Essays on the Microeconomics of Technology Adoption
with Application to Ethiopian Agriculture

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Abstract

The dissertation explores the role of land reforms and agricultural extension in promoting technology adoption in the Ethiopian agricultural sector. The first two essays of the dissertation are devoted to examining the role of property rights institutions in promoting technology adoption. In the second chapter, we provide a theoretical framework which shows that an important mechanism through which improved property rights influences technology adoption is by altering the optimal contractual arrangements economic agents choose, but the magnitude of this impact depends partly on the degree of credit market imperfections prevailing in the economy. We analyze this in the agricultural sector in a developing country setting and develop a model which predicts that by reducing both tenure insecurity and transaction costs, credible land title reforms provide incentives for farmers to move towards contracts that encourage the adoption of chemical fertilizers.

In the third chapter, we estimate the impact of improved land rights on farmers' choice of land and labor contracts and technology adoption using panel data from Ethiopia, which introduced legislation that gave farmers perpetual land use rights aimed at improving their tenure security. The empirical approach allows us to empirically disentangle the direct impact of improved tenure security on technology adoption, by reducing the risk of expropriation, from its indirect impact through its effect on the optimal choice of land and labor contracts. The econometric results

demonstrate improved property rights in Ethiopia have their greatest effect on the adoption of chemical fertilizers by transforming the agrarian contractual structure.

The fourth chapter evaluates the impact of the Ethiopian agricultural extension program in promoting the use of chemical fertilizers among farmers by employing propensity score matching and inverse probability weighting methods. These methods help us arrive at credible estimates of the impact of the Ethiopian agricultural extension program by carefully handling endogeneity problems that have bedeviled prior research aimed at estimating the impact of extension programs on technology adoption and overall farm performance in several developing economies. Our empirical results show that the Ethiopian extension program increases both the likelihood of chemical fertilizer adoption and enhances the intensity of fertilizer use by farmers, but the impact is heterogeneous across households.

Chapter 1

Introduction

A vast majority of cross-country growth studies show that differences in technological progress explain much of the variation in economic growth and standard of living among countries. This suggests that a serious inquiry into the fundamental causes of poverty and underdevelopment must focus on identifying the key factors that limit the rate of innovation and technology adoption in less developed economies. In particular, as major advances in frontier technology typically take place in developed economies, the results imply that exploring factors that hamper the ability of individuals and firms in developing economies from adopting existing technology should provide clues as to why a significant proportion of the world population lives under abject poverty.

This dissertation makes contribution to the study of the economics of technology adoption in developing economies by exploring the role of property rights institutions and agricultural extension in promoting the adoption of modern agricultural technology. In the first two essays, we use economic theory and data from Ethiopia to argue that an important channel through improved land rights promotes technology adoption is by influencing the optimal land and labor contracts farmers choose. To this end, we build a model which demonstrates that by reducing risk of expropriation and transaction costs, credible land reforms provide farmers the incentive to switch to contracts that promote the adoption of chemical fertilizers. Finally, we present empirical evidence that supports this hypothesis, using panel data from Ethiopia, which introduced legislation aimed at strengthening the tenure security of farmers.

The last chapter evaluates the impact of the Ethiopian agricultural extension program, the largest public extension program in Sub-Saharan Africa, in promoting the adoption of chemical fertilizers by farmers in rural Ethiopia. Our empirical approach carefully handles the selection problems that have traditionally undermined the credibility of past research that examined the impact of agricultural extension programs on technology adoption and farm productivity in developing economies. The present study also goes beyond estimating the average impact of the program and presents estimates of heterogeneous treatment effects of agricultural extension on different sets of agricultural households participating in the program. Our econometric analysis shows that while the Ethiopian extension program increased both the probability of adoption and the intensity of use of chemical fertilizers by farmers in the country, this impact is heterogeneous across households.

