The Productivity Impacts of Formal and Informal Land Rights: Evidence from Madagascar

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Abstract

This paper studies the relationship between land rights and agricultural productivity. Whereas previous studies used proxies for soil quality and instrumental variables to control for the endogeneity of land titles, the data used here include precise soil quality measurements, which in principle allow controlling for the unobserved heterogeneity between plots. Empirical results suggest that formal land rights (i.e., land titles) have no impact on productivity, but that informal land rights (i.e., landowners' subjective perceptions of what they can and cannot do with their plots) have heterogeneous impacts on productivity.

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1. Introduction

In his best-selling book *The Mystery of Capital*, de Soto (2000) claims that the poor in developing countries own about US$1 trillion worth of assets – a figure roughly comparable to the 2010 gross domestic product of South Korea – but that it is often the case that the lack of well-defined property rights in the same developing countries prevents the poor from capitalizing on those assets.

Leaving aside the assumptions de Soto makes about the value of those assets and the efficacy of the legal system in most developing countries (Woodruff 2001), empirical studies by Acemoglu et al. (2001, 2005) and Acemoglu and Johnson (2005) have shown that institutions – property rights institutions in particular – have not only had long-term impacts on comparative economic development, but they are also the main cause of differences in economic performance between countries.

Within countries, more specifically in developing-country agriculture, economists have theorized since the works of Feder and Noronha (1987), Feder and Feeny (1991), and Migot-Adholla et al. (1991) that there are three causal mechanisms through which well-defined property rights can increase agricultural productivity (and thus the welfare of landowners) within an effective legal system. First, property rights allow landowners to lease out or sell their plots of land to more productive individuals. Second, property rights give landowners stronger incentives to maintain and improve their plots. Third, property rights allow landowners to use their plots as collateral to obtain loans that can be used to finance investments in land or the purchase of production inputs. In other words, clearly defined land rights should lead to productivity gains, all else being equal.[1]

As a result, land reform has been part and parcel of the development *Zeitgeist* for some time, although the empirical evidence on the impact of land tenure on productivity is, at best, mixed (Place 2009). In several countries, a land title is often worth no more than the paper it is printed on, either because the state has failed to broadcast its power to remote rural areas (Herbst 2000) or because the transaction costs involved in defending one's claim to a plot of land through the legal system are exceedingly high (Fafchamps and Minten, 2001).

This paper looks at the effect of land rights in Madagascar by looking at whether formal land rights (whether a plot is titled) and informal land rights (whether the landowner believes she can lease the plot out, sell it, plant trees on it, build a tomb on it, and by whether she believes her children will have the same rights as herself on the plot) have any impact on agricultural productivity. In this paper, "informal land rights" thus refer to the landowner's subjective beliefs regarding whether she can do specific things on or with her plot of land.[2]

In this context, knowing the productivity impacts of land rights is crucial for policy. In April 2005, the Millennium Challenge Corporation signed a $110 million, four-year compact with the government of Madagascar – more than 2 percent of Madagascar's gross domestic product that year – which included an important land tenure component, and whose goal was to "increase land titling and land security" (Millennium Challenge Corporation 2010). But this raises the question of whether land titles have a discernable impact on agricultural productivity in Madagascar. One of the goals of this paper is thus to show whether these titles actually improve agricultural productivity.

Although the impact of land rights has previously been studied in Madagascar (Jacoby and Minten 2007), the data used in this paper allow building upon previous results so as to potentially go one step further as far as the identification of the impact of land rights on agricultural productivity goes. The data include several plots per household, which in principle allows controlling for the unobserved heterogeneity between households.[3] More importantly, even though there already are several studies on the impacts of land rights on agricultural investment or productivity or both, the data used in this paper include precise soil quality measurements (i.e., carbon, nitrogen, and potassium percentages; soil pH; and clay, silt, and sand content) for each plot, which allows one to effectively control for the unobserved heterogeneity between plots instead of having to rely on proxies for soil quality. Such soil quality controls have so far been missing from the literature on the productivity impacts of land rights in developing countries.[4]

An empirical specification of the agricultural productivity equation lies at the core of this paper which includes both formal and informal land rights as well as the plot characteristics that are

both readily observable (e.g., soil color; position on the toposequence; source of irrigation, etc.) and those that are typically unobservable (e.g., soil carbon, nitrogen, and potassium content; soil pH; clay, silt, and sand percentages) as potential determinants of agricultural productivity.[5] The main finding is that land titles appear to have no statistically significant impact on agricultural productivity in this context. This finding is robust to the various alternative specifications presented in this paper. In contrast, some informal land rights are significantly associated with changes in agricultural productivity, but in puzzling ways: the right to lease the plot out and the right to build a tomb on it are associated with a decline in productivity, whereas the right to plant trees is associated with an increase in productivity. The hypothesized mechanisms through which these informal land rights affect productivity are discussed below.

By including soil quality controls, this paper improves upon the usual strategy aimed at identifying the impact of land rights by controlling for the (typically) unobserved heterogeneity between plots that has plagued previous studies (Besley 1995; Brasselle et al. 2002). Indeed, the inclusion of soil quality measurements as a determinant of agricultural productivity has the potential to purge the error term of its correlation with whether a plot is titled. In other words, because individuals may seek to title higher quality plots (Besley 1995), the inclusion of soil quality measurements reduces the bias of the estimated effect of land titles.

The contribution of this paper to the literature on land rights is thus threefold. First and foremost, the inclusion of precise soil quality measurements allows accounting for an important source of unobserved heterogeneity between plots, which in turn allows eliminating an important source of bias in the estimated relationship between land titles and agricultural productivity – a source of bias that is present in almost all observational studies of the impacts of land rights. Second, the core finding in this paper – that land titles do not increase productivity in this context – flies in the face of the dominant development discourse, which almost takes the claim that land titles improve productivity as a truism. Third, this paper studies the impact of informal land rights (i.e., subjective landowner perceptions regarding what they can and cannot do with their plots) alongside formal land rights (i.e., land titles) and shows that these informal land rights have heterogeneous, sometimes unexpected impacts on productivity. Taken together then, the inclusion of household fixed effects, precise soil quality measurements, as well as formal and

informal land rights paint a picture of productivity impacts of land rights that is as complete as possible in the absence of data derived from an experiment specifically aimed at studying the impact of land rights on productivity.

2. Land Titles, Land Rights, and Land Tenure Institutions in Madagascar

The state of land tenure institutions in Madagascar is best described by the *Lettre de politique foncière*, a document summarizing the proceedings of a workshop on land tenure organized by the Ministry of Agriculture in early 2005.[6] The *Lettre de politique foncière* stemmed directly from the objectives delineated in Madagascar's Poverty Reduction Strategy Paper and was written in order to describe the situation and clearly define priorities for policy makers.

The *Lettre de politique foncière* describes how customary rights have gradually receded since Malagasy independence in 1960 as land has increasingly become a traded asset. As a result, landowners have been increasingly turning to the state to define their property rights. Because untitled and uncultivated lands officially belong to the state, half a million requests to obtain government lands are pending (Bertrand et al. 2008). Land titling, however, has been and is still proceeding at a snail's pace: a total of 330,000 titles have been delivered over the last century and, as of 2005, only about 1,000 new titles were delivered annually.[7] Some requests for land titles have been pending for several decades (Teyssier et al. 2008), and as plots are passed on from one generation to the next and broken up into smaller plots through bequests, formal land titles fall into obsolescence due to the prohibitive costs of keeping them up to date. Moreover, according to Teyssier et al. (2007), titling a plot of land can take up to 10 years and cost about US$900 once one accounts for bribes and other "unofficial" costs. In a country where the GDP per capita in 2010 was equal to $415 (IMF 2011), this represents a substantial amount of money.

