

Efficiency and Productivity Differential Effects of Land Certification Program in Ethiopia Quasi-experimental Evidence from Tigray

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TABLE OF CONTENTS

Abstract	3
1. Introduction	3
2. Literature Review: Property Rights and Agricultural Productivity	4
Tenure Security: Investment Effect	5
Tenure Security: Market Efficiency Effect	5
Access to Credit: Interlinked Collateral (Indirect Tenure Insecurity).....	5
3. Method of Analysis.....	7
Data Envelopment Analysis	7
The Malmquist Index.....	8
The Catching-Up Effect (M_{12}^e)	9
Productivity Gap between Best-Practice Frontiers (Frontier-Shifter Effect, M_{12}^f).....	9
Stochastic Dominance Analysis	10
4. Data and Identification Strategy	11
5. Results and Discussion.....	11
Descriptive Analysis.....	11
Structural Efficiency Comparisons: Parametric Approach.....	13
Explaining Productivity Differences: DEA-Based Malmquist Index Approach.....	14
Overall Productivity Difference.....	15
6. Conclusions	19
References.....	20

LIST OF TABLES

Table 5.1—Mean comparison tests for key household-level variables.....	12
Table 5.2—Mean comparison tests for key plot-level variables	13
Table 5.3—Stochastic production frontier estimates—pooled data.....	14
Table 5.4—Stochastic production frontier estimates of plots with and without certificates.....	14
Table 5.5—Malmquist index for comparison of group performance (M_{12}) between farms with and without certificates.....	15
Table 5.6—Test results of first-order stochastic dominance of (two-sample Kolmogorov-Smirnov test).....	16
Table 5.7—A component of the Malmquist index (M_{12}^e) for comparison of within-group efficiency spread in farms with and without land use certificates	17
Table 5.8—A component of the Malmquist index (M_{12}^f) for comparison of productivity between the group frontiers for farms with and without land use certificates	18

LIST OF FIGURES

Figure 2.1—Land certification and agricultural productivity	6
Figure 5.1—Cumulative distribution function for the overall productivity effects of land certificate (first-order stochastic dominance)...	17
Figure 5.2—Cumulative distribution function for internal (technical) efficiency effects of land certificate (first-order stochastic dominance)	18
Figure 5.4—Cumulative distribution function for technology (frontier-shifting) effects of land certificate (first-order stochastic dominance)	19

ABSTRACT

Although theory predicts that better property rights to land can increase land productivity through tenure security effects (investment effects) and through more efficient input use due to enhanced tradability of the land (factor intensity effect), empirical studies on the size and magnitude of these effects are very scarce. Taking advantage of a unique quasi-experimental survey design, this study analyzes the productivity impacts of the Ethiopian land certification program by identifying how the investment effects (technological gains) would measure up against the benefits from any improvements in input use intensity (technical efficiency). For this purpose, we adopted a data envelopment analysis–based Malmquist-type productivity index to decompose productivity differences into (1) within-group farm efficiency differences, reflecting the technical efficiency effect, and (2) differences in the group production frontier, reflecting the long-term investment (technological) effects. The results show that farms without a land use certificate are, on aggregate, less productive than those with formalized use rights. We found no evidence to suggest this productivity difference is due to inferior technical efficiency. Rather, the reason is down to technological advantages, or a favorable investment effect, from which farm plots with a land use certificate benefit when evaluated against farms not included in the certification program. The low level of within-group efficiency of farms in each group reinforces the argument that certification programs need to be accompanied by complementary measures such as an improved financial and legal institutional framework in order to achieve the promised effects.

Keywords: land certification, data envelopment analysis, Malmquist index, productivity, Ethiopia

1. INTRODUCTION

Poor agricultural productivity and food insecurity are persistent features of many developing countries. Governments and international agencies have therefore rightly embraced agricultural intensification as the primary means for inducing technological change in developing countries that have high population pressure and low agricultural productivity. Integral to this growing global interest in a public policy research and development agenda is the issue of land tenure security (Holden, Deininger, and Ghebru 2010). Because of the conventional view that traditional or “customary” land rights impede agricultural development (Johnson 1972; Gavian and Fafchamps 1996), many developing countries and major multilateral organizations have advocated formalization of land rights (through registration and certification of land rights) as a top priority in their economic development agendas (Atwood 1990; IFAD 2001; Bonfiglioli 2003; Deininger 2003; Holden, Deininger, and Ghebru 2011).

In theory, there are three routes through which secure property rights may influence agricultural productivity. The first is by *encouraging long-term land investment* and *adoption of new technologies* (Barrows and Roth 1990; Besley 1995; Sjaastad and Bromley 1997; Deininger and Jin 2006). According to this hypothesis, afraid of not recouping the investment made, the land user without formalized property rights hesitates to spend resources on land-improving technologies (conservation, manure, fertilizer, and so on). As a result, the demand for investment declines and productivity suffers. Second, secure property rights are also thought to influence agricultural productivity because they *encourage efficient resource use (factor intensity)*. The establishment of clear ownership of land, it is thought, lowers the cost and risk of transferring the land, which improves factor intensity through reallocation of land to more efficient producers. It has also been claimed that secure property rights can stimulate efficient resource use by *reducing land-related disputes* (Deininger and Castagnini 2006; Holden, Deininger, and Ghebru 2008) and may thereby contribute to better access to credit if land can be used as collateral.

As discussed in Section 2, the literature on land tenure reforms is lacking in empirical assessment of the reforms’ direct impacts on land productivity. Especially absent is an examination of the routes through which secure property rights can influence productivity: the *technological effect* and the *factor intensity effect*. Taking advantage of data from a quasi-experimental design of a household survey from the northern highlands of Ethiopia, this paper introduces some innovative elements in evaluating the productivity effects of the land certification program in Ethiopia.¹ Rather than simple comparisons of relative productivity differentials between farms with and without a certificate, this study decomposes such group differences in productivity into (1) differences in within-group efficiency spread or individual performance within each group (the catching-up effect or factor intensity effect) and (2) differences in technology (the distance between group frontiers, or technology effect). We accomplish this task of analyzing the group productivity difference by constructing a nonparametric Malmquist productivity index based on data envelopment analysis (DEA).

¹ The recent land certification program in Ethiopia is arguably the largest land administration program carried out over the last decade in Africa, and possibly the world (Deininger, Ali, and Alemu 2008a). This program departs from traditional titling interventions in developing countries by issuing non-alienable use right certificates rather than full titles. See the previous study by Holden, Deininger, and Ghebru (2009) for a detailed discussion of the land certification program in the Tigray region of Ethiopia (the study area), the first region in the country to start the certification program, in 1998.

Comparing the performance of a group of farms with formalized land use rights (a certificate) against those without a certificate, the objectives of the study are twofold. First, we wish to examine whether or not there are any productivity-enhancing benefits from land certification. The analysis enables us to understand the overall productivity differential effects of the land certification program. Second, we aim to isolate and examine the pathways through which land certification influences agricultural productivity. This analysis is the core of the paper and provides insights into how the investment effects (technological gains) of land certification would measure up against the benefits from any improvements in input use intensity (technical efficiency).

There exists a broad range of research studies analyzing the efficiency of farms in developed and developing economies. These studies encompass the issues of technical, allocative, scale, and scope efficiency as well as change in productivity over time. Technical efficiency is attained when the best available technology is used. Taking market prices as given, allocative efficiency holds when resource allocation decisions minimize cost, maximize revenue, or more generally maximize profit. Scale efficiency means that firms are of the appropriate size, so that no industry reorganization would improve output or earnings. Scope efficiency refers to the economies of joint production, where the cost of producing joint products is less than the sum of the products' stand-alone production costs.

However, due to the nonreliability of input and output prices, and the subsistence nature of the smallholder farm producers in the study area, the measures of efficiency performance described in this paper do not capture the effects of the intervention (the land certification program) on the allocative or scope efficiency of farms. Rather, the efficiency measures used in this paper are based on a comparison of the performance of farms (both with and without land certificates) evaluated against a constant-returns-to-scale technology. This methodology implies that the possible routes for efficiency improvements due to the land certification program may involve the removal of pure technical inefficiencies (a catching-up effect), the removal of scale inefficiencies (adoption of best-practice technology), or both. We are not aware of any other study on the productivity impacts of land reforms that analyzes and decomposes efficiency (technical efficiency) and productivity (technological or scale) effects.