1.1 Property Rights, Contracts, and Technology Adoption

Investigating the factors that explain the observed low adoption of modern agricultural technology by farmers in developing economies, particularly in Sub-Saharan Africa, has been the subject of extensive economic research in recent times (Duflo et al., 2009; Conley and Udry, 2010; Suri, 2011). This literature identifies a host of factors including limited access to credit, imperfect information, riskiness of technology, small farm size, lack of education, uncertainty in the supply of complementary inputs, and poor transportation infrastructure as the major culprits for the limited adoption of superior technology in these countries (Feder et al., 1985; Foster and Rosenzweig, 2010). While these studies enhance our understanding of the process of technology adoption in poor economies, they are restricted to identifying the proximate determinants of technology adoption, and do not address the fundamental factors which cause these constraints to exist in these economies in the first place.[1]

To identify the fundamental factors that explain technology adoption, we resort to a dominant view in the economic growth literature, which presents institutions as a deep determinant of innovation and adoption of technology, and ultimately economic performance (Robinson et al., 2004; Rodrik et al., 2002). This theory in particular presents differences in the strength and quality of property rights institutions, institutions that protect ordinary citizens and firms from direct expropriation by the government and powerful elites, as the underlying reason as to why firms in some countries invest more in the development and adoption of new technology. Proponents of this theory argue that the gulf in the quality of these institutions across societies also accounts for the significant discrepancy in the observed levels of investment in both human and physical capital, which, together with divergence in technical progress, ultimately explains the astounding difference in income and quality of life observed internationally.

While this literature goes beyond the proximate determinants of economic growth, the fact that institutions are broadly defined to include the social, political, legal, and economic organization of a society has made it difficult to identify which institutions are important and identify the specific mechanisms through which they influence economic performance. Nevertheless, there has been recently an attempt to unbundle economic institutions into property rights and contracting institutions, and understand the relative important of these institutions in determining economic

[1] For example, they do not fully explain why there is low level of investment in infrastructure, or why there are significant market imperfections in the first place if indeed poor infrastructure and market imperfections explain the observed low adoption of modern agricultural technology in developing economies.

performance (Acemoglu and Johnson, 2003).[2] Much of this research, however, is done at the macroeconomic level (See Acemoglu et al., 2002; Rodrik et al., 2002).

Nonetheless, a thorough understanding of how institutions influence economic behavior also requires a careful examination of the specific channels through which institutions influence the behavior of households and firms at the microeconomic level. The first two essays of the dissertation are aimed at directly linking property rights and technological progress at the microeconomic level; they carefully identify the specific mechanisms through which improved property rights influences the adoption of new technology in a developing-country setting.

These two chapters have the following three specific objectives: (1) analyze and estimate the impact of improved land rights on modern fertilizer adoption (2) identify the mechanisms by which changes in property rights influence technology adoption, and (3) explore the roles of credit market imperfections in influencing the impact property rights institutions have on farmers' decisions to adopt technology. We argue that improved property rights influences technology adoption by altering the optimal land-labor contractual arrangements and provide microeconomic evidence that relates improved land use rights and technology adoption using data from Ethiopia.

Specifically, we show that improved land rights promotes technology adoption by altering the agrarian contractual structure by lowering land transfer costs and reducing the risk of expropriation which in turn influences the land and labor contracts farmers choose. Because these contracts do have different incentives and risk-sharing mechanisms embodied in them, they influence farmers' decision to adopt new technology, in particular when the returns of the new technology are

[2] Acemoglu and Simon define contracting institutions as "the rules and regulations governing contracting between ordinary citizens, for example, between a creditor and a debtor or a supplier and its customers," while property rights institutions are defined as "as the rules and regulations protecting citizens against the power of the government and elites."

uncertain. However, credit market imperfections undermine the impact that changes in property right regimes have on technology adoption directly but also indirectly by limiting the ability of farmers to choose contracts that are otherwise conducive to the adoption of new technology.

The study presents a model of endogenous technological progress in the agricultural sector of a developing economy, and improves upon existing studies of technological adoption in developing economies in three major ways: (1) it goes beyond proximate determinants of technology adoption, and offers microeconomic evidence supporting the view that property rights institutions are key underlying determinants of technology adoption; (2) in addition to direct impact of expropriation, the study identifies an important mechanism (i.e., contract choice) through which property rights institutions influence technology adoption, and by doing so it promotes our understanding on the interaction between property rights institutions and contracting institutions; (3) by linking property rights and technology adoption through contracts, the study also shows that property rights which are traditionally thought to influence long term investment, in fact do affect short-term investment, as it alters the contractual arrangements economic agents enter into that have different incentive and risk-sharing mechanisms built in them which affect short term returns; and (4) explores how imperfections in the credit markets influence agrarian contractual structure and thereby affect the relationship between property rights institutions and technology adoption.