In addition, the central government agency in charge of land tenure is overwhelmed. The buildings in which titling records are held are often in an advanced state of decay, which makes record-keeping a heroic endeavor as some records have already been irreversibly damaged. The government employees in charge of the administration of lands face difficult working conditions and often have to bring their own materials to work. The *Lettre de politique foncière* concludes that the land titling system is bankrupt and that many landowners feel insecure on their own

lands. Furthermore, land conflicts occur frequently, acquiring a land title is practically impossible without bribing the relevant authority figures, and landowners appear to have little to no incentive to invest in their own plots (Dabat and Razafindraibe 2008).

Among the causes identified by the *Lettre de politique foncière* for this situation are (i) a lack of legal knowledge among landowners; (ii) the complexity, length of time, and costliness of the procedure leading up to the acquisition of a land title (Teyssier et al. 2008); (iii) the lack of funds allocated to the management of lands at the local level; (iv) the centralization of land administration; and (v) the lack of intermediaries between the central government and smallholders.

Small landowners have adapted to the situation. Many rural communities have chosen to opt out of the legal system (Bernstein 1992) by putting in place their own informal system of land titles, called *petits papiers* ("small papers"; see Jacoby and Minten 2007 for a discussion). Under this system, which has burgeoned all over the country even in the absence of a coordinated effort, informal land titles are officialized at the community level, and many land sales are accompanied by a *petit papier*. Because they are informal, however, these *petits papiers* are only valid within the community and do not protect landowners against the possibility of adverse possession from outside the community (Baker et al. 2001).[8]

As a consequence of the *Lettre de politique foncière*, important efforts have been made since 2005 to reform land tenure institutions in Madagascar. Generally speaking, the objective of these reforms has been a greater recognition of untitled private property. In 2005, the management of lands was decentralized at the commune level and the ownership of untitled private property was legally recognized (Republic of Madagascar 2005). In 2006, a law and subsequent government decree have allowed communes to open a *guichet foncier* (land tenure office) where landowners could get certificates documenting their property rights on their plots, and where an official map of the lands in the commune would be kept (Republic of Madagascar 2006). Further efforts have been made to map out and classify public lands as well as define rights on these lands (Republic of Madagascar 2008a; 2008b). As of writing this paper, even though the *coup d'état* of March

2009 has caused a decline in the amount of available funds available for land tenure via a sharp drop in foreign aid, the reform continues to move forward (Programme national foncier 2011).

3. Empirical Framework

The contribution of this paper lies in the way the impacts of land rights is identified, so this section focuses on the equations to be estimated as well as the identification strategy used to establish the causal impact of formal land rights on agricultural productivity.

3.1. Estimation Strategy

While similar studies usually focus on the impact of property rights on investment in land, the data used here do not include information on long-term investments (e.g., tree planting, as in Deininger and Jin 2003 or Dercon and Ayalew 2007). Although the data include information on five different kinds of short-term investments, these investments were made in too few cases to allow using them as outcomes. Landowners reported having applied manure on their plots in 21 percent of cases; urea in less than 1 percent of cases; NPK and pesticides in 3 percent of cases; and having treated their seeds in a little over 1 percent of cases. Consequently, and because land rights should in principle have unambiguously positive effects on agricultural productivity, this paper relies on a reduced-form approach by directly looking at the impact of property rights on agricultural productivity rather than looking at the intermediate impact of property rights on investment.

The first specification of the agricultural productivity equation is a "kitchen-sink" specification that includes measures of both formal and informal land rights as well as soil quality measurements. Because the rights captured by the informal measures of property rights are in principle included among the bundle of rights that come with formal rights (i.e., land titles), controlling for informal land rights in addition to formal land rights may understate the impact of formal land rights on productivity. Likewise, investments in soil quality could be a mechanism through which formal land rights affect agricultural productivity, so that controlling for soil quality measurements in addition to controlling for formal land rights may understate the impact of formal land rights on productivity.

To account for these two possibilities, the results of three additional specifications of the agricultural productivity equation are presented: (i) a specification which excludes both informal land rights and soil quality measurements; (ii) a specification which includes soil quality measurements but excludes informal land rights; and (iii) a specification which includes informal land rights but excludes soil quality measurements. A fourth specification, which excludes formal land rights but includes both informal land rights with and without soil quality measurements is also included so as to assess the impacts of informal land rights and offer a complete set of results. Various statistical tests – a test of joint significance of the household fixed effects, a Hausman test of exogeneity of the land title variable, and a test of joint significance of the soil quality measurements – are ultimately conducted in order to determine which set of results should be preferred.

The first specification to be estimated in this paper is such that

$$\ln y_{ijk} = \alpha_1 + \beta_1 t_{ijk} + \theta_1 r_{ijk} + \delta_1 z_{ijk} + \gamma_1 \ln s_{ijk} + \epsilon_{1ijk}. \quad (1)$$

On the left-hand side of equation 1, y represents the yield (i.e., output per unit of land) on plot i belonging to household j in village k. Because rice is the staple crop in Madagascar, data collection focused on rice agriculture, and so this paper focuses only on rice productivity. On the right-hand side of equation 1, t is a dummy variable equal to one if the plot is titled and equal to zero otherwise, i.e., a measure of formal land rights; r is a vector of dummy variables for whether the landowner believes she can sell the plot, lease it out, plant trees, or build a tomb, and for whether her children will have similar rights on the plot, i.e., measures of informal land rights; z is a vector of plot characteristics (i.e., cultivated area; whether the plot suffered from crop disease; distance from the landowner's dwelling; soil color; position on the toposequence; and source of irrigation); s is a vector of soil quality measurements (i.e., carbon, nitrogen, and potassium contents; soil pH; and clay, silt, and sand contents); and ϵ is an error term with mean zero. In what follows, the specification in equation 1 will be referred to as the ordinary least squares (OLS) specification.

The specification in equation 1 unrealistically assumes that the error term is uncorrelated with any of the variables on the right-hand side of equation 1. As economists have long recognized, it is likely that more productive plots are more likely to be titled (Besley 1995; Brasselle et al. 2002). To account for this possibility, the dummy variable t for whether the plot is titled is replaced by its predicted value from a first-stage instrumenting regression in the second specification to be estimated in this paper, such that

$$\ln y_{ijk} = \alpha_2 + \beta_2 \hat{t}_{ijk} + \theta_2 r_{ijk} + \delta_2 z_{ijk} + \gamma_2 \ln s_{ijk} + \epsilon_{2ijk}, \quad (2)$$

where $\hat{t}$ is the predicted value of t obtained from the first-stage instrumenting regression in which t is regressed on r, z, s, and on a dummy variable equal to one if the plot was inherited or given to the landowner and equal to zero if it was purchased or cleared by the landowner (see section 3.1 for a discussion of this latter variable's validity as an instrument in this context). In what follows, the specification in equation 2 will be referred to as the instrumental variables (IV) specification, and the validity of the IV used will be discussed in section 3.1 below.

In both equations 1 and 2, it is likely that the error term includes unobserved household characteristics that are correlated with the variables included on the right-hand side. To account for this possibility, and because the data include several households who own more than one plot, the third specification includes household fixed effects, such that

$$\ln y_{ijk} = \alpha_3 + \beta_3 t_{ijk} + \theta_3 r_{ijk} + \delta_3 z_{ijk} + \gamma_3 \ln s_{ijk} + \pi_3 d_{jk} + \epsilon_{3ijk}, \quad (3)$$

where d is a vector of household fixed effects.[9] In what follows, the specification in equation 3 will be referred to as the fixed effects (FE) specification.

Lastly, the specifications in equations 2 and 3 are combined into a fixed effects instrumental variables (FE-IV) specification, such that

$$\ln y_{ijk} = \alpha_4 + \beta_4 \hat{t}_{ijk} + \theta_4 r_{ijk} + \delta_4 z_{ijk} + \gamma_4 \ln s_{ijk} + \pi_4 d_{jk} + \epsilon_{4ijk}. \quad (4)$$

The instrumental variable used in equation 4 is the same as in equation 2, and section 3.1 discusses the IV, along with other identification considerations.

Because equations 1 to 4 present a kitchen-sink approach (i.e., they include all the available explanatory variables), which may understate the causal impact of formal land rights, section 3.2 discusses variants of equations 1 to 4 aimed at disentangling the reduced-form causal impacts of formal land rights from the mechanisms through which formal land rights may increase agricultural productivity (Pearl 2009).

3.2. Identification Strategy

In order to discuss the identification of causal impacts, it is helpful to start with a description of what the ideal data set would look like to serve as a benchmark against which to compare the data used in this paper.

Short of a randomized control trial in which the treatment would consist in titling randomly selected plots and would test whether productivity is higher in the treatment group than in the control group (see Duflo et al. 2008 for a general exposition of the method and Barrett and Carter 2010 for a discussion of its limitations), the ideal data set in this context would include repeated observations on the plots belonging to households across several villages.

In terms of variables, that ideal data set would include time-varying plot-level information on production (i.e., y above), soil quality (i.e., s), and the characteristics of the plot (i.e., z) within each household, and it would also include time-varying information on formal land rights (i.e., titling status, or t) and informal land rights (i.e., r) within a significant number of households. Using that ideal data set, it would be possible to study the dynamic effects of land rights on agricultural productivity while controlling for unobserved heterogeneity between plots, households, and villages.

Compared to that idealized benchmark, the data used in this paper are cross-sectional, and so they do not allow studying the dynamic relationship between land rights and agricultural

productivity. Even if such a data set were available, it is unlikely that there would be much variation within each household in formal land rights over time (especially in a context in which the government emits less than 1,500 new titles annually). It is even more unlikely that there would be much variation in informal land rights within each household over time, since beliefs about what one can and cannot do on or with one's plots take a long time to form and are unlikely to change much once they are formed.

How is the impact of land rights on agricultural productivity identified? Both productivity and land rights vary between plots within each household, so absent any correlation between the regressors and the error term, the coefficient vector (β, θ) in equation 1 measures the impact of land rights on productivity. It is usually not the case, however, that the regressors and the error term are uncorrelated. Following Besley (1995), the plots in a given village could be more likely titled than in other villages. For example, the institutions in a given village could be such that a land title would bring nothing more than what the village elders can grant a landowner. Or it could be that the landowners who seek titles differ in systematic ways from those who do not. For example, they could be wealthier, more educated, have a better knowledge of the legal system, and so on. In such cases, the inclusion of household fixed effects (as in equation 3) allows controlling for the endogeneity of land titles.[10]

It could also be, however, that the plots whose landowners seek titles differ systematically from those whose landowners do not. For instance, they could have better irrigation, lower carbon content, a more acidic soil, and so on. In this case, the best one can do is to include as many controls as possible. In this paper, these controls include a vector of soil quality measurements; the size of the area cultivated on the plot; a dummy variable for whether the plot suffered from a crop disease during the last season; the distance between the landowner's dwelling and the plot; controls for the color of the soil; controls for the plot's position on the toposequence; and controls for the plot's source of irrigation.

The inclusion of both household fixed effects and soil quality measurements in principle allows identifying the causal impact of land rights on productivity, but this paper also presents the results of instrumental variable specifications (i.e., equations 2 and 4), both for comparability

with previous studies (Besley 1995; Brasselle et al. 2002) and to tease out the reduced-form causal impacts of land titles from the mechanisms through which land titles increase productivity, as discussed in the next section.

As discussed above, the empirical strategy used by Besley (1995) and Brasselle et al. (2002) is adapted to this context, and the dummy for whether the plot is formally titled is instrumented with a dummy variable equal to one if the plot was inherited or given to the landowner and equal to zero if it was purchased or cleared by the landowner. The identifying assumption is that the way in which a plot came to be owned by an individual landowner should have no impact on a plot's productivity (except through the presence of a formal title), given the plot-level controls included in equation 2, but it has an impact on whether the landowner seeks a title.

On the one hand, even if a plot's mode of acquisition impacts soil quality, this is controlled for by the inclusion of soil quality measurements and other observable plot characteristics in the productivity equation. On the other hand, the longer a plot has been owned by the landowner's family, the more likely it is to be accompanied by a title that is in principle easily transferable to the landowner relative to plots that have been purchased from strangers or cleared by the landowner. Because the most convincing instrumental variables involve some form of randomization so as to introduce a plausibly exogenous variation with which to identify a causal impact, the instrumental variable used here is far from ideal. Again, it is included here to make the results comparable with those of previous studies.

Lastly, although it is possible that the landowner's subjective perceptions of informal land rights r are also endogenous to agricultural productivity, the data unfortunately do not include valid instruments for those variables, so specifications with and without informal land rights are presented so as to gauge the sensitivity of the impact of formal land rights (i.e., land titles) on agricultural productivity to their presence among the set of covariates. Consequently, the reader should be careful not to interpret the estimated coefficients for those informal land rights as causal.

3.3. Reduced-Form Causal Impacts versus Mechanisms

The kitchen-sink specification of the agricultural productivity equation in equations 1 to 4 may suffer from significant shortcomings if one is interested in the causal impact of specific treatment variables.

Indeed, following economic theory, it is likely that one of the mechanisms through which formal and informal land rights increase agricultural productivity is investment in soil quality (Feder and Noronha 1987; Feder and Feeny 1991; and Migot-Adholla et al. 1991). For example, a landowner may be more likely to apply fertilizer on a titled plot than on an untitled plot, simply because she is likely to reap the fruits of her investment for a longer period of time on the titled plot since it is less likely to be taken from her than the untitled plot, everything else equal.[11] In that case, controlling for both land rights and soil quality measurements could lead to underestimating the causal impact of land rights.

Likewise, the inclusion of informal land rights alongside formal land rights can lead to underestimating the causal impact of formal land rights. In the context of an effective legal system, a land title would give a landowner a bundle of rights which includes among other things the rights to sell the plot, to lease it out, to plant trees on it, and to build a tomb on it, and which would guarantee that a landowner's children would have the same rights to the plot as the landowner. If land titles truly increase productivity, controlling for informal land rights when also controlling for the presence of a formal land title will lead to underestimating the causal impact of formal land titles on agricultural productivity. One should keep in mind, however, that any new formal land titling program will be situated in places where informal land rights such as those studied here already exist. Consequently, formal titles will rarely create rights that are not at least partly observed in practice.

Still, to account for these two possibilities, three additional versions of the agricultural productivity equations 1 to 4 are presented: (i) a version that excludes both informal land rights and soil quality measurements so as to focus purely on formal land rights; (ii) a version that includes soil quality measurements but excludes informal land rights; and (iii) a specification that includes informal land rights but excludes soil quality measurements. Lastly, a version that

excludes formal land rights but includes informal land rights both with and without soil quality measurements is also included so as to offer the most complete and robust set of results possible.

4. Data and Descriptive Statistics

The data used in this paper were collected in 2002 under the US Agency for International Development's BASIS Collaborative Research Support Program. A total of 516 plots belonging to 300 randomly selected households in 17 randomly selected villages were surveyed in the central highlands of Madagascar. Because rice is the staple crop in Madagascar, the survey focused on rice agriculture. Because of missing values, and to concentrate on the plots for which output has been strictly positive, the analysis retains a total of 473 plots belonging to 290 households for analysis.

The average household in the sample owned 1.6 plots, so a significant number of the households in the data (i.e., 169 households out of 290) owned only one plot. Because of the sampling scheme, standard errors are clustered at the village level unless otherwise noted.

The unique feature of the data is that five soil cores were extracted in random locations from each selected plot of a sub-sample of rice plots and sent to the World Agroforestry Centre in Nairobi for wet chemistry and spectral analysis. In total, sample soil cores were extracted from rice plots belonging to 300 households. All the soil cores underwent spectral analysis, but because wet chemistry is both costly and destructive, a sub-sample of 234 soil cores went through wet chemistry analysis, which allows precisely measuring a soil sample's carbon, nitrogen, and potassium contents; its pH level; as well as its clay, silt, and sand percentages. The results of the wet chemistry analysis were then used as dependent variables in imputing regressions that relied on principal component scores derived from a spectral analysis of the full sample as their independent variables. This ultimately allowed imputing precise soil quality measurements for the entire sample of plots. Appendix table A1 shows that the adjusted R^2 measures were above 0.85 in five of the seven imputing regressions. See Shepherd and Walsh (2002) for a validation of this method, and Barrett et al. (2010) for a description of the soil analysis protocol. Because the soil quality measurements are generated regressors, standard

errors are bootstrapped unless otherwise noted whenever soil quality measurements are included among the regressors.[12]

Table 1 presents descriptive statistics for the variables in this paper. The yield on the average plot was equal to 37 kilograms of rice per are,[13] or 3.7 metric tons of rice per hectare, the production of which required on average 0.16 hectares of land. This rice was produced on plots which on average contained 2.4 percent carbon, 0.2 percent nitrogen, and 0.2 percent potassium; had a soil pH of about 5.1;[14] and contained 28.2 percent clay, 26.4 percent silt, and 45.1 percent sand.

Roughly one in five plots was stricken by crop disease during the last production season, and the average plot was located about ten minutes away on foot from the landowner's house. The soil was predominantly black in 51 percent of cases, red in 18 percent of cases, and either brown or white in 31 percent of cases. The vast majority (62 percent) of plots are lowland rice plots while most of the remainder (38 percent) are hillside plots, with only very few plots (2 percent) located on hilltops. Finally, 45 percent of plots are irrigated by a dam, 37 percent are irrigated by a spring, and only 15 percent are irrigated by rainfall.

As regards informal land rights, landowners report perceiving that they have the right to sell on 56.4 percent of the plots; the right to build a tomb on 15.2 percent of the plots;[15] the right to lease out on 72.3 percent of the plots; the right to plant trees on 51.6 percent of the plots; and they report perceiving that their children will have the same rights as themselves on 46 percent of the plots. Although respondents were given for each informal right question the opportunity to respond that they did not know whether they had that right along with the usual "yes" and "no" options, no respondent chose that answer for any of the informal rights.

Almost a third (32.3 percent) of all plots in the sample are titled (i.e., this measures the proportion of landowners who answer the question "Is there a title for this plot?" in the affirmative),[16] which is close to the national average of 28 percent.[17] Moreover, almost two thirds (64.3 percent) of the plots were inherited, a little under a third (31.9 percent) were purchased, and few of them were either received as a gift (0.6 percent) or cleared by the

landowner (2.3 percent). The landowner intends to seek a title for almost half of the plots in the sub-sample of untitled plots and would be willing to pay about US$2.87 per are to do so,[18] or about US$47 in total for the average plot.

Before proceeding with the econometric analysis of the impact of land rights on productivity, it is instructive to simply look at the unconditional impact of land titles on various indicators. Table 2 thus splits the sample along formal land rights – i.e., titled and untitled plots – and reports descriptive statistics for each informal land right, i.e., the right to sell, whether the landowner's children will have the same rights on the plot, the right to build a tomb, the right to lease the plot out, and the right to plant trees. Table 2 further reports descriptive statistics by titling status for how the plot was acquired as well as for the soil quality measurements.

Although one would expect owners of titled plots to have more informal land rights on their plot than owners of untitled plots, the results in the first part of table 2 indicate otherwise. Indeed, although the fact that a landowner's children will have similar rights as herself on the plot is significantly more prevalent on titled plots, the right to sell and the right to build a tomb are both significantly more prevalent on *un*titled plots. Moreover, both inherited plots and the plots received as gifts are more likely to be titled, but purchased plots are more likely to be untitled. These results, while *prima facie* puzzling, are likely due to the fact that many land titles have not been kept up to date, and so they fail to effectively guarantee the rights of landowners.

Titled plots differ systematically from untitled plots along almost every soil quality measurement. Titled plots have consistently higher soil carbon, nitrogen, and sand contents, but systematically lower potassium, and clay contents, and systematically lower levels of soil pH. This suggests that soil quality may play a role in the decision of landowners to seek a title for their plots, but also that investment in soil quality may be a mechanism through which land titles affect agricultural productivity, which makes the part of the analysis that attempts to separate reduced-form causal effects from mechanisms discussed in section 3.2 all the more relevant. Lastly, there is no significant difference in mean rice yield between titled and untitled plots.

5. Estimation Results and Discussion

The comparisons just discussed between titled and untitled plots fail to control for confounding factors. This section addresses this problem by systematically studying the impact of formal and informal land rights on productivity.

5.1. Estimating the Productivity Impacts of Land Rights: Kitchen-Sink Approach

Table 3 presents estimation results for four specifications of the agricultural productivity equation: (i) OLS (equation 1); (ii) IV (equation 2); (iii) FE (equation 3); and (iv) FE-IV (equation 4). As discussed elsewhere (Barrett et al. 2010), there is a consistent inverse relationship between plot size and productivity in these data, as the results suggest that doubling the size of the average plot would lead to a decrease in yield of 21 percent (in the FE specification) to 35 percent (in the OLS specification).

A plot's position on the toposequence impacts productivity in that hillside plots are less productive at the margin than hilltop or lowland plots, but this is true only insofar as household fixed effects are omitted. This suggests that relatively less productive households cultivate hillside plots, and that once the unobserved heterogeneity between households is controlled for, a plot's position on the toposequence no longer matters.

The positive effects on productivity of structural irrigation (as opposed to irrigation by rainfall, the omitted category) are about the same whether a plot is irrigated by a dam or by a spring. This is true for all specifications, but the magnitude of the impact is considerably higher for specifications accounting for the unobserved heterogeneity between households. Again, this suggests that households that are less productive at the margin are the ones cultivating plots irrigated by a dam or spring instead of rainfall.

Except for a plot's potassium content or its pH, the soil quality measurements are, for the most part, statistically insignificant when considered individually. The soil quality measurements are jointly significant, however, in the IV, FE, and FE-IV specifications.[19] In any event, the lack of statistical significance of individual soil quality measurements need not be a concern: in his comprehensive economic history of agriculture over the last two centuries, Federico (2005, page 7) discusses how the most convincing studies of the impact of soil quality on productivity find

that only extreme values of soil pH really affect land productivity once other factors are controlled for.

Turning to the variables of interest, formal land rights do not have the posited theoretical impact on productivity at the margin, as the coefficient on whether a plot is titled is never significant at any of the conventional levels in any of the specifications in table 3.

Informal land rights matter in only a few cases. Whether a landowner believes she can lease out her plot is associated with increased productivity at the margin in the OLS specification, but with *de*creased productivity at the margin in the FE specification. Likewise, the right to build a tomb on the plot is also associated with decreases in productivity in both the FE and FE-IV specifications. The former effect is consistent with the literature associating land leases with a considerable amount of tenurial insecurity in Madagascar (Blanc-Pamard and Rakoto Ramiarantsoa 2000; Sandron 2008; Bellemare 2012). Both these results are discussed in more detail in section 5.2 below. Lastly, the right to plant trees is associated with increases in productivity in the FE specification.

A comparison of the results in table 3 also indicates that, depending on the specification, different results obtain. Comparing the naïve OLS with the FE specification, which controls for the unobservable heterogeneity between households, while the sign of the coefficient capturing the impact of a land title remains unchanged, the size the coefficient is increased by about one order of magnitude. There exists a similar difference between the estimated impact of a land title in the OLS and IV specification, but the latter results will not be discussed given that the instrument is weak in this cross-sectional context: the Cragg-Donald test of the null hypothesis that the instrument is weak has an F-statistic equal to 2.61 (see Stock and Yogo 2002). The weak instrument problem is considerably lessened in the FE-IV specification, where the F-statistic on the instrument is very close to the weak-instrument threshold of 10, and which is perhaps the most credible of all four specifications in table 3. When comparing the FE-IV specification with the FE specification, although the estimated impact of a land title changes from negative to positive, the impact remains statistically insignificant at any of the conventional levels.

The results in table 3 suggest that in this context, formal land rights (i.e., land titles) have no impact on agricultural productivity but informal land rights (i.e., the landowner's subjective perceptions with respect to specific rights on the plot) affect productivity in heterogeneous ways. Because the results in table 3 may understate the causal impacts of land rights, the next section presents estimation results aimed at separating the reduced-form causal impacts of land rights on agricultural productivity from the mechanisms through which land rights affect agricultural productivity.

5.2. Reduced-Form Causal Effects vs. Mechanisms

The results in table 3 often control for the causal mechanisms between the "treatment" variables of interest (i.e., the presence of formal or informal land rights) and the final outcome under study (i.e., agricultural productivity) while seeking to estimate the reduced-form causal effect of these treatment variables. See section 3.3 for a discussion. To address these concerns, specifications were estimated without either soil quality measurements or measures of informal land rights; with soil quality measurements but without measures of informal land rights; and without soil quality measurements but with measures of informal land rights. A synthesis of the estimated effects of formal land rights on agricultural productivity is then presented in table 4, along with estimation results for the estimated effects of informal land rights that exclude a control for formal land rights, both with and without soil quality measurements in table 5.[20]

Looking at the results in table 4, however, the overarching result is that although there are some changes in magnitude, the coefficient on the dummy variable for whether the plot is titled is never statistically significant at any of the conventional levels.

The next step was to conduct (i) tests of joint significance of the household fixed effects, (ii) Hausman tests in order to determine whether the IV was necessary, and (iii) tests of joint significance for the soil quality measurements as well as for the informal land rights measures. The household fixed effects are everywhere jointly significantly different from zero in table 4, which indicates that one should focus on FE or FE-IV specifications. For the Hausman test of exogeneity of the land title dummy variable in the FE specifications in table 3, the $\chi^2(21)$

statistic of the test was equal to 0.68, which translates into a *p*-value of 1.00, thus suggesting that one should focus on FE specifications.

Looking into the FE specification in the third column of table 3, the $\chi^2(7)$ statistic for soil quality measurements was equal to 17.06 and the $\chi^2(5)$ statistic for informal land rights was 11.04, which means one can reject the null hypotheses that (i) the soil quality measurements are jointly insignificant, and (ii) the informal land rights variables are jointly insignificant with respective *p*-values equal to 0.02 and 0.05. So if one were forced to pick a preferred specification, one should pick the specification in the third column of table 3, i.e., FE including informal land rights and soil quality measurements.

Table 5 then presents results for the impacts of informal land rights on agricultural productivity excluding a control for whether the plot is titled, both with and without soil quality controls. Once again, this is because investments in soil quality may be a mechanism through which informal land rights affect productivity. Because the data did not include valid instruments for each and every informal land right included in table 5, the best one can do is focus on the FE estimation results. In this case, the inclusion of soil quality controls in the fourth column of table 5 makes the landowner's subjective perception of whether she can build a tomb on her plot statistically significant, with the end result that whether the presence of a formal title is controlled for, subjective perceptions of informal land rights end up having the same impacts on agricultural productivity.

That the right to build a tomb on the plot decreases productivity suggests that specific taboos (Ruud 1960) or cultural mores (Graeber 1995) might play an important role in constraining productivity on the plots on which one can build a tomb.[21] It may seem puzzling that the right to build a tomb would entail a loss of productivity given that there is no *a priori* reason why this should be the case. In this context, however, it is likely that plots on which one can build a tomb belong to the clan and cannot truly become private property, which decreases one's incentives to invest in them. Because the Malagasy regularly organize two- to three-day extended family reunions called *famadihana* (turning of the bones) during which they take the bodies of the ancestors out of the family tomb and wrap them in fresh shrouds as part of the cult of the

ancestors (Graeber 1995), and because these ceremonies tend to be destructive to the soil around a tomb, it is not unlikely that landowners who expect to build tombs on their plots simply choose not make productivity-enhancing investments on the same plots.

To investigate this result further, an alternative specification (not shown) of the productivity equation was estimated during preliminary work for this paper which was augmented with the interaction between the number of people over the age of 64 in the household and the dummy for whether the landowner had the right to build a tomb on the plot. In that alternative specification (i) the interaction between the number of elderly individuals within the household and the dummy for whether the landowner can build a tomb had negative impact on productivity which was significant at the 1 percent level; and (ii) the dummy for whether the landowner can build a tomb no longer had a significant impact on productivity. Given that life expectancy is a little under 63 years in Madagascar, this suggests that landowners who expect to have to build a tomb on their plot soon may be less likely to have recently made productivity-increasing investments on their plots. Lastly, looking at the FE columns of table 3 and 5, the impact of the right to build a tomb on agricultural productivity is the same, i.e., the right to build a tomb is associated with decreases in productivity.

Likewise, that the right to lease a plot out decreases productivity is consistent with the empirical evidence associating land leases with a considerable amount of tenurial insecurity in Madagascar (Blanc-Pamard and Rakoto Ramiarantsoa 2000; Sandron 2008; Bellemare 2012). In this context, there are pronounced life-cycle effects, as land leases occur primarily between elderly landlords and young tenants, and over a third of the plots in Madagascar are under some form of land tenancy (Bellemare 2012). Thus, a landowner who has the right to lease her plot out will almost always do so in old age, so that the intention to lease a plot out is most likely indistinguishable from the right to do so in this context. As a consequence, a landowner may choose to underinvest in her plot's productive capacity, or may have chosen to underinvest in her plot's productive capacity in the past, if she knows she will be leasing it out in the future.

This result deserves further investigation, especially since the right to lease out is related to other transfer rights, most notably the right to sell. Indeed, one would expect that all plots where the

right to sell exists, the right to lease also exists, but it isn't necessarily so: though there are 394 plots for which those rights are the same (i.e., the landowner can both sell the plot and lease it out or the landowner can neither sell the plot nor lease it out), there are 79 plots for which those rights differ (i.e., the landowner can either sell the plot or lease it out, but not both). Moreover, two different dummy variables were defined: a variable equal to one if the landowner perceives she has both the right to sell and the right to lease out and equal to zero otherwise, and a variable equal to one if the landowner perceives she has the right to lease out but not to sell. Controlling for unobserved heterogeneity by including household fixed effects shows that the coefficients on both those dummy variables are negative and statistically significant. The results (not shown) also suggest that the right to sell and the right to lease out are jointly associated with decreases in productivity, but the right to lease out, absent the right to sell, is associated with a larger decrease in productivity.

Finally, that the right to plant trees is associated with increases in agricultural productivity in the FE specifications of tables 3 and 5 is not surprising, as landowners usually plant trees to prevent soil erosion or to improve soil fertility.

6. Conclusion

This paper has studied the effect of formal and informal land rights on agricultural productivity in rural Madagascar. As such, its main contribution has been to improve upon the identification of the effects of property rights, first by using precise soil quality measurements to control for the unobserved heterogeneity between plots, and then by attempting to separate reduced-form causal impacts of property rights on agricultural productivity.

Following through with the results of the empirical specification which emerged as the preferred one after a series of statistical tests, while formal land rights (i.e., land titles) have no impact on agricultural productivity in this context, result suggests that there is a negative association between the right to lease out and agricultural productivity. This is presumably due to the considerable amount of tenurial insecurity that is associated with the land rental market in Madagascar (Bellemare 2012), although this is merely speculative given that the data do not allow exploring the mechanism by which the right to lease might decrease productivity. There is

also evidence that the right to build a tomb on the plot is associated with a decrease in productivity while the right to plant trees is associated with an increase in productivity.

That formal land rights have no significant impact on productivity in this context echoes the conclusions of Atwood (1990) and Place (2009) for Africa as well as of Jacoby and Minten (2007) for Madagascar. Consistent with this, in his seminal study of state power in Africa, Herbst (2000, page 191) notes that

> "France was notable for its unusually unsuccessful efforts to disrupt customary tenure during the colonial period, despite its sweeping laws that theoretically made wholesale changes in land tenure (…) France relied on administrative fiat to try to change customary tenure procedures."

In other words, while land titling did reasonably well in replacing customary land tenure institutions in British colonies, they were much less effective in doing so in French colonies, and so it should perhaps come as no surprise that land titles play no special role in increasing agricultural productivity in the context of a French colony like Madagascar. This is consistent with Brasselle et al.'s (2002) findings for Burkina Faso, another French colony. Whether land rights are more effective in former British colonies than they are in former French colonies should be explored more carefully by future researchers given the current emphasis on institutions in economics (Acemoglu and Robinson, 2012).

Although these results says nothing about the impact of land rights on productivity in a context where the legal system is effective, they do point to institutional failures at a level beyond that of the community, given that the results in this paper control for institutional differences between communities. Because many land titles have not been kept up to date, it is not surprising that land titles should have no impact on agricultural productivity in this context. Given data limitations, however, it remains impossible to test whether it is indeed institutional failures at a level beyond that of the community which drives the empirical result for formal land rights. As for informal land rights, one can only speculate as to the causal mechanisms through which these rights impact productivity given data limitations and, as such, the investigation of these causal mechanisms is left for future research.

In terms of policy implications, although the empirical results in this paper strongly suggest that land titles have no statistically significant impact on agricultural productivity in Madagascar, one should mistake a lack of statistical significance for a lack of economic significance. Indeed, the US government's Millennium Challenge Corporation signed a $110 million, four-year compact with the government of Madagascar in 2005 which included an important land tenure component, and whose goal was to "increase land titling," and thus land security (Millennium Challenge Corporation 2010). But in a context where land titles do not seem to have the improve agricultural productivity, the finding that land titles do not have such an impact is highly relevant for policy in that it helps knowing where to allocate aid dollars at the margin. Here, it looks as though aid might be better allocated to a reform of the legal framework within which agriculture takes place. Policy should be based on empirical evidence – not theoretical beliefs.

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Table 1. Descriptive Statistics (n=473)

Variable	Coefficient	(Std. Dev.)
Yield (Kg/Are)	37.427	(27.734)
Cultivated Area (Ares)	16.433	(19.134)
Soil Quality Measurements		
Carbon (Percent)	2.403	(1.079)
Nitrogen (Percent)	0.213	(0.090)
Soil pH	5.069	(0.306)
Potassium (Percent)	0.206	(0.068)
Clay (Percent)	28.210	(3.651)
Silt (Percent)	26.409	(6.408)
Sand (Percent	45.134	(8.034)
Plot Characteristics		
Crop Disease Dummy	0.186	(0.390)
Distance from House (Walking Minutes)	10.289	(10.774)
Black Soil Dummy	0.505	(0.501)
Red Soil Dummy	0.184	(0.388)
Brown or White Soil Dummy	0.311	(0.463)
Lowland Plot Dummy	0.619	(0.486)
Hilltop Plot Dummy	0.027	(0.164)
Hillside Plot Dummy	0.353	(0.478)
Irrigated by Rain Dummy	0.152	(0.360)
Irrigated by Dam Dummy	0.450	(0.498)
Irrigated by Spring Dummy	0.372	(0.484)
Land Rights		
Right to Sell Dummy	0.564	(0.496)
Right to Build a Tomb Dummy	0.152	(0.360)
Right to Lease Out Dummy	0.723	(0.448)
Right to Plant Trees Dummy	0.516	(0.500)
Kids Will Have the Same Rights Dummy	0.459	(0.499)
Inherited Plot Dummy	0.643	(0.480)
Purchased Plot Dummy	0.319	(0.467)
Plot Received as Gift Dummy	0.006	(0.079)
Plot Obtained Through Clearing Dummy	0.023	(0.151)
Formal Title Dummy	0.323	(0.468)

Table 2. Selected Descriptive Statistics for Untitled vs. Titled Plots (n=473)

	Untitled Plots (n=320)		Titled Plots (n=153)		
Variable	**Mean**	**(Std. Dev.)**	**Mean**	**(Std. Dev.)**	**Difference**
Disaggregated Land Rights Measures					
Right to Sell Dummy	0.609	(0.489)	0.471	(0.501)	***
Children Will Have Same Rights Dummy	0.397	(0.490)	0.588	(0.494)	***
Right to Build a Tomb Dummy	0.181	(0.386)	0.092	(0.289)	***
Right to Lease Out Dummy	0.719	(0.450)	0.732	(0.444)	
Right to Plant Trees Dummy	0.531	(0.500)	0.484	(0.501)	
Mode of Acquisition					
Inherited Plot Dummy	0.609	(0.489)	0.712	(0.454)	**
Purchased Plot Dummy	0.356	(0.480)	0.242	(0.430)	***
Plot Received as Gift Dummy	0.000	(0.000)	0.020	(0.139)	**
Plot Obtained Through Clearing Dummy	0.022	(0.147)	0.026	(0.160)	
Soil Quality Measurements					
Carbon (Percent)	2.279	(0.055)	2.663	(0.098)	***
Nitrogen (Percent)	0.205	(0.005)	0.231	(0.008)	***
Soil pH	5.114	(0.018)	4.976	(0.020)	***
Potassium (Percent)	0.213	(0.004)	0.190	(0.005)	***
Clay (Percent)	28.432	(0.201)	27.745	(0.301)	**
Silt (Percent)	26.536	(0.361)	26.143	(0.511)	
Sand (Percent)	44.797	(0.463)	45.840	(0.603)	*
Rice Yield					
Mean	38.523	(1.661)	35.136	(1.858)	

Note: The symbols ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels.

Table 3. Agricultural Productivity of Formal and Informal Land Rights

	OLS			IV			FE			FE-IV		
	Coefficient		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**
Formal Title	-0.018		(0.072)	-0.306		(0.686)	-0.138		(0.175)	0.434		(0.712)
Right to Sell	-0.057		(0.083)	-0.117		(0.136)	0.076		(0.283)	0.184		(0.237)
Right to Lease Out	0.191	**	(0.082)	0.247		(0.151)	-0.713	**	(0.319)	-0.550		(0.354)
Rights of Children Identical	0.006		(0.077)	0.060		(0.159)	0.144		(0.304)	0.213		(0.364)
Right to Plant Trees	-0.032		(0.091)	-0.022		(0.091)	0.784	*	(0.445)	0.521		(0.492)
Right to Build a Tomb	0.054		(0.164)	0.028		(0.186)	-0.818	*	(0.447)	-0.709	**	(0.343)
Log of Plot Size	-0.346	***	(0.030)	-0.343	***	(0.031)	-0.213	***	(0.069)	-0.225	***	(0.054)
Crop Disease	-0.088		(0.104)	-0.083		(0.103)	-0.092		(0.150)	-0.040		(0.146)
Distance from House	-0.003		(0.002)	-0.002		(0.002)	-0.004		(0.007)	-0.004		(0.006)
Red Soil	-0.183		(0.118)	-0.186		(0.111)	-0.001		(0.206)	0.042		(0.152)
Brown or White Soil	-0.062		(0.083)	-0.075		(0.082)	0.256	*	(0.142)	0.221		(0.122)
Hilltop Plot	-0.206		(0.245)	-0.142		(0.347)	-0.428		(0.353)	-0.486		(0.330)
Hillside Plot	-0.117	*	(0.069)	-0.127	*	(0.072)	-0.184		(0.163)	-0.172		(0.115)
Irrigated by Dam	0.180	**	(0.076)	0.176	**	(0.081)	0.305	*	(0.183)	0.434	*	(0.224)
Irrigated by Spring	0.184	***	(0.071)	0.179	**	(0.072)	0.330		(0.204)	0.437	**	(0.210)
Carbon	-0.683		(0.862)	-0.340		(0.898)	-0.292		(3.122)	0.052		(1.627)
Nitrogen	0.954		(0.992)	0.593		(0.994)	0.143		(3.178)	-0.173		(2.251)
Soil pH	-0.136		(1.431)	-0.552		(1.056)	-28.728	**	(13.900)	-23.790		(15.787)
Potassium	0.208		(0.283)	0.185		(0.202)	-7.854	**	(3.193)	-7.659	**	(3.265)
Clay	0.198		(2.473)	-0.395		(2.715)	-4.215		(4.663)	-5.186		(4.195)
Silt	-0.666		(1.894)	-1.031		(1.469)	12.342		(13.122)	7.583		(15.184)
Sand	-0.578		(3.206)	-1.313		(2.876)	11.514		(9.149)	9.878		(7.295)
Intercept	4.061	***	(0.117)	4.120	***	(0.154)	3.823	***	(1.158)	3.433	***	(0.582)
Number of Observations	473			473			473			473		
Household Fixed Effects	No			No			Yes			Yes		
Bootstrap Replications	500			-			500			-		
F-statistic (Instrument)	-			2.89			-			9.61		
p-value (All Coefficients)	0.00			0.00			0.00			0.00		

p-value (Soil Quality)	0.97	0.05	0.02	0.02
R^2	0.38	0.35	0.97	0.97

Note: The symbols ***, **, and * respectively denote statistical significance at the 1, 5, and 10 percent levels. The *F*-statistic is used to assess whether the instrumental variable is weak (Stock and Yogo 2002). The two *p*-values respectively refer to a test of the null hypothesis that all coefficients are equal to zero, and a test of the null hypothesis that the coefficients on the soil quality measurement variables are equal to zero.

Table 4. Agricultural Productivity Impacts of Formal Land Rights (n=473)

Specification	Soil Quality	Informal Land Rights	Coefficient on Land Title
Block 1: Soil Quality and Informal Land Rights Both Excluded as Regressors			
OLS	No	No	-0.035
IV	No	No	-0.484
FE	No	No	0.028
FE-IV	No	No	0.420
Block 2: Soil Quality Included, Informal Land Rights Excluded as Regressors			
OLS	Yes	No	-0.009
IV	Yes	No	-0.553
FE	Yes	No	0.001
FE-IV	Yes	No	0.282
Block 3: Soil Quality Excluded, Informal Land Rights Included as Regressors			
OLS	No	Yes	-0.044
IV	No	Yes	-.0345
FE	No	Yes	-0.104
FE-IV	No	Yes	0.666
Block 4: Soil Quality and Informal Land Rights Both Included as Regressors			
OLS	Yes	Yes	-0.018
IV	Yes	Yes	-0.306
FE	Yes	Yes	-0.138
FE-IV	Yes	Yes	0.434

Note: The symbols ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels. Each block represents a set of specification which include or exclude the soil quality measurements (i.e., the ln *s* variables in equations 1 to 4) and which include or exclude the informal land rights measures (i.e., the *r* variables in equations 1 to 4). Each line within a block respectively corresponds to the specifications in equations 1 to 4 (i.e., OLS, IV, FE, and FE-IV). The last column presents the estimated impact of a formal land title on agricultural productivity for each specification. In no case is that estimated impact statistically significant. A full set of results is available from the author.

Table 5. Agricultural Productivity Impacts of Informal Land Rights

	OLS			FE			OLS			FE		
	Coefficient		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**	**Coefficient**		**(Std. Err.)**
Right to Sell	-0.037		(0.082)	0.116		(0.256)	-0.054		(0.077)	0.102		(0.267)
Right to Lease Out	0.164	**	(0.075)	-0.714	**	(0.319)	0.188	**	(0.080)	-0.674	**	(0.313)
Rights of Children Identical	-0.003		(0.058)	0.153		(0.209)	0.003		(0.072)	0.161		(0.319)
Right to Plant Trees	-0.032		(0.091)	0.719	**	(0.360)	-0.032		(0.090)	0.721	*	(0.432)
Right to Build a Tomb	0.031		(0.173)	-0.569		(0.375)	0.055		(0.163)	-0.792	*	(0.435)
Log of Plot Size	-0.347	***	(0.029)	-0.222	***	(0.070)	-0.347	***	(0.030)	-0.216	***	(0.067)
Crop Disease	-0.088		(0.097)	-0.040		(0.175)	-0.089		(0.103)	-0.079		(0.150)
Distance from House	-0.004		(0.002)	-0.005		(0.005)	-0.003		(0.002)	-0.004		(0.007)
Red Soil	-0.126		(0.123)	-0.045		(0.237)	-0.183		(0.118)	0.009		(0.207)
Brown or White Soil	-0.025		(0.079)	0.161		(0.190)	-0.061		(0.083)	0.248	*	(0.140)
Hilltop Plot	-0.194		(0.241)	-0.151		(0.309)	-0.210		(0.241)	-0.442		(0.352)
Hillside Plot	-0.119	*	(0.063)	-0.104		(0.179)	-0.116	*	(0.069)	-0.181		(0.162)
Irrigated by Dam	0.211	***	(0.066)	0.254		(0.188)	0.180	**	(0.076)	0.336	*	(0.192)
Irrigated by Spring	0.197	***	(0.073)	0.294		(0.207)	0.184	**	(0.072)	0.356	*	(0.212)
Carbon							-0.704		(0.853)	-0.209		(3.065)
Nitrogen							0.977		(0.980)	0.067		(3.141)
Soil pH							-0.110		(1.452)	-27.536	**	(13.598)
Potassium							0.210		(0.280)	-7.807	**	(3.181)
Clay							0.234		(2.421)	-4.449		(4.595)
Silt							-0.644		(1.884)	11.194		(13.049)
Sand							-0.533		(3.175)	11.119		(8.869)
Intercept	4.041	***	(0.107)	3.814	***	(0.359)	4.057	***	(0.119)	3.729	***	(1.152)
Number of Observations		473			473			473			473	
Household Fixed Effects		No			Yes			No			Yes	
Bootstrap Replications		-			-			500			500	
p-value (All Coefficients)		0.00			0.00			0.00			0.00	
p-value (Soil Quality)		-			-			0.97			0.01	
R^2		0.36			0.97			0.38			0.97	

Note: The symbols ***, **, and * respectively denote statistical significance at the 1, 5, and 10 percent levels. The two *p*-values respectively refer to a test of the null hypothesis that all coefficients are equal to zero, and a test of the null hypothesis that the coefficients on the soil quality measurement variables are equal to zero.

Table A1. Soil Quality Measurement Imputation Regressions (n=234)

Variable	Carbon	Nitrogen	Potassium	pH	Clay	Silt	Sand
Principal Component 1	-21.866	-1.61	-0.809	77.237	-17.844	0.411	-62.696
	(3.630)	(0.308)	(0.708)	(27.731)	(34.451)	(1.809)	(40.802)
Principal Component 2	34.244	3.2	-0.058	-147.601	92.245	12.092	55.525
	(6.167)	(0.523)	(1.218)	(47.572)	(59.100)	(3.103)	(69.996)
Number of Soil Samples	234	234	234	234	234	234	234
Village Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.88	0.89	0.57	0.94	0.90	0.99	0.37

Note: Reproduced from Barrett et al. (2010). Standard errors are in parentheses. The results of these regressions are used to impute the values of the dependent variables (i.e., carbon, nitrogen, potassium, pH, clay, silt, and sand) for the entire sample of 473 plots. Each column regresses a soil quality measurement obtained by wet chemistry on the principal components obtained from spectral analysis. The estimated coefficients are then used to predict each dependent variable for the whole sample.

[1] Using data from Paraguay, Carter and Olinto (2003) disentangle the investment-demand and credit-supply effects of property rights reform and find that if the credit supply effect does not manage to relax credit constraints, landowners will substitute investment in fixed assets for investment in current (i.e., expropriation-immune) assets, with the result that the benefits of property rights reform largely accrue to wealthier landowners, who are less likely to be credit constrained. Likewise, Besley and Ghatak (2009) show that depending on the degree of competition in the credit market, it is in theory possible for some borrowers to be made worse off by property rights reform. Testing the theoretical frameworks developed in either Carter and Olinto (2003) or Besley and Ghatak (2009) is well beyond the scope of the data used in this paper.

[2] See also Fenske (2010) for a study of incomplete property rights in Côte d'Ivoire. The survey questionnaire used here, however, failed to ask respondents about the origins of these subjective perceptions. See Delavande et al. (2010) for an overview of the literature on subjective perceptions in development economics.

[3] Specifically, the estimation sample consists of 473 plots belonging to 290 households and there are 132 households who own more than one plot.

[4] While the data used by Goldstein and Udry (2008) include measures of soil pH and organic matter, the focus of their paper is on the relationship between the property rights and political power of landowners.

[5] Although precise measures of soil quality are observed here, they are typically unobservable. In a slight abuse of language, the remainder of this paper will refer to them as "unobservable" even though they are observed in this context.

[6] Most of the information in this section is discussed extensively in an edited volume by Sandron (2008).

[7] Although this number may seem low, it has emerged as a consensus about the number of titles emitted annually between the participants of the aforementioned workshop on land tenure organized by the Ministry of Agriculture in early 2005. A 2010 audit of the administration of land tenure in Madagascar reports that only 1,500 new titles are delivered annually. See page 22 of the audit report at http://www.notariat-francophone.org/wp-content/uploads/2010/10/rappor_mada_version_9_septembre-2010.pdf.

[8] Both the bankruptcy of the formal titling system and the emergence of the *petits papiers* system in Madagascar offer evidence against the evolutionary theory of land rights, a critique of which can be found in Platteau (1996).

[9] Because households do not move from one village to the other within the cross-sectional data used in this paper, these fixed effects also account for the heterogeneity of customary rights and institutions at the level of the community (i.e., the unobserved heterogeneity between villages).

[10] In contrast with Burkina Faso, where different individuals within a household own different plots (Udry 1996), in Madagascar the household head owns all the household's plots.

[11] A similar reasoning applies to informal land rights.

[12] Because the soil quality data were given to the author as is, it was not possible to bootstrap the entire procedure (i.e., the imputation of soil quality measurements *and* the estimation of equations 1 to 6). Thus, only the standard errors of the estimated equations themselves were bootstrapped.

[13] One hectare is equal to 100 ares, and one are is equal to 100 square meters.

[14] Given that distilled water has a (neutral) pH of 7, this denotes a relatively high level of soil acidity in the sample.

[15] It may seem puzzling that one can build tomb on lowland rice plots, which are flooded. A plot's cultivated area is smaller than a plot's total area, however, so that if one were to build a tomb on a lowland rice plot, the tomb would be built on the dry edge of the plot, or the plot would be drained so as to accommodate a tomb.

[16] It is unfortunately impossible to tell whether the titles belong to the respondents or to their family members, in which case the instrumental variables approach used in this paper would be invalid. For this reason, the IV and FE-IV results are presented purely for comparison with previous studies, and the empirical results in this paper include specifications both with and without the instrumental variable.

[17] Such a figure might seem high in a context where the emission of new land titles is as slow as discussed in this paper. There was a large number of land titles emitted, however, when Madagascar's land tenure institution were founded upon the country's independence in 1960.

[18] At the time of the survey, US$1 ≈ 300 Ariary.

[19] One should be careful not to give soil quality measurements a structural interpretation. These variables are included here as control variables. Ideally, one would include each soil quality measurement along with its square and its interactions with other inputs. Given the sample size, however, it was not possible to do so in this case. Thus, although one would expect a nonlinear structural relationship between yield and soil pH (Federico 2005), for instance, this variable enters equations 1 to 4 only linearly because of the role of soil pH as a control variable. To ensure that the results for land rights are robust to nonlinearities in soil quality, however, robustness checks (not shown) were conducted in which the soil quality measurements entered nonlinearly (i.e., the squared logarithm of each soil quality measurement was used as regressor instead of the logarithm of each soil quality measurement), but this did not change the qualitative results in tables 3 and 4.

[20] The effect of formal land rights (i.e., whether a plot is titled) on soil quality controls were estimated during preliminary empirical work. These results are not shown but are available from the author. In only one case (an FE-IV specification regressing the percentage of potassium in the soil on a dummy for whether the plot is titled and on controls plot characteristics) was the effect of formal land rights significant. Even in that case, the effect was barely significant at the 10 percent level.

[21] For instance Stifel et al. (2011) find that the number of days for which agricultural work is prohibited has a negative impact on agricultural productivity.