Based on the results from the DEA-based Malmquist productivity index, we find that farms without a land use certificate are, on aggregate, less productive than those with formalized use rights. Further, using the decomposed analysis, we find no evidence to suggest that any productivity difference between the two groups of farms is due to differences in technical efficiency. Rather, the reason comes down to "technological advantages," or a favorable investment effect, from which farm plots with land use certificates benefit when evaluated against those farms not included in the certificates. The low level of within-group efficiency of farms in each group reinforces the argument that certification programs need to be accompanied by complementary measures such as an improved financial and legal institutional framework in order to achieve the promised effects.

This paper is organized as follows. Section 2 reviews the conceptual framework for the economic benefits of land reforms. The analytical approach adopted in this study to measure productivity and productivity differences is discussed in Section 3. Section 4 describes the data sources and summary statistics, while the last two sections are devoted to the discussion of results and concluding remarks.

2. LITERATURE REVIEW: PROPERTY RIGHTS AND AGRICULTURAL PRODUCTIVITY

Property rights theory does not emphasize who "owns" land but rather analyzes the formal and informal provisions that determine who has a right to enjoy *benefit streams* that emerge from the use of assets and who has no such rights (Libecap 1989; Eggertsson 1990; Bromley 1991). These rights need to be sanctioned by a collective in order to constitute effective claims. Property rights to land can cover one or more of the following: "access, appropriation of resources and products, provision of management, exclusion of others, and alienation by selling or leasing," with only ownership conferring "the cumulation of all of these" (de Janvry et al. 2001, 2; see also Ostrom 2001). In various combinations or *bundles*, these rights are significant for agricultural development inasmuch as they encourage different positive behaviors toward land (investment) and toward other people (dispute resolution). The recent literature on property rights over land and other natural resources commonly uses a broad classification of property regimes: open access (no rights defined), public (held by the state), common (held by a community or group of users), and private (held by individuals or "legal individuals" such as companies).

Reflecting neoliberal thinking on private property rights and development, Besley (1995) identified three channels through which farmers' acquisition of clearly defined property rights to land can, in principle, increase agricultural productivity: (1) technological change—long-term investment in land, (2) smooth functioning of the land (rental) markets that lubricate factor-ratio adjustment, and (3) facilitating access to (in)formal credit or informal collateral arrangements.

Tenure Security: Investment Effect

Farm households' investment in practices that enhance the long-term viability of agricultural production hinges significantly on expectations regarding the length of time over which the investors (farmers) might enjoy the benefits, which mostly are long-term. These expectations are affected by any sense of tenure insecurity (whether through ownership disputes, eviction, or expropriation by the government). Titling (ownership officially documented and verified via land certificates) enhances the landholder's sense of tenure security, boosting incentives to invest in advancements that enhance long-term sustainability of agricultural production (such as land improvements, conservation practices, and adoption of new technology), which ultimately may increase farm productivity (Gavian and Fafchamps 1996; Hayes, Roth, and Zepeda 1997; Gebremedhin and Swinton 2003; Deininger and Jin 2006; Deininger et al. 2008; Holden, Deininger, and Ghebru 2009).

Tenure Security: Market Efficiency Effect

In addition to its investment-enhancing effects, formalization of land rights is also thought to influence agricultural productivity through the tradability effect by facilitating the smooth functioning of land transactions (in the Ethiopian context, land rental markets) because imperfections in such markets (transaction costs and ownership uncertainties) may be more severe when agents of the market lack formal land use rights. From the supply-side perspective, for instance, without clear and definite claims to the land, farmers (potential landlords) can be reluctant to transfer ownership to others (that is, to rent or lease out land) for fear of losing the land through administrative redistribution (Deininger, Ali, and Alemu 2008b; Ghebru and Holden 2008). In such circumstances, it is possible that the landholder may operate the land by him- or herself instead of transferring it even if the land's productivity would be far better under a different operator (the potential tenant) with better skill and complementary farm inputs. Better property rights to land could therefore come to the rescue to reduce the cost and risk of land transactions, ultimately improving factor mobility resource allocation and, thus, farm productivity.

Access to Credit: Interlinked Collateral (Indirect Tenure Insecurity)

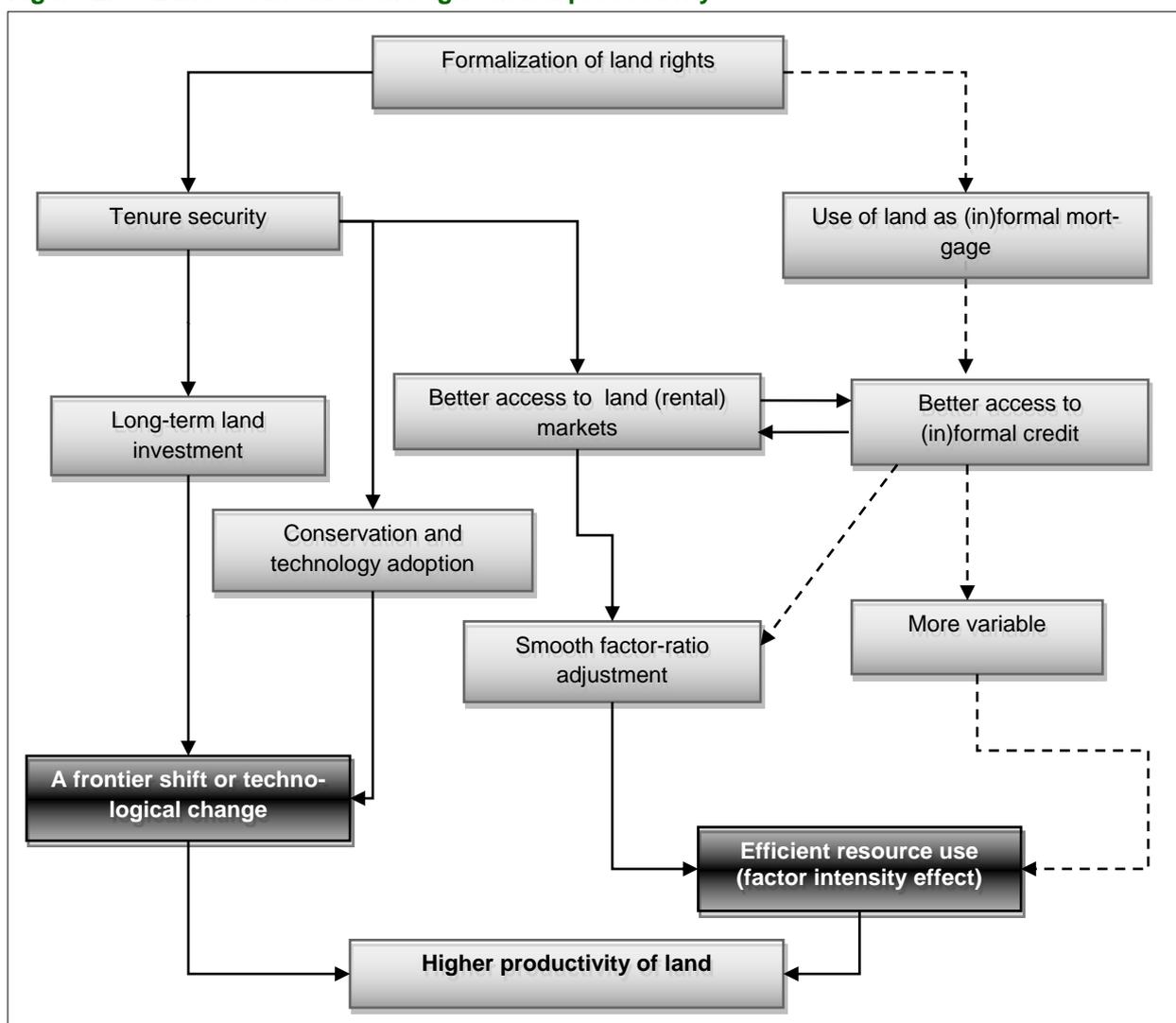
Finally, advocates of land titling have prioritized well-defined rights to landownership, reasoning that land title can stimulate investment by means of a credit effect. According to this hypothesis, turning land into a transferable commodity enables farmers to use it as collateral to access the credit needed for productivity-enhancing investments. However, since the non-freehold land certificates provided in Ethiopia provide use rights, limited transfer rights (no rights to sell), and no mortgaging rights, we are not able to evaluate the impact of this channel in the Ethiopian context (a limitation reflected in the broken lines in Figure 2.1).² Despite the fact that land is not mortgageable in Ethiopia and therefore cannot formally be used as a loan guarantee, there are practices in the study area that make use of agricultural land for informal mortgages.³ Under such arrangements, which involve the informal land tenancy market, full use of an agricultural landholding is transferred from the borrower (landlord) in exchange for an interest-free cash loan for the duration of the credit period. Assuming that land registration and certification reduce boundary and ownership disputes, the use of parcels with no certificate as informal mortgages can be minimal. Under these conditions, farmers who have no registered and documented land rights may find it expensive, if not impossible, to get access to this type of informal credit due to the lack of guarantee that informal money lenders look for. Formalizing land rights through land registration and certification⁴ may reduce such liquidity constraints, enabling farmers to improve variable input use and, in turn, increasing farm-level efficiency.