At a policy level, our analysis in the two chapters shows that the impact of land reforms on agricultural productivity is pronounced if these reforms are credible and are accompanied by policies that address imperfections in the credit and land rental markets. In particular, the empirical results show that the direct impact of property rights on technology adoption is limited if farmers are not allowed to use their land as collateral, as it is presently the case in Ethiopia.

1.2 Agricultural Extension and Technology Adoption

A significant portion of the population in most African countries derives its livelihood from the agricultural sector. However, the sector is characterized by high volatility and very low productivity. Many economists and agricultural experts view low adoption of chemical fertilizers and modern seeds as the primary cause for the stagnation observed in African agriculture (Duflo et al., 2011; Sachs, 2004). Thus, several governments in the continent, with the assistance of international donors, have invested considerable resources to promote the adoption of these productivity-enhancing technologies by farmers in their respective countries. Leading examples of such interventions are agricultural extension programs, which are among the most widely used policy instruments in the continent and throughout the developing world aimed at popularizing these technologies (Evenson, 2001; Anderson and Feder, 2007).

The major goal of agricultural extension programs is to transfer knowledge from researchers to farmers, thereby not only advertising new technologies to farmers but also building their human capital to better utilize existing technologies through technical training, with a view to boosting productivity and narrowing the gap between actual and potential yields. The literature in particular identifies two important gaps that agricultural extension programs help bridge: technology and management gaps (Anderson and Feder, 2007). Accordingly, agricultural extension programs shrink the gap between the technology presently in use by farmers and the latest available technology by accelerating the transfer of technology from researchers to farmers. Furthermore, these programs make farmers better managers through instruction and demonstration of improved farming practices. In addition to these important roles, extension agents help provide feedback to researchers that would potentially help in the development of technologies that are appropriate to the local economic and agro-ecological conditions (Evenson, 2001).

While several agricultural extension programs exist in the developed world, a vast majority of the labor force in these programs works in developing countries (Umali and Schwartz, 1994). These programs are primarily financed and run by governments in these countries with a very limited role played by the private sector and other non-governmental organizations (Feder and Zijp, 2001; Swanson et al., 1990). The major explanation offered for this heavy government involvement in agricultural extension is the public-good nature of the service provided by the programs: the delivery of non-rival and potentially non-excludable information. Apart from the contention that social benefits from these programs exceed the private returns for farmers, some point out that government intervention in the programs can be justified if the public can provide the service cheaply or the private sector does not provide the service at all (Van den Ban, 2000).

This fourth chapter of the dissertation explores the impact of the Ethiopian agricultural extension program in promoting the adoption of chemical fertilizers. This is the largest government-run agricultural extension program in Sub-Saharan Africa with over 60,000 personnel serving around 39% of farmers in the country. According to the Ethiopian Agricultural Transformation Agency (2013, p. 16) the goal of the Ethiopian agricultural extension program is to "improve the livelihoods of smallholder farmers and contribute to Ethiopia's agricultural growth by ensuring rapid transfer and continued adoption of relevant technologies and best practices through a farmer-focused, innovation-led, and sustainable service delivery." The program is a key pillar of the current government's development strategy, known as Agricultural Development Led Industrialization, which is designed to achieve economic growth and structural transformation in the economy by raising productivity in the agricultural sector.

The evidence on the impact of the agricultural extension programs on technology adoption and farm productivity, however, is mixed. While some authors report negligible returns to public investment on extension programs, other provide evidence of strong impact on technology adoption and farm performance. Evenson (2001) provides an excellent survey of these empirical results. These contradictory results are partly due to the fact that agricultural extension is just one of the host of factors that influence farmers' decisions to adopt new technologies, and thus impact of extension program can be greatly limited by factors such as imperfections in credit and insurance markets and other infrastructural bottlenecks (See Feder et al., 1985; Foster and Rosenzweig, 2010 for a review of the literature on technology adoption in developing countries). Others suggest that impact of extension is highest when the informational disequilibrium is the greatest, implying that reported returns vary depending on at what phase of the program these returns are estimated. In addition, some authors argue the effectiveness of extension programs depends on the mode of delivery of information (Schwartz and Zijp, 1994). Apart from these issues, traditional research aimed at evaluating the impact of extension programs is bedeviled by selection problems, as participation in these programs is typically on voluntary basis (self-selection) and/or depends on government priority due to limited available public resources devoted to these programs (administrator selection).

The objective of the research presented in the fourth chapter of the dissertation is to evaluate the impact of the Ethiopian agricultural extension program in promoting technology adoption among farmers by employing some of the latest program evaluation techniques, namely propensity score matching and inverse probability weighting methods. These methods enables us to overcome selection problems that have undermined the credibility of results obtained in traditional research that attempted to estimate the impact of extension programs on technology adoption and productivity in several developing economies. The present research also goes beyond estimating the average impact of the program and provides estimates of heterogeneous treatment effects of the Ethiopian agricultural extension program on different sets of agricultural households participating in the program. Accordingly, using nationally representative data from four major regional states in Ethiopia, we find that the extension program enhances the probability of adoption of chemical fertilizers and increases the intensity of fertilizer use by farmers, but the effect is heterogeneous across households

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Chapter 2

Property Rights, Contracts, and Technology Adoption: A Theoretical Framework

2.1 Introduction

In this chapter, we develop a simple model that links changes in property rights regimes, contracts, and technology adoption in the agricultural sector. Agriculture presents an ideal opportunity to rigorously study the interaction between property rights, contracts, and the adoption of technology at the microeconomic level. In fact, the coexistence of sharecropping arrangements with fixed rental and wage contracts, despite the perceived inefficiency and lower intensity of inputs associated with the former, occupied economists for a long time. Different explanations have been forwarded to explain this phenomenon. Some of the earlier explanations present sharecropping as a risk-sharing mechanism. That is, unlike fixed rental contracts, sharecropping contracts protect the tenant from production risk. Similarly, because under wage contracts the landlord fully bears the risk and she may find it optimal to adopt share contracts as a risk-management strategy. However, Stiglitz (1974) showed that farmers can achieve the same level of risk sharing as in sharecropping arrangement by combining fixed rent and wage contracts, and thus to understand the existence of sharecropping contracts one needs to incorporate imperfect information explicitly into the analysis. He argued that sharecropping is an optimal contract in an environment characterized by significant yield risk and when inputs are not fully observable by the landlord. Other authors point to cost of monitoring and differences in productivity between the landlord and the tenant as major determinants of contract choice (Eswaran and Kotwal, 1985; Agrawal, 1999).

In this study, we introduce risk of expropriation and transaction costs (land transfer costs) in the traditional principal-agent framework. By making these two parameters depend on the level of property rights the landlord enjoys on her land, we will be able to analyze how changes in property rights institutions affect the optimal land and labor contracts she enters with the tenant, and its implication on the use of technology on the specific plot of land.

2.2 Model Setup

Our objective here is to develop a model that systematically links property rights and technology adoption under three contractual arrangements: fixed wage contracts, fixed rental contracts, and sharecropping arrangements. Thus, consider a landlord with total land size T. The landlord can potentially enter into three types of contracts: (1) she can farm the land using hired labor (wage contract) with or without family labor, (2) she can rent out the land (fixed rental contract), or (3) she can enter into a sharecropping arrangement. The sharecropping contract may involve cost-sharing arrangements as well. We further assume the landlord can enter into these contracts with a large number of identical tenants but only with one tenant at a time.[3]

The production function $f : R_+^3 \to R_+$ is strictly concave and is assumed to be twice differentiable in both labor and fertilizer, the two inputs employed along with managerial (entrepreneurial) skill that captures the efficiency in the management of the farm, $A_i \in R_{++}$, where $i \in \{landlord, tenant\}$; $A_l \in R_{++}$ and $A_t \in R_{++}$ represent the managerial skills of the landlord and tenant, respectively. More specifically, the production function is specified as $Q = A_i f(x, l; q)$, where x and l denote

[3] To facilitate the discussion, assume the landlord is female and the tenant is male.

fertilizer and labor, and θ represents production uncertainty (such as weather risk) that make the returns on investment in the technology uncertain.

To analyze the impact of improved property rights on contracts and technology adoption, assume the landlord does not have secure property rights over the land. We follow Besley (1995) who identifies three mechanisms through which improved land rights influence investment: (1) by reducing tenure insecurity (2) by reducing land transfer costs (3) by enabling the landlord to use the land as collateral. In the empirical setting, the land certification program does not allow farmers to sell their land or borrow against it. Thus, we focus on the first two mechanisms.

Assume that the landlord faces (1) risk of eviction by the government or powerful elites, with probability $\tau(R) \in (0,1)$, which depends on the level of property rights, R, that the landlord enjoys, where R is some index (a scalar) that measures the level of property rights. Thus, $\tau'(R) < 0$; and (2) transaction costs, $\gamma(R,C,\alpha): R_{+}^{3} \rightarrow R_{+}$, which refers to all land transfer costs the landlord incurs when she participates in the land rental market, including the cost of finding a tenant and the cost of activities she carries out ex ante to protect herself from losing the land to the person who rents it. The magnitude of the transaction cost is assumed to be decreasing in the level of property rights enjoyed by the household and the quality of contracting institutions (C) in the region, i.e., $\frac{\partial\gamma(R,C,\alpha)}{\partial R} < 0$ and $\frac{\partial\gamma(R,C,\alpha)}{\partial C} < 0$, where α represents the share of the tenant in total output.[4] Note that $\gamma(R,C,0) = 0$ as land is not transferred under wage contract. We further

[4] We follow Acemoglu and Johnson (2003) who define contracting institutions as institutions that enforce contracts between private economic agents.

assume $\gamma(R,C,\alpha) < \gamma(R,C,1)$, $\forall \alpha \in (0,1)$. That is, land transfer costs are higher under a rental market than under a sharecropping arrangement.[5]

We assume that input choices are made at the beginning of the production cycle and all investment will be forgone if the farmer is evicted from the land during the production season. The goal here is to understand how the presence of eviction threats and transaction costs influence contract choice, and how that translates into the choice of technology. We will also investigate how credit market imperfections and production uncertainty influence this process. Figure 1 presents the mechanisms through which property rights, contracts, and technology adoption are linked and the role of credit and insurance markets, as well as the quality of contracting institutions in influencing these mechanisms.

To analyze the impact of risk of expropriation on contract and technology choice it is convenient to introduce a random variable ϕ with the following distribution:[6]

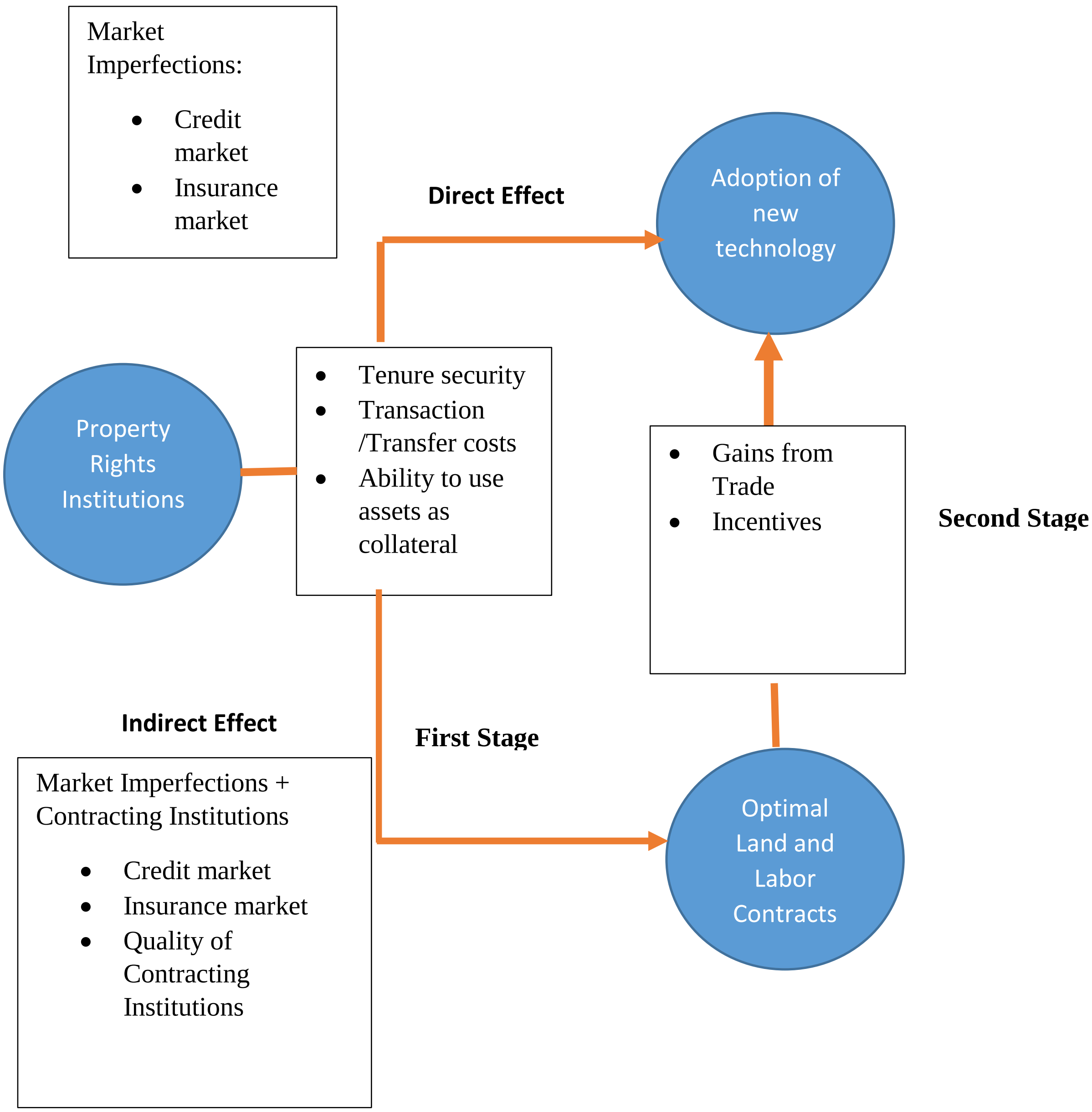
$$\phi = \begin{cases} \dfrac{1}{1-\tau(R)}, \textit{with probability } 1-\tau(R) \\ 0, \textit{with probability } \tau(R) \end{cases}$$

Note that $E\phi = 1$. To simplify our analysis assume production risk, θ, enters multiplicatively i.e. $f(x,l,\theta) = \theta f(x,l)$ and $E\theta = 1$. We will assume throughout the paper that ϕ and θ are independent.

[5] The intuition is that the more complete the land transfer, the higher the land transfer cost. And land transfer is most complete under rental contract where the landlord has no say in production or management of the farm. Only Proposition 2 relies on this assumption. Even then what we need is for transaction costs under rental contract to be higher than under sharecropping arrangements.

[6] The reason for the introduction of ϕ is to help us derive an expression for marginal risk premium and which would enable us to link risk of expropriation and contract choice with convenience.

Figure 1 – Linking Property Rights and Technology Adoption



Thus, ignoring transaction costs for the moment, we can express the income of the landlord, Y_l, as:

$$Y_l = (1-\tau(R))\phi(1-\alpha)A_l\theta f(x,l) - (1-\beta)p_x x + r \qquad (1)$$

where $\alpha \in [0,1]$ is the tenant's share of output, $\beta \in [0,1]$ represents the tenant's share of input cost and $r \in R$ is rent received by the landlord. We have fixed the price of output at 1, and p_x denotes the price of fertilizer

Thus, equation (1) says the expected income of the landlord is:

$$EY_l = (1-\tau(R))(1-\alpha)A_l f(x,l) - (1-\beta)p_x x + r$$

the realization of Y_l, for a given θ, is $(1-\alpha)A_l\theta f(x,l) - (1-\beta)p_x x + r$ with probability $1-\tau(R)$ and $-(1-\beta)p_x x + r$ with probability $\tau(R)$.

Similarly, the income of the tenant, Y_t, can be expressed as:

$$Y_t = (1-\tau(R))\phi\alpha A_t\theta f(x,l) - \beta p_x x - r \qquad (2)$$

Note that under rental contract we have $\alpha = \beta = 1$ and $r > 0$, and under wage contract we will have $\alpha = \beta = 0$ and $r < 0$. We have pure output sharing and input-put sharing contracts under sharecropping.[7] That is,

(1) pure output sharing contract : $\alpha \in (0,1)$, $\beta = 0$ and $r \geq 0$

(2) input-output sharing contract: $\alpha \in (0,1)$, $\beta \in (0,1)$ and $r \geq 0$

Note that under this formulation, the tenant is solely responsible for management of the farm under rental contract while the responsibility of managing the farm under wage contract falls on the

[7] See Laffont and Matoussi (1995) for a similar specification of contracts.

landlord. Under sharecropping contract, we are assuming the management of the farm is shared between the landlord and the tenant according to their share in output. That is, under sharecropping contract, total farm output is given by $\left[(1-\alpha)A_l + \alpha A_t\right] f(x,l)$, where $(1-\alpha)A_l f(x,l)$ and $\alpha A_t f(x,l)$ represent of the absolute shares of the landlord and the tenant in total farm output, respectively.

Let U represent the utility function of the tenant. As it is standard in the literature, we assume the utility of the tenant is separable into income and effort. Hence, denote $\psi(l): R_+ \to R_+$ as the disutility associated with work. We assume $\psi' > 0$ and. $\psi'' > 0$.

2.3 Tenure Security and Gains from Trade

This section analyzes the impact of tenure insecurity on contract choice and technology adoption. Assume (i) the landlord is risk neutral, (ii) the tenant is risk averse, (iii) all inputs are observable by the landlord (and hence there is no incentive problem/moral hazard), iv) there is no weather risk (or other production uncertainty), and (v) there are no transaction costs. The assumption that all inputs are observable by the landlord implies the landlord does not have to worry about the tenant's incentive compatibility constraint For now let's ignore the possibility of cost-sharing arrangement under sharecropping contracts (i.e. we will consider the case $\beta = 0$). Hence, the landlord's program is given by:

$$\max_{\alpha,\beta,r,x,l} (1-\tau(R))(1-\alpha)A_l f(x,l) + r$$

subject to:

$$EU\left(\alpha(1-\tau(R))\phi A_t f(x,l) - r\right) - \psi(l) \geq U(\overline{w}) \ldots\ldots\ldots\ldots\ldots (\lambda)$$

$$0 \leq \alpha \leq 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mu)$$

where $U(\overline{w})$ represents the tenant's reservation utility, and λ and μ are the Lagrange multipliers of the respective constraints. Suppose $A_t > A_l$ and define the marginal risk premium of the tenant as $\rho \equiv 1 - \frac{EU'\phi}{EU'}$.[8] Denote α^* as the optimal value of α that solves the landlord's program above.

PROPOSITION 1: Under assumptions (i)-(iv), if $\rho > \frac{A_t - A_l}{A_t}$, then the landlord chooses wage contract; if $\rho < \frac{A_t - A_l}{A_t}$, then fixed rental contract is the optimal contract.

Proof **:**

The first order conditions of the landlord's program are:

$$(1-\alpha)(1-\tau(R))A_l \frac{\partial f}{\partial l} + \lambda\left(\alpha EU'\phi(1-\tau(R))A_t \frac{\partial f}{\partial l} - \frac{\partial \psi}{\partial l}\right) = 0$$

$$(1-\tau(R))(1-\alpha)A_l \frac{\partial f}{\partial x} + \lambda EU'\left((1-\tau(R))\alpha\phi A_t \frac{\partial f}{\partial x}\right) = 0$$

$$([-A_l f(x,l)](1-\tau(R)) + \lambda EU'\phi(1-\tau(R))A_t f(x,l)) - \mu \leq 0 \quad \text{and}$$

$$(([-A_l f(x,l)](1-\tau(R)) + \lambda EU'\phi(1-\tau(R))A_t f(x,l)) - \mu)\alpha = 0$$

$$\alpha - 1 \leq 0 \text{ and } \mu(\alpha - 1) = 0$$

$$(1 - \lambda EU') = 0$$

From the complementarity condition involving α we have

$$([-A_l f(x,l)](1-\tau(R)) + \lambda EU'\phi(1-\tau(R))A_t f(x,l) - \mu) \leq 0$$

First Suppose that $\alpha \neq 1$. This implies $\mu = 0$. Hence, we have

$$\left([-A_l] + \frac{EU'\phi}{EU'}A_t\right) \leq 0, \text{ as } \lambda = \frac{1}{EU'}$$

[8] The marginal risk premium measure measures how the risk premium changes with output/income. Note that $\rho = -Cov(U', \phi) > 0,$ for a risk averse agent where $U'' < 0$.

Rearranging the above equation yields,

$$1-\frac{A_l}{A_t} \le 1-\frac{EU'\phi}{EU'}$$

From the complementarity condition we see that, if $1-\frac{EU'\phi}{EU'} > \frac{A_t - A_l}{A_t}$, $\alpha^* = 0$.

Now we can get the value of μ by setting $\alpha = 1$, which yields

$$\mu = -A_l f(x,l)(1-\tau(R)) + \frac{EU'\phi}{EU'}(1-\tau(R))A_t f(x,l)$$

From the complementarity condition that involves μ, we can see that if $\mu > 0$, then $\alpha^* = 1$

But $\mu > 0$ only if $1-\frac{EU'\phi}{EU'} < \frac{A_t - A_l}{A_t}$. Q.E.D.

The condition in Proposition 1 shows the two counterbalancing effects the landlord needs to consider in choosing the optimal contract. On one hand, the more risk averse the tenant is, the fewer inputs he will apply if he rents the land, and hence his profit would be very low, which limits the amount of rent the landlord can extract from him. On the other hand, if the tenant is much more productive than the landlord in his managerial capacity, the rent the landlord can charge the tenant would be higher. Hence, Proposition 1 says if the risk premium is greater than the productivity differential between the two parties, then the landlord would find it optimal to hire the tenant as a wage laborer, and choose the level of inputs herself, while pushing the tenant to his reservation utility.

By the same token, if the productivity differential dominates marginal risk premium, then fixed rental becomes the optimal contract, and the landlord transfers the land to the tenant. Therefore, if prior to the land certification program the risk of expropriation was high enough so that ρ was greater than $\frac{A_t - A_l}{A_t}$ but the introduction of the program sufficiently reduces risk of expropriation and causes ρ to be lower than $\frac{A_t - A_l}{A_t}$, the optimal contract changes from wage to rental contract, i.e., the landlord participates in the land rental market.

What is the implication of this on fertilizer use? To see that, focus on the first order condition involving the demand for fertilizer under wage contract, which simplifies to:

$$(1-\tau(R))A_l \frac{\partial f}{\partial x} = p_x \tag{3}$$

Note that in the first best case where there is no risk of expropriation, if $A_t > A_l$, the landlord would transfer land to the tenant and at the optimum we would have $A_t \frac{\partial f}{\partial x} = p_x$.

Therefore, adding and subtracting $A_t \frac{\partial f}{\partial x}$ and $A_l \frac{\partial f}{\partial x}$ to (3), and rearranging terms, equation (3) can be expressed as:

$$\underbrace{-A_l \tau(R)\frac{\partial f}{\partial x}}_{\substack{\text{direct impact of}\\ \text{expropriation on the demand}\\ \text{for modern fertilizer}}} - \underbrace{(A_t - A_l)\frac{\partial f}{\partial x}}_{\substack{\text{indirect impact of risk expropriation}\\ \text{on fertilizer demand by preventing}\\ \text{gains from trade}}} + A_t \frac{\partial f}{\partial x} = p_x \tag{4}$$

From (4) we can see that fertilizer demand is low under the risk of expropriation, and this is due to two effects: (1) the direct of impact of expropriation on fertilizer demand; and (2) the indirect impact of expropriation on technology adoption by preventing gains from trade (i.e., influencing contract choice). That is, under the conditions specified in Proposition 1, the presence of the risk of expropriation implies the landlord needs to provide full insurance to the risk averse agent by offering her a wage contract, and this results in the potential loss of gains from trade when

$\rho > \frac{A_t - A_l}{A_t}$. Therefore, the land certification program, if it is credible and if it does sufficiently reduce the risk of expropriation, promotes technology adoption (1) directly by reducing uncertainty under any contract and (2) altering the optimal contract (to rental contract) by reducing the marginal risk premium of the tenant, which results in the transfer of land to the tenant who is more efficient and will use more units of fertilizer.

2.4 Risk of Expropriