the output dispersion and land dispersion of farmers: $std(\log(y)) = 1.24$, and $std(\log(\bar{l})) = 0.77$. Their ability can be computed from my production function using their of inputs and outputs and the standard deviation is 0.91. Then I can compute the correlation between farmers' ability and their land holdings to be 0.12.

The agricultural employment share of Malawi (64.1%) is from Table 4.5 of *2013 Malawi Labour Force Survey* published by National Statistical Office. This number is used in the calibration of the baseline experiment. I also consider part-time farming in Section 5.3, where the full-time and part-time employment shares are also from the survey. I use the percentage of rural residences working in agriculture as an approximate full-time agricultural employment share (62.1% of total population). Similarly, urban residences working in non-agriculture are treated as full-time workers (9.8%); part-time farmers include urban residence working in agriculture and rural residence working in non-agriculture (28.1%).[29]

[28] In Table 3.3, land under more than one form of tenure is also classified into different categories, not automatically treated as "other forms of tenure" (nor automatically considered untitled in my paper).

[29] Table 4.5 has no information on the percentages of urban/rural residences. I estimate it using the following method. Suppose x is the percentage of urban residences, and N_a, N_a^u, N_a^r are the economy-wide, urban, and rural agricultural employment shares, respectively. Then x

I use the Gini coefficient of consumption in urban sector as an approximation of the Gini coefficient of non-agriculture. The National Statistical Office of Malawi estimates this number to be 0.48 in the year 2005.[30]

The economy-wide capital-output ratio (1.01) is computed using Penn World Table 6.3, following the standard procedures described in Caselli (2005). I extend my model to include land development in Section 5.1, where I use the share of land development as a fraction of total agricultural capital. This number is from the FAO country statistics of Malawi, which reports this number to be 40.1%.

Appendix C Robustness

C.1 Factor Shares

In this section I discuss my results associated with different factor shares. There is some consensus in the literature that the labour share in agriculture should be around one half. Therefore, I assign a labour share of 0.46 following Valentinyi and Herrendorf (2008). It follows that, the remaining 0.54 is the sum of capital and land share. Unfortunately, the estimated capital and land shares differ widely in the literature. For example, Valentinyi and Herrendorf (2008) (VH hereafter) estimate that the land share is half of the capital share, while Restuccia and Santaeulàlia-Llopis (2015) (RS hereafter) estimate that the land share is two times that of the capital share. In my benchmark calibration, I use the middle point of their estimations and assume both capital and land share are 0.27. Now I report my results when the capital and land shares are assigned according to VH — 0.36 and 0.18 respectively — and according to RS — 0.18 and 0.36 respectively.

can be solved from the following relationship: $N_a = xN_a^u + (1-x)N_a^r$.

[30]The statistical office provides two Gini coefficients: the Gini coefficient of consumption and that of wealth. The consumption measure maps to the ability distribution better than the income measure since income inequality contains the contribution from transitory shocks. The WDI database provides the Gini coefficient of income at the national level, which is similar to the Gini coefficient of consumption I used here.

Table 4: The Impact of Land Titling

Changes after Land Titling (Normalize the values at $\theta = 1$ to 1)	VH Shares	My Shares	RS Shares
Agr. Output (Y_a)	1.00	1.01	1.02
Agr. Labour Productivity (Y_a/N_a)	1.43	1.82	2.60
Non-agr. Output (Y_n)	1.26	1.39	1.50
Non-agr. Labour Productivity (Y_n/N_n)	0.83	0.77	0.72
Real GDP ($\bar{p}Y_a + Y_n$)	1.18	1.27	1.35
Median Farmer's Ability	1.22	1.38	1.60
Median Worker's Ability	0.84	0.80	0.77

Note:
[1] The capital and land shares are as follows: VH — 0.36 and 0.18; my shares — 0.27 and 0.27; RS — 0.18 and 0.36.
[2] The table shows the value of all variables after land titling, while their values before land titling are normalized to one.
[3] Real GDP is computed with the price fixed at the $\theta = 1$ case ($\bar{p}$).

Table 4 shows the impact of land titling in an economy with 100% untitled land under different factor shares. Note that I normalize the value of the variables before land titling to be one. Land titling has its largest impact with RS factor shares and the smallest impact with VH shares, while its impact with my baseline calibration lies in the middle. For example, land titling increases agricultural labour productivity by 160% with RS shares, 82% with my baseline calibration, and only 43% with VH shares. The reason is actually simple. The land share in RS is the largest (0.36), hence land titling has its largest impact. A high land share implies a low capital share, which also exacerbates the impact of land misallocation: a low capital share makes it harder for farmers to use capital to substitute for the misallocated land in production. As a result of this comparison, I do not use the higher land share from RS in my baseline experiment to be conservative.

C.2 Correlation Parameter ρ

The parameter ρ governs the correlation between agricultural ability z_a and non-agricultural ability z_n. In my baseline experiment, I choose the value of ρ such that

Table 5: Robustness Check of ρ

Spearman's Correlation	0.25	0.3	0.35	0.4	0.45
Change of Agricultural Productivity	76.8%	79.4%	82.5%	85.3%	88.4%
Change of GDP	24.0%	25.5%	27.1%	28.9%	30.5%

Note:
[1] This table shows how land titling changes agricultural productivity and GDP under different values of ρ.
[2] Agricultural productivity is measured by labour productivity Y_a/N_a.
[3] GDP is measured with the price fixed at the level of 100% untitled land.

the Spearman's rank correlation between z_a and z_n is 0.35, as estimated in Lagakos and Waugh (2013). In this section, I perform robustness tests by changing the values of ρ such that the Spearman's rank correlations are 0.25, 0.3, 0.35, 0.4, and 0.45. For each value of ρ, I re-calibrate the whole model. Table 5 shows how land titling changes agricultural productivity and real GDP per capita under different values of ρ. In general, the efficiency gain from land titling is not sensitive to ρ. When ρ increases from 0.25 to 0.45, land titling increases agricultural productivity by a value between 76.5% and 88.4%. The change of GDP after land titling features a similar pattern.

Appendix D Re-Calibration

In Section 5.1, Section 5.3, and Section 5.4, I extend my model to allow for land development and expropriation risk, part-time farming, and a frictional capital market. As a result, I re-calibrate the whole model with these extensions. The assumptions on functional forms are kept the same as in Section 4.1. All parameters existing in my original calibration are also chosen to match the same moments as described in 4.1 while their calibrated values differ. Please see Table 6 for their values associated with each re-calibration. There are also a few new parameters in each extension, and I have discussed them in the text of the extensions. I summarize their values as well as the targets in the Table 7.

Table 6: Re-Calibration: Common Parameters

Category and Parameter		Value		
		Expropriation	Part-time Farming	Frictional Capital
Technology	A	1	1	1
	κ	1	1	1
	ω	0.34	0.55	0.62
	η	0.24	0.24	0.24
	γ	0.54	0.54	0.54
	α_n	0.33	0.33	0.33
Preference	$\bar{c}$	0.49	0.61	0.58
	ϕ	0.005	0.005	0.005
Endowments	L	0.53	0.53	0.53
	K	0.69	0.71	0.72
Ability	ζ_a	1.49	0.96	0.96
	ζ_n	0.94	1.53	0.91
	ρ	2.24	2.24	2.24
Untitled land	σ_ε	0.78	0.78	0.79
	β_1	0.24	0.16	0.17
Barrier	ξ	0.92	0.95	0.91

Note: This table shows the value of common parameters after re-calibration in Section 5.1, Section 5.3, and Section 5.4, respectively. Their targets are the same as described in Section 4.1.

Table 7: Re-Calibration: Parameters Specific to Extensions

Parameters	Value	Target
Expropriation		
ϕ_{exp}	0.067	Expropriation once in every 15 years
p_k	3.94	Price of investment relative to consumption goods
α_s	0.53	Share of land development among agricultural capital
Part-time Farming		
c^P	0.0067	Employment share of part-time individuals
Frictional Capital		
β_3	1.14	Correlation between capital and ability
β_4	-0.37	Correlation between capital and land
ε_k	0.62	Dispersion of capital