² See previous studies by Holden, Deininger, and Ghebru (2009) and by Ghebru and Holden (2009) for detailed discussion of the evolution of the land tenure system in Ethiopia and the recent land certification program in the Tigray region.

³ At the time of the fieldwork, we noted a few cases in which landlords rented their fields to tenants whom they had borrowed money from.

⁴ Ethiopian farmers, by law, are not landowners but holders of land use rights. Thus, the recent land policy reform that formalizes land rights does not provide full titling to the holder but only registers land and provides land use certificates. In this paper, we use the terms *titling* and *certification* interchangeably.

Figure 2.1—Land certification and agricultural productivity



Source: Conceptual framework developed by the authors.

Against this backdrop, the formalization of land rights and the resultant tenure security can be hypothesized to have an overall land productivity effect through two major channels:

1. The “technological effects” of land-related investment and technology adoption that have a lasting effect, causing a shift in a production frontier
2. The “factor intensity effect” of (either or both)
 - a. relative ease in farm factor-ratio adjustment (enabling farms to operate at an optimal scale) facilitated through a reduction in ownership uncertainty and a smoothing of land transactions; and
 - b. An improvement in variable input use intensity through reducing the transaction cost of accessing the informal credit market, thereby reducing the liquidity constraint.

Although a growing body of literature explores the impact of tenure reforms on investment, access to credit, and tradability of land in Africa (Feder, Onchan, and Chalamwong 1988; Pinckney and Kimuyu 1994; Besley and Coast 1995; Deininger and Feder 1998; Li, Rozelle, and Brandt 1998; Place and Migot-Adholla 1998; Smith 2004; Jacoby and Minten 2007; Do and Iyer 2008; Holden, Deininger, and Ghebru 2009, 2011), empirical assessments of the direct effects of such interventions on land productivity are very scarce. One exception is a study by Holden, Deininger, and Ghebru (2009), which assessed the overall land productivity impacts of the low-cost land registration and certification program in Ethiopia. However, this study did not distinguish between the routes through which secure property rights can influence agricultural productivity: the technological effect and the factor intensity effect.

Based on this brief review of theory and relevant literature, the objectives of the present study are twofold. First, we wish to examine whether or not land certification produces any productivity-enhancing benefits. This analysis serves as a vehicle for understanding the overall productivity differential effects of the land certification program. Second, we aim to isolate and examine the pathways through which land certification influences agricultural productivity. This analysis is the core of the paper and provides insights into how the *technological gains* (investment effects) of land certification would measure up against the benefits from improvement in technical efficiency (factor intensity). To the best of our knowledge, there is no other study on the productivity impacts of land reforms that has attempted to show these decomposed effects.

3. METHOD OF ANALYSIS

There are two main competing methods for estimating the relative efficiency of farms: parametric (stochastic frontier analysis) and nonparametric (DEA).⁵ The parametric approach assumes a functional relationship between output and inputs and uses statistical techniques to estimate the parameters of the function. While this approach provides a convenient framework for conducting hypothesis testing, the results can be sensitive to the behavioral assumption and the functional forms chosen. The nonparametric approach (DEA), in contrast, has the advantage of imposing no a priori parametric restrictions on the underlying technology. It constructs a linear, piecewise function from empirical observations on inputs and outputs without assuming any functional relationship between them.

DEA is not without criticism, however, since it is a deterministic approach that gives no account of stochastic elements. A disadvantage common in this method is thus its sensitivity to outliers and data measurement errors. Because this approach assumes any deviation from a frontier as a possible inefficiency, the efficiency score estimates can be biased (downward) if the production process is largely characterized by stochastic elements. Since this paper is interested only in analyzing the overall productivity difference between two groups of farms, not in explaining the efficiency score estimates per se, and since we expect the efficiency ranking of farms would be similar under both alternative approaches, we use the nonparametric DEA technique developed by Charnes, Cooper, and Rhodes (1978).⁶

Exogenous factors like government policy interventions or implementation of new development programs may provide rural farm household units with the various types and degrees of opportunities and challenges that ultimately affect their productivity. Productivity is defined here as the ability of a farm either to produce the maximum possible output from a given bundle of inputs and a given technology, or to produce the given level of output from the minimum amount of inputs for a given technology. The change in productivity due to policy interventions can be of a short-term nature (affecting factor intensity) or can have a long-term horizon (affecting technological adoption). Thus, productivity differences or changes can be attributed to or decomposed into two components: pure technical efficiency and differences in technology.

Most empirical studies, thus far, have analyzed farm productivity differentials based entirely on a method of pooling decisionmaking units to form a common benchmark frontier, according to which performances are evaluated. Such an aggregate measure of performance (efficiency) pays no attention to the aforementioned sources of productivity differences or changes. In an attempt to fill this gap and characterize potential productivity differentials in terms of pure technical efficiency difference and technological differences, the present study uses a two-step nonparametric approach. In the first step, we use DEA to estimate efficiencies as an explicit function of discretionary (observed) input–output variables.⁷ To evaluate productivity differences of farms that belong to two distinct groups (based on the policy intervention of land certification), in the second step we adopt a DEA-based Malmquist productivity index that defines group-specific frontiers in order to compare relative performances. The estimation methods used in this study are explained below.

Data Envelopment Analysis

DEA is a linear programming technique for constructing a nonparametric, piecewise linear envelope for a set of observed output and input data (Charnes, Cooper, and Rhodes 1978; Fare, Grasskopf, and Lovell 1994). Assuming that

$X^i = (X_1^i, X_2^i, \dots, X_M^i) \in \mathfrak{R}_M^+$ denotes the input vector to produce Y^i , where i corresponds to a group to which a farm plot

⁵ See Coelli (1995) for comprehensive reviews of the two approaches.

⁶ Comprehensive studies conducted on the sensitivity of efficiency measures to the choice of DEA versus parametric approaches reveal that despite quantitative differences in the efficiency score estimates between the two approaches, the ordinal efficiency rankings of farms obtained from the two approaches appear to be quite similar (Sharma, Leung, and Zaleski 1999; Wadud and White 2000).

⁷ Recent applications of the DEA method on the estimation and explanation of agricultural efficiency in developing countries include Shafiq and Rehman (2000) on Pakistani cotton farms; Dhungana, Nuthall, and Nartea (2004) on Nepali rice farms; and Chavas, Petrie, and Roth (2005) on Gambian farms.

belongs,⁸ the feasible production frontier that describes the technology of the farming units can be defined in terms of correspondence between the output vector Y^i and the input requirement set $L^i(Y^i)$, where

$$L^i(Y^i) = \{X^i : (X^i, Y^i) \in T^i(X^i)\} \quad (1)$$

The production possibility set (input requirement set) $L^i(Y^i)$ provides all the feasible input vectors that can produce the output vector Y^i , where $T^i(X^i)$ is the technology set of a group or the government program i , showing that X^i can produce Y^i .

Assuming constant returns to scale, Farrell (1957) proposed a radial measure of technical efficiency in which the efficiency is measured by radial reduction of the levels of inputs relative to the frontier technology, holding the output level constant.⁹ Stated otherwise, Farrell's input-oriented measure of technical efficiency estimates the minimum possible expansion of X^i , which is given by

$$F^i(X^i, Y^i) = \min\{\varepsilon : \varepsilon X^i \in L^i(Y^i)\} \quad (2)$$

As formalized by Fare and Lovell (1978), Farrell's input-saving efficiency measures are the same as the inverse of Shephard's input distance function, which provides the theoretical basis for our "adapted" Malmquist productivity index.¹⁰ Therefore, within the context of input distance function, equation (2) can be rewritten as¹¹

$$D^i(X^j, Y^j) = \max_{\mu_{ij}} \{\mu_{ij} : (X^j / \mu_{ij}) \in L^i(Y^j)\} \quad (3)$$

where $i, j = 1, 2$; $D^i(X^j, Y^j)$ represents the input distance function for a farm in program or group j with respect to the frontier technology of group i ; the scalar μ_{ij} is the maximum reduction (contraction) of the input vector of a farm plot belonging to group or program j (X^j); and the resulting deflated input vector (X^j / μ_{ij}) and output vector (Y^j) are on the frontier of the farming system under group or program i .

The Malmquist Index

The Malmquist index was introduced by Caves, Christensen, and Diewert (1982) and developed further by Fare, Grasskopf, and Lovell (1994). The index is normally applied to the measurement of productivity change over time and can be multiplicatively decomposed into an efficiency change index and a technical change index. Similarly, the adapted Malmquist index (the performance index for program evaluation) applied in this paper can be multiplicatively decomposed into an index reflecting the efficiency spread among farms operating within each group (the internal efficiency effect) and an index reflecting the productivity gap between the best-practice frontiers of two different programs or groups (the technology effect). A recent application of a DEA-based Malmquist index on cross-sectional microdata is a study by Jaenicke (2000), who analyzed the productivity differential effects of a crop rotation farming system.

Taking the best-practice farms under group i as a reference or base technology, with C_n being the number of farms in Group 1 (the *without certificate* group) and C_w number of farms in Group 2 (the *with certificate* group), the input-oriented Malmquist productivity index developed by Fare, Grasskopf, and Lovell (1994) can be defined as

$$M_i(Y_j^1, Y_j^2, X_j^1, X_j^2) = \frac{\left(\prod_{j=1}^{C_n} D^i(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^i(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} = \frac{1/\varepsilon_{i1}}{1/\varepsilon_{i2}} = \frac{\varepsilon_{i2}}{\varepsilon_{i1}} \quad (4)$$

where $i = 1, 2$. The above ratio evaluates the distance of the farms in each group from a single reference technology i . The numerator evaluates the average (geometric mean) distance of farms in Group 1 from frontier i while the denominator evaluates the average distance of farms in Group 2 from frontier i . Since there is no practical reason to prefer either frontier as a reference technology, the forthcoming analysis is made based on the geometric mean of the two indexes generated using each group's frontier as reference. As a result, equation (4) can be rewritten as

⁸ Since the emphasis of the study is to explain the potential productivity differentials with respect to formalized use rights, from this point on we adopt two groups: Group 1, farms with no land use certificate, and Group 2, those with a certificate.

⁹ The input-oriented model implicitly assumes cost-minimizing behavior of farmers; the output-oriented DEA, on the other hand, assumes revenue-maximizing behavior. In our case, it is thus reasonable to assume that farmers have a budget constraint and therefore try to minimize costs.

¹⁰ $F^i(X^j, Y^j) = \text{Min } \varepsilon = [D^i(Y^j, X^j)]^{-1}$, where $i, j = 1, 2$.

¹¹ The expression $D^i(X^j, Y^j)$ is the maximum value by which the input vector can be divided and still produce a given level of output vector Y .

$$M_{12}(Y_j^1, Y_j^2, X_j^1, X_j^2) = \left[\frac{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}} \left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right]^{\frac{1}{2}} = \left[\begin{matrix} \mathcal{E}_{12} & \mathcal{E}_{22} \\ \mathcal{E}_{11} & \mathcal{E}_{21} \end{matrix} \right]^{\frac{1}{2}} \quad (5)$$

Thus, the two ratios inside the square brackets evaluate the distance of each farm from a single reference frontier. The first ratio evaluates the average distance of farms in Group 1 divided by the average distance of farms in Group 2 using a technology defined by the best-practice farms from Group 1. The second ratio is a similar quotient, taking Group 2's frontier as reference. Also, when comparing the two groups, to avoid the limitations associated with defining an "ideal" or "representative" farm to represent each group, the aggregation of the distances or efficiency scores is conducted using the geometric mean, which utilizes information from all farm plots.

A Malmquist index (M_{12}) greater than 1 indicates a higher productivity of farms cultivated under the second property-rights group (plots with land use certificate) than plots without a land certificate. This is so since the maximum reduction of an input vector of a Group 1 farm necessary to reach the technology frontier under group i is always higher than that of a corresponding Group 2 farm. The reverse holds true if M_{12} is less than 1, implying that farms under the first group or program are superior to those in the second group.

With particular relevance to the theme of this study, the use of the Malmquist productivity index provides an opportunity to further decompose the overall productivity differences between groups (M_{12}) into the following two subcomponents:

$$M_{12}(Y_j^1, Y_j^2, X_j^1, X_j^2) = \frac{\left[\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right]^{\frac{1}{C_n}} \left[\frac{\left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_w}} \left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right]^{\frac{1}{2}}}{\left[\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right]^{\frac{1}{C_w}} \left[\frac{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_w}} \left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right]^{\frac{1}{2}}} \quad (6)$$

$$= \underbrace{\frac{\mathcal{E}_{22}}{\mathcal{E}_{11}}}_{\text{catching-up effect}} * \underbrace{\left[\begin{matrix} \mathcal{E}_{11} & \mathcal{E}_{12} \\ \mathcal{E}_{21} & \mathcal{E}_{22} \end{matrix} \right]^{\frac{1}{2}}}_{\text{frontier shifter (technology gap)}}$$

The Catching-Up Effect (M_{12}^e)

The first subcomponent of the Malmquist productivity index compares the difference in internal technical efficiency, or within-group efficiency spread. Its value is given by the ratio of the geometric means of the distance of farms in each group from their group-specific frontier or technology, given by

$$M_{12}^e = \frac{\left[\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right]^{\frac{1}{C_n}}}{\left[\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right]^{\frac{1}{C_w}}} = \frac{\mathcal{E}_{22}}{\mathcal{E}_{11}} \quad (7)$$

A value of M_{12}^e greater than 1 indicates that the efficiency spread is bigger (that is, there are lower efficiency levels) among farms in Group 1 than in Group 2. In a sense, this means, on aggregate terms, that farms in Group 2 seem to catch up better with the performance of their own best-practice farms than do farms in Group 1.

Productivity Gap between Best-Practice Frontiers (Frontier-Shifter Effect, M_{12}^f)

The second subcomponent of the Malmquist index, which measures the distance between the best-practice frontiers of Groups 1 and 2, is given by

$$M_{12}^f = \frac{\left[\frac{\left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}}{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right]^{\frac{1}{2}}}{\left[\frac{\left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}}{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}} \left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right]^{\frac{1}{2}}} = \left[\begin{array}{cc} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{array} \right]^{\frac{1}{2}}. \quad (8)$$

Similar to the first subcomponent, a value of M_{12}^f greater than 1 indicates greater productivity of the frontier of Group 2 than that of Group 1. In a case of no internal technical efficiency difference between the two groups (that is, if the first subcomponent of the index— M_{12}^e —is equal to 1), any productivity difference represented by the Malmquist index (M12) can be explained only by a technological gap between the two groups—the distance between the two respective frontiers (that is, M_{12}^f).

Under this approach, Malmquist productivity index comparisons are predicated on the assumption that the production process on farm plots with land use certificates uses an entirely different technology than those plots without land use certificates. Based on this assumption, we can distinguish and compare four different performance measures of farms: Group A—performance evaluation of farms *without certificate* using a technology frontier defined by farms *without certificate*, Group B—performance evaluation of farms *with certificate* using a technology defined by farms *without certificate*, Group C—performance evaluation of farms *with certificate* using a technology defined by farms *with certificate*, and Group D—performance evaluation of farms *without certificate* using a technology defined by farms *with certificate*.

As a result, each index given by equations (5)–(8) is a function of four separate input distance functions: two standard (within-group) distance function values and two intergroup distance function values. We follow the technique of Fare, Grasskopf, and Lovell (1994) to estimate the relative measures of efficiency by solving separate a linear programming problem for each farm under the four categories. Considering group technology i as the reference or benchmark frontier, a linear programming problem for a farm belonging to group j can be stated as

$$[D^i(x^j, y^j)]^{-1} = \min \varepsilon_{ij}, \quad (9)$$

such that (a) $y_j z_{ij} - y_j \geq 0$, (b) $x_j \varepsilon_{ij} - x_i \geq 0$, (c) $z_{ij} \geq 0$, and (d) $\sum_j z_{ij} = 1$, where y_j is a vector of output in the bench-

mark sample, x_j is the $m \times n$ matrix of inputs for the j^{th} farm in the benchmark sample, and ε_{ij} is the $n \times 1$ vector of intensity weights indicating the input levels that the farm should aim at to achieve efficiency (Fare, Grasskopf, and Lovell 1994). Note that when the performance of the j^{th} farm is compared with a frontier generated from a sample excluding farm j , then assuming constant returns to scale is sufficient to ensure the existence of a solution to the linear programming problem, reducing the importance of constraint (d). The introduction of this additional restriction on the sum of weights thus allows us to generalize the problem to the case of variable returns to scale.

Stochastic Dominance Analysis

The main analytical problem that is common in this kind of nonparametric (DEA) productivity analysis is the difficulty of testing the statistical significance of such indexes, which result only from the ratio of the (arithmetic/geometric) means of group efficiencies (see discussions above). In order to obtain some insights, however, into the statistical significance of the DEA-based Malmquist indexes, we invoke the concept of first-order stochastic dominance, which allows us to compare and rank the distribution of measures of farm performance. Let X and Y denote the cumulative distribution functions of productivity for two groups of farms (say, the control group of *without land certificate* and the treatment group of *with certificate*, respectively). The first-order stochastic dominance of productivity of farms *with certificate*, $Y(\varepsilon)$, relative to the productivity of farms *without certificate*, $X(\varepsilon)$, is given by

$$X(\varepsilon) - Y(\varepsilon) \leq 0 \quad \forall \varepsilon \in \mathfrak{R}, \text{ with strict equality for some } \varepsilon. \quad (10)$$

For an empirical strategy of testing whether group productivities are statistically different, we follow Banker (1996), adopting a nonparametric two-sided Kolmogorov-Smirnov (K-S) test.¹² Based on the empirical distributions of $X(\varepsilon)$ and $Y(\varepsilon)$, the hypothesis that X is to the left of Y can be tested by the two-sided K-S statistic tests with the null and alternative hypothesis expressed as

¹² For details on the K-S test, see Conover (1999).

$$H_0 : X(\varepsilon) - Y(\varepsilon) = 0 \quad \forall \varepsilon \in \mathfrak{R}, \quad \text{Vs} \quad H_1 : X(\varepsilon) - Y(\varepsilon) \neq 0 \text{ for some } \varepsilon \in \mathfrak{R}. \quad (11)$$

Hence, in order to conclude that A is stochastically dominated by B , we need to reject the null hypothesis. The K-S test uses the maximum vertical deviation between the curves of the two groups, as the statistic D given by

$$D = \sqrt{\frac{mn}{N}} \max_{1 \leq i \leq N} \{X_m(\varepsilon_i) - Y_n(\varepsilon_i)\}, \quad (12)$$

where m and n are the sample sizes from the empirical observations of farms *without certificate* (X) and farms *with certificate* (Y), respectively, and $N = m + n$. Note that unlike the t-statistic, the value of the D statistic (and hence the p-value) is not affected by scale changes such as using log. The K-S test is thus a robust test that looks only at the relative distribution of the efficiency measures of sampled farms.

4. DATA AND IDENTIFICATION STRATEGY

In conducting the analysis of the productivity effects of the land use certification program in the region, we came across a methodological challenge mainly due to potential self-selection problems during program implementation, with reasons ranging from administrative to household specific. Thus, we exercised utmost caution to deal with households that fail to collect land certificates for household-specific reasons, which may cause correlations between the treatment (the certificate) and the outcome (farm productivity as yield per hectare) variables. Thus, before applying a random sampling exercise, we conducted a thorough investigation of the process of the land registration and certification program in the region. To mitigate the methodological challenge of potential self-selection, the household survey took advantage of the coincidence that the land certification program was implemented during construction of a microdam in the study area, resulting in a quasi-experimental setup.

The land certification program in Tigray was a one-shot, large-scale project, without any major follow-up projects. However, for purpose of egalitarian distribution of the high-quality land, the regional land regulation allows for future redistribution of irrigated parcels; therefore no land certificates are issued for such parcels (TNRS 1997). The fact that the 1998/99 land certification in the region coincided with construction of a microdam in the sample area provided a unique opportunity for a quasi-experiment, since farm households from two communities (one upstream and another downstream) were excluded from the certification program for administrative reasons and not by the choice of the households. Thus we were able to identify the control group as households from the two excluded communities and the treatment group as households from two contiguous communities. Although certainly not a randomized controlled trial (RCT), the research design did ensure balance on a range of pre-treatment (pre-land certification) covariates between the beneficiary and nonbeneficiary communities. In other words, it is reasonable to consider nonselected communities as a plausible control group to isolate the causal effects of the land certification program because they are believed to have socio-economic, biophysical, and agroecological attributes comparable to those of the selected communities (the treatment group).

As a result, we took a random sample of 80 farm households from each of the four communities (two each from the treatment and control areas), with a total sample of 320 farm households operating 1,356 parcels. Though utmost caution was exercised to minimize household-level selection problems, the research design certainly did not meet the rigorous standards of an RCT to maintain the comparability of parcels included in the sample. Consequently, it was important to assess whether parcels from the treatment and control groups were balanced on observable characteristics. Such evidence would provide tentative evidence that the selection criteria were “as if random” and therefore the exercise can be treated as a quasi-experiment. Hence, we adopted a propensity score matching (PSM) method to help us minimize any potential plot-specific selection bias. Using observable plot characteristics as a control variable in the PSM, we identified 1,042 comparable farm plots with and without certificates that satisfied the balancing and common support properties.

5. RESULTS AND DISCUSSION

Descriptive Analysis

Table 5.1 summarizes some key characteristics of farm households based on their possession of a land use certificate. Signifying the caution exercised while sampling the respondents, the household characteristics in Table 5.1 show that farmers with and without a certificate have comparable demographic and endowment variables such as the sex and age of household head, the average size of household, the number of males and females in the labor force, and key livestock endowment variables like cows and oxen. Despite these similarities, there are marked differences in terms of long-term

land-related investments¹³ of households with a land use certificate versus those without. The proportion of farm households who were engaged in conservation their own plots is slightly higher, at 94.3 percent, for those with a land use certificate than for those without the certificate, only 83.9 percent. Similarly, the percentage of households who had considered improving or maintaining an existing conservation structure is also significantly higher for those with a certificate, 40.7 percent, compared with only 28.6 percent for households without a land certificate.

Table 5.1—Mean comparison tests for key household-level variables

Variable	With certificate	Without certificate	
	Mean (Standard error)	Mean (Standard error)	
Household demographic and endowment variables			
Sex of the household head (male=1; female=0)	0.721 (0.0380)	0.750 (0.0411)	
Age of the household head	45.614 (1.1865)	45.045 (1.4799)	
Size of the household	5.086 (0.2084)	4.830 (0.2261)	
Male labor force members	1.200 (0.0819)	1.080 (0.0852)	
Female labor force members	1.250 (0.0650)	1.143 (0.0681)	
Number of dependents in the household	1.471 (0.1041)	1.598 (0.1116)	
Number of cows	0.936 (0.0825)	0.768 (0.0822)	
Number of oxen	1.164 (0.0933)	1.071 (0.0972)	
Other livestock endowment ⁺	0.593 (0.0737)	0.357 (0.0738)	>**
Off-farm income opportunity ⁺⁺	0.079 (0.0228)	0.045 (0.0196)	
Long-term land investment and modern input use			
Investment in new conservation structures	0.943 (0.0197)	0.839 (0.0349)	>**
Maintenance of conservation structures	0.407 (0.0417)	0.286 (0.0429)	>**
Household's use of chemical fertilizer	0.621 (0.0411)	0.500 (0.0475)	>**
Household's use of organic fertilizer	0.636 (0.0408)	0.625 (0.0460)	
Household's use of improved seed varieties	0.579 (0.0419)	0.464 (0.0473)	>*
Number of observations	161	135	

Source: Authors' computation

Notes: * Significant at 10%, ** significant at 5%, *** significant at 1%, **** significant at 0.1%.

⁺ Tropical livestock unit equivalent. ⁺⁺ Off-farm income sources excluding gifts, aid, remittance, and other nonlabor incomes.

A summary of plot-level variables used in both the stochastic frontier and DEA-based Malmquist index analyses is provided in Table 5.2. As shown in the upper part of the table, there is no significant difference between plots with a certificate and those without a certificate in terms of output level and input use intensity. On average, output value per *tsimdi*¹⁴ is slightly higher on farm plots with a land use certificate than on those without a certificate, though the difference is not significant at a conventional level.

A summary of plot-specific long-term land investments and new technology adoption, presented in the bottom part of Table 5.2, reveals a significant difference between the two groups of plots.¹⁵ Reinforcing the claim that land certification does improve tenure security and encourage long-term land-related investments (see discussions in Section 2), the result shows that a significantly larger proportion of farms with land certificates has been conserved (56 percent) as compared with plots without land use certificates (51 percent). The chance of improvement or maintenance of an existing conservation structure is also significantly higher on plots with a certificate (21 percent) than on those without (15 percent).

Showing the difference in new technology adoption, the summary result also depicts a higher likelihood of application of chemical as well as organic fertilizer (53 percent and 29 percent, respectively) on plots with a land certificate than on plots without a certificate (only 46 percent and 23 percent, respectively). These summary results are consistent with results of a study by Holden, Deininger, and Ghebru (2009) that was conducted in a similar study area.

¹³ In this paper, long-term land-related investments are captured by household decisions on land-improving technologies such as anti-erosion conservation measures, application of organic and inorganic fertilizers, and adoption of new farming practices that entail long-term benefits.

¹⁴ *Tsimdi* is a local area measurement unit equivalent to a quarter of a hectare.

¹⁵ All the variables summarized are in their dummy (dichotomy) form to show a shift or a jump in the frontier, which may not be the case had their level form been considered.

Table 5.2—Mean comparison tests for key plot-level variables

Variable	Plots with certificate		Plots without certificate		t-test
	Mean	Standard error	Mean	Standard error	
Input intensity and output level					
Total value of output / <i>tsimdi</i> [*] (Ethiopian birr)	699.96	19.27	671.52	21.16	
Total labor / <i>tsimdi</i> (no. of days)	34.53	1.02	33.23	0.99	
Oxen/ <i>tsimdi</i> (number of days)	14.25	0.47	17.36	0.56	<***
Seed cost / <i>tsimdi</i> (birr)	96.46	3.34	93.01	4.82	
Chemical fertilizer / <i>tsimdi</i> (kg)	12.67	0.79	13.79	0.89	
Long-term land investment and modern input use					
Long-term land investment	0.56	0.020	0.51	0.023	>*
Improved conservation structures	0.21	0.017	0.15	0.016	>***
Well-maintained structures	0.23	0.017	0.25	0.020	
Just maintained structures	0.04	0.008	0.05	0.010	
Not maintained structures	0.10	0.012	0.13	0.015	
Chemical fertilizer (dummy)	0.53	0.021	0.46	0.023	>**
Organic manure/compost (dummy)	0.29	0.019	0.23	0.019	>**
Seed type (1 = improved, 0 = otherwise)	0.22	0.017	0.20	0.018	
Log of output value	5.82	0.053	5.59	0.084	>*
Number of observations	566		476		

Source: Authors' computation.

Notes: * Significant at 10%, ** significant at 5%, *** significant at 1%, **** significant at 0.1%;

* *Tsimdi* is a local area measurement equivalent to 0.25 hectare.

At the outset, the empirical evidence from the mean comparison tests of the two groups of farms shows that there is a marked difference in terms of long-term land-related investment and new technology adoption. We use this evidence as an empirical basis for further testing of the productivity impact of land certification, considering separate benchmarks (group-specific production frontiers) for each group of farm plots. This strong assumption is further reinforced by a positive and statistically significant certificate variable (when this variable was included as a right-hand-side variable together with the customary farm inputs) from parametric results of alternative stochastic frontier analyses (SFAs) in the next section.

Structural Efficiency Comparisons: Parametric Approach

To reinforce the results from the summary statistics and assess whether land certification has any potential productivity-enhancing effect, we conducted a parametric SFA by including an indicator variable *certificate* as a right-hand-side variable alongside the customary farm inputs (labor, oxen, fertilizer, and so on). Since this variable is constructed as a dummy variable (plots with a land certificate = 1, and 0 otherwise), any positive and significant coefficient for this variable posits a frontier-shifter effect of land certification, a preliminary empirical condition to proceed with the decomposed analysis of the DEA-based Malmquist index approach.

Using the specifications of the Cobb-Douglas production function, where results are interpreted as input-specific output elasticity, a positive and statistically significant *certificate* variable reported in Table 5.3 indicates that, on average, the best-practice farms with a land use certificate perform better than the best-practice farms without a certificate. In other words, the frontier defined by plots with a land certificate is superior to the frontier defined by those without a land certificate. This result supports the basic assumption of the analysis that production on farm plots with a certificate uses different technology than production on farm plots without a certificate.

Table 5.3—Stochastic production frontier estimates—pooled data

Variable	Coefficient (Standard error)	
CONSTANT	5.3933	(0.1655)***
Log of cultivated area	0.3658	(0.0542)***
Log of labor, man-days	0.2092	(0.0329)***
Log of oxen-days	0.0624	(0.0307)**
Log of seed cost, Ethiopian birr	0.2343	(0.0284)***
Log of chemical fertilizer, kilogram	0.0256	(0.0072)***
Certificate (plot with certificate = 1)	0.1176	(0.0522)**
sigma2	3.7082	(0.2363)
Lambda	9.8764	(0.0845)
Log-likelihood	-680.11	
Technical efficiency score	0.45	

Source: Authors' computation.

Notes: Number of observations = 1,042.

* Significant at 10%, ** significant at 5%, *** significant at 1%, **** significant at 0.1%.

Results from a separate SFA, reported in Table 5.4, also show key comparable results from both groups of farm plots. In both groups (plots with and without certificate), output is most responsive to area under cultivation, labor, and value of seed. Despite the SFA results from the pooled data in Table 5.3, the very high estimates of technical inefficiency in both groups (shown by the very low technical efficiency scores of 47 percent and 41 percent for plots with and without a land use certificate, respectively) may indicate little difference between the two groups' within-group efficiency spreads.

Table 5.4—Stochastic production frontier estimates of plots with and without certificates

Variable	Without certificate (n = 476)		With certificate (n = 566)	
	Coefficient (Standard error)		Coefficient (Standard error)	
CONSTANT	5.1009	(0.2312)***	5.8103	(0.2099)***
Log of cultivated area	0.3081	(0.0835)***	0.4179	(0.0676)***
Log of labor, man-days	0.2720	(0.0790)***	0.2025	(0.0392)***
Log of oxen-days	0.1019	(0.0859)	0.0266	(0.0359)
Log of seed cost, Ethiopian birr	0.2624	(0.0404)***	0.1539	(0.0374)***
Log of chemical fertilizer, kilogram	0.0195	(0.0103)*	0.0276	(0.0094)***
sigma2	4.2082	(0.2963)	2.2778	(0.1562)
Lambda	11.576	(0.0935)	4.1102	(0.0687)
Log-likelihood	-720.11		-758.44	
Technical efficiency score	0.41		0.47	

Source: Authors' computation.

Notes: * Significant at 10%, ** significant at 5%, *** significant at 1%, **** significant at 0.1%.

The major aim of the study being to explain the source or cause of the productivity differential effects of land certification by comparing the performance of farm plots with and without a certificate, we further investigated whether any productivity differential is (1) due to a mere difference in pure technical efficiency or within-group efficiency spread (the ability to catch up with the best-practice farms of each respective group) or (2) due to a technology gap (dominance of the frontier of one group over that of the other). Even if the parametric (SFA) results and evidence from the mean comparison tests discussed above are indicative to suggest the dominance of the second factor as a possible explanation for the productivity differential between the two groups, this can be tested more rigorously by applying a DEA-based Malmquist index approach.

Explaining Productivity Differences: DEA-Based Malmquist Index Approach

As shown in Section 3, the choice of base technology (or reference technology) when computing the Malmquist index affects the outcome of the index and, thereby, the interpretation. Therefore, we analyze the group productivity differences using the averages of results when each group is used as a reference technology. For mere comparison, results of the adapted Malmquist index are reported in arithmetic and geometric averages. Table 5.5 reports the overall group productivity differences—the composite Malmquist productivity index as shown in equation (6)—while Tables 5.6 and 5.7 show results of the decomposed subcomponents of the productivity index—the effects of the within-group efficiency spread (equation [7]) and the technology gap or frontier dominance effect (equation [8]), respectively.

Overall Productivity Difference

As discussed in Section 3, a value of the Malmquist index smaller than unity corresponding to group i means that, on average, group i is more productive (performs better) than the other group. From Table 5.5, the value of the index equal to 1.2367 corresponding to the *without certificate* group shows that, on average, farm plots without a land use certificate are less productive than plots with formalized land use rights; that is, on average, plots without a certificate require 124 percent of the inputs required by plots with a land use certificate to be equally productive (be on the same frontier). This result is further elaborated by the index shown on the second row of Table 5.5. In this case, the index value of 0.8086 means that, on average, the group of farm plots with a land use certificate are more productive than their counterparts without a land certificate, requiring only 80.7 percent of the inputs required by those without a land certificate to be equally productive.

Table 5.5—Malmquist index for comparison of group performance (M_{12}) between farms with and without certificates

Group/scenario 1 \ 2	Arithmetic mean		Geometric mean	
	No certificate	With certificate	No certificate	With certificate
No certificate	1	1.2367	1	1.1669
With certificate	0.8086	1	0.8570	1

Source: Authors' computation.

As mentioned before, the major analytical bottleneck that is common in this kind of nonparametric analysis (DEA) is the difficulty of testing statistical significance. In order to obtain some insights into the statistical significance of the productivity difference results, we invoke the concept of first-order stochastic dominance, which allows us to compare and rank the distribution of measures of farm performance. Statistical significance test results from a two-sided Kolmogorov-Smirnov (K-S) test show the overall productivity difference to be statistically significant. As reported in columns 1 and 2 of Table 5.6, the null hypothesis of identical distribution of overall productivity between the two groups is rejected at 5 percent. This result is diagrammatically elaborated in the first-order stochastic dominance analysis in Figure 5.1, where the performance (shown as efficiency scores) of farm plots with land use certificates unambiguously dominates the performance of those plots without certificates. The result is robust no matter which group was considered to define the benchmark frontier.

Table 5.6—Test results of first-order stochastic dominance of (two-sample Kolmogorov-Smirnov test)

Group	Reference technology	Performance evaluation of:	Efficiency scores Mean/ Standard deviation)	P-values for two-sample Kolmogorov-Smirnov test [†]				
				Overall productivity difference		Difference in technical efficiency	Technology gap (frontier difference)	
				Group A Versus Group B	Group C Versus Group D	Group B Versus Group C	Group B Versus Group D	Group A Versus Group C
				(1) ⁱ	(2) ⁱⁱ	(3) ⁱⁱⁱ	(4) ^{iv}	(5) ^v
A	Without certificate	With certificate	0.510 (0.329)					
B	Without certificate	Without certificate	0.451 (0.250)	0.042	0.056	0.637	0.050	0.017
C	With certificate	With certificate	0.446 (0.234)					
D	With certificate	Without certificate	0.422 (0.270)					

Source: Authors' computation.

Notes: [†]H₀: Distributions are equal against; H₁: Distribution of first group dominates distribution of second.

ⁱ Specifically tests whether the first quotient of the Malmquist index in equation (5), that is,

$$\left[\frac{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right] = E_{12}/E_{11}, \text{ is significantly greater than 1 or not.}$$

ⁱⁱ Specifically tests whether the second quotient of the Malmquist index in equation (5), that is,

$$\left[\frac{\left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right] = E_{22}/E_{21}, \text{ is significantly greater than 1 or not.}$$

ⁱⁱⁱ Specifically tests whether the quotient of the decomposed Malmquist index in equation (7), that is,

$$\left[\frac{\left(\prod_{j=1}^{C_n} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right] = E_{22}/E_{11}, \text{ is statistically greater than 1 or not.}$$

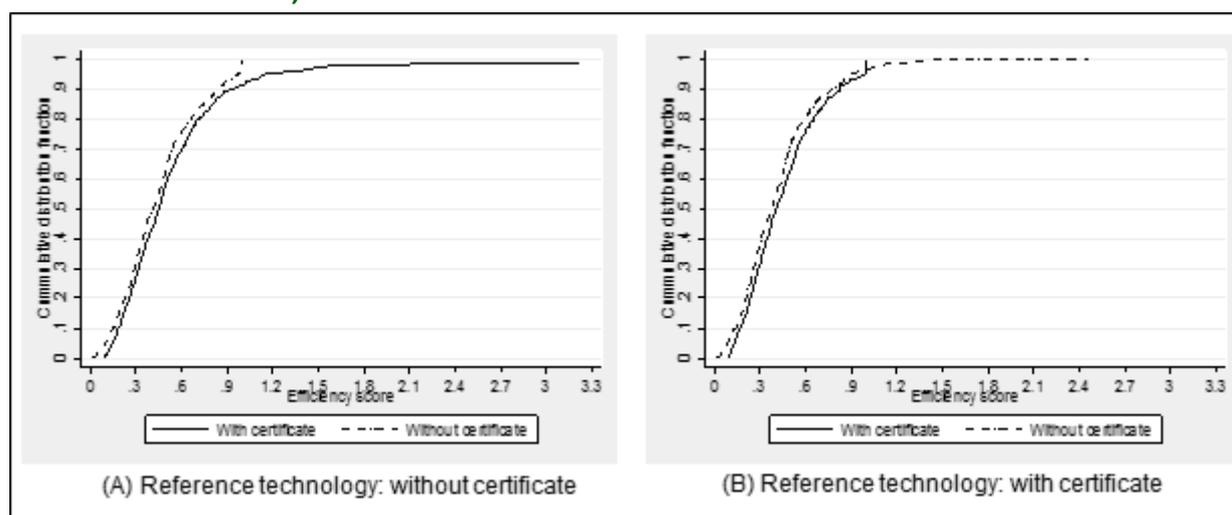
^{iv} Specifically tests whether the first quotient of the decomposed Malmquist index in equation (8), that is,

$$\left[\frac{\left(\prod_{j=1}^{C_n} D^2(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^1, X_j^1) \right)^{\frac{1}{C_n}}} \right] = E_{11}/E_{21}, \text{ is greater than 1 or not.}$$

^v Specifically tests whether the second quotient of the decomposed Malmquist index in Equation (8), i.e.,

$$\left[\frac{\left(\prod_{j=1}^{C_w} D^2(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}}{\left(\prod_{j=1}^{C_w} D^1(Y_j^2, X_j^2) \right)^{\frac{1}{C_w}}} \right] = E_{12}/E_{22}, \text{ is greater than 1 or not.}$$

Figure 5.1—Cumulative distribution function for the overall productivity effects of land certificate (first-order stochastic dominance)



Source: Authors' computation.

The empirical contribution of this approach is more prodigious when the decomposed results of the DEA-based Malmquist index are analyzed. Using the two subcomponents of the index, we are able to explain the overall group productivity difference in terms productivity gap that is attributed to differences in pure technical efficiency (the within-group efficiency spread) and the productivity gap that is explained by a difference between the group frontiers (the technology gap, M_{12}^f). Table 5.7 and 5.7 report these components of the index, respectively.

Table 5.7—A component of the Malmquist index (M_{12}^e) for comparison of within-group efficiency spread in farms with and without land use certificates

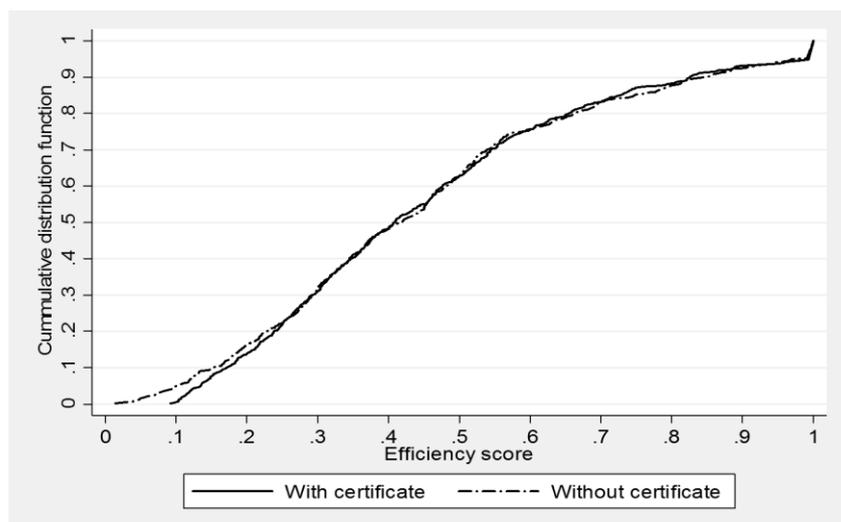
Group/scenario	Arithmetic mean		Geometric mean	
	No certificate	With certificate	No certificate	With certificate
2				
1				
No certificate	1	1.0059	1	1.0451
With certificate	0.9941	1	0.9568	1

Source: Authors' computation.

As shown in Table 5.7 above, a value slightly greater than 1 for the catching-up effect (1.0451) shows that farm households belonging to the group without land certificates have, on average, a relatively lower internal efficiency (a higher efficiency spread) than those with land certificates when both types of farms are evaluated against their respective production frontiers. Stated otherwise, this result indicates that farms with a land use certificate have a slight edge over plots without a certificate in terms of catching up with their respective best-practice farms.

However, the two-sided K-S test shows the difference to be statistically insignificant. As reported in column 3 of Table 5.6, the K-S test for similarity between the distributions of the two groups shows that the null hypothesis, *distribution of pure technical efficiency between the two groups is identical*, cannot be rejected. The first-order stochastic dominance analysis (Figure 5.2) also shows that there is not much difference between the two groups based on the *within-group efficiency spread* parameter. Results are even more elaborated when the index is computed using the arithmetic average, which yields a value of the decomposed index approximately equal to unity (1.0059 and 0.9941, respectively, as reported in Table 5.7). This result supports the earlier results from the mean comparison tests that revealed no significant difference in input use intensity between the groups of farm plots.

Figure 5.2—Cumulative distribution function for internal (technical) efficiency effects of land certificate (first-order stochastic dominance)



Source: Authors' computation.

The result from the second subcomponent of the Malmquist index that compares the relative distance from their production frontiers of respective groups (the technology gap) is shown in Table 5.8. Similar to the interpretations of the overall Malmquist index in Table 5.5, a value smaller than 1 means the reference group that defines the technology enjoys a superior technology (that is, a frontier), while a value greater than 1 indicates inferiority. Considering the group of farm plots with land use certificates as reference (second row of Table 5.8), the value of the decomposed component equal to 0.8134 is nothing but an input-saving parameter, by which inputs applied in plots without a certificate can be multiplied and still produce the same level of output. This is synonymous with saying that, on average, plots with a land use certificate enjoy a technological advantage (operate on a higher frontier) compared with plots without a land certificate. This shows that with proper interventions (in this particular case, land certification), there is an input-saving potential for those plots without a land use certificate as compared with those with formalized land use rights.

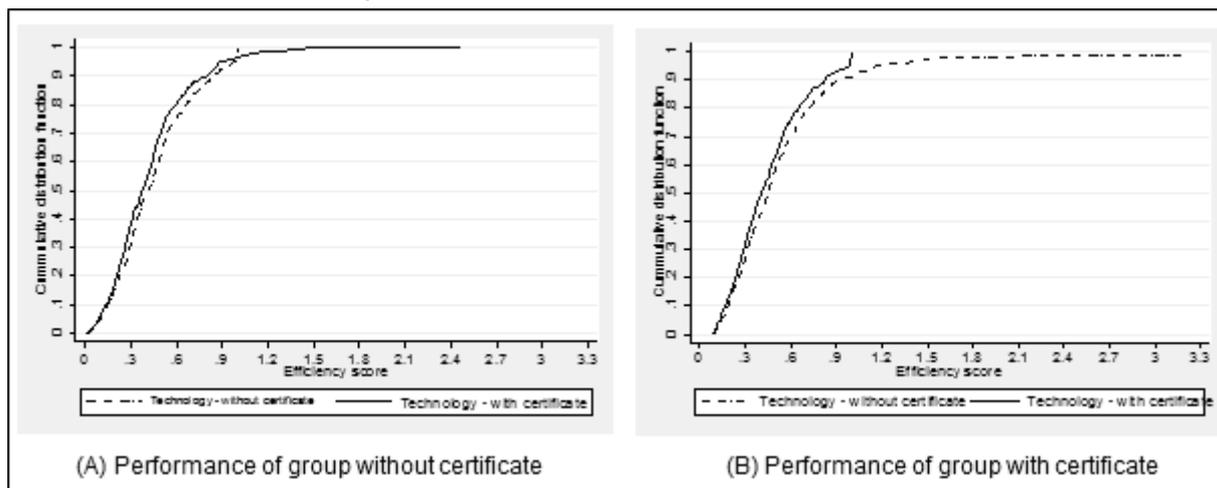
Table 5.8—A component of the Malmquist index (M_{12}^f) for comparison of productivity between the group frontiers for farms with and without land use certificates

Group/scenario	Arithmetic mean		Geometric mean	
	No certificate	With certificate	No certificate	With certificate
1 \ 2				
1				
No certificate	1	1.2294	1	1.1165
With certificate	0.8134	1	0.8957	1

Source: Authors' computation.

The first-order stochastic dominance analysis, shown in Figure 5.4, supports this evidence by showing the superiority of the frontier defined by best-practice farms with a certificate over the frontier of those without a certificate. For instance, with particular relevance to farm plots without a certificate, their relative performance under the without certificate technology dominates their efficiency when evaluated against the technology defined by the with certificate farms (shown in panel A of Figure 5.4). On the other hand, the superiority in relative efficiency of plots with a certificate is far greater in relation to the best-practice farms without certificate than it is in comparison with the technology within their own group (shown in panel B of Figure 5.4 below).

Figure 5.4—Cumulative distribution function for technology (frontier-shifting) effects of land certificate (first-order stochastic dominance)



Source: Authors' computation.

Both of these nonparametric evidences show the superiority of the *with certificate* frontier over the *without certificate* frontier. Results from the two-sided Kolmogorov-Smirnov (K-S) test reported in Table 5.6 reaffirm this result. Both null hypotheses—(1) identical distribution of relative performance of farms without a certificate regardless of the benchmark technology¹⁶ (column 4 of Table 5.6) and (2) identical distribution of relative efficiency of farms with a certificate regardless of the benchmark technology (column 5 of Table 5.6)—are rejected with 5 percent level of significance in favor of the dominance of the *with certificate* frontier over the *without certificate* frontier.

6. CONCLUSIONS

Despite the fact that issues of land rights and tenure security are high on the global policy agenda, comprehensive studies of how such new land reforms affect agricultural productivity are scarce. Taking advantage of a detailed plot-specific household survey from the northern highlands of Ethiopia, this study analyzes the productivity impacts of the Ethiopian land certification program by identifying how the investment effects (technological gains) would measure up against the benefits from any improvements in input use intensity (technical efficiency).

Based on the results of a DEA-based Malmquist productivity index, we found that farms without a land use certificate are, on aggregate, less productive than those with formalized use rights. Using the decomposed analysis, we found no evidence to suggest that this productivity difference between the two groups of farms is due to differences in technical efficiency. Rather, the reason comes down to *technological advantages*, or a favorable investment effect that farm plots with a land use certificate benefit from when evaluated against those without a certificate. Results from a first-order stochastic dominance analysis support the empirical findings, showing the dominance in overall productivity of farm plots with a certificate over those plots without a certificate.

Therefore, the recent wave of land certification projects in the country may not be an ill-advised direction since such a policy measure was found to improve farm competitiveness and productivity. However, as indicated by results that show a low level of within-group efficiency of farms in each group, the certification program by itself may not achieve the promised effects of enhancing agricultural productivity unless it is complemented by measures such as improving the financial and legal institutional frameworks.

¹⁶ Referring to equation (8), this null hypothesis tests whether $E_{11}-E_{21} = 0$ or, more specifically, whether $E_{11}/E_{21} = 1$. If we cannot reject the null hypothesis, then the two frontiers intersect and there is no dominance of the one frontier over the other. The alternative hypothesis is dominance of the distribution of the first efficiency measure over the second.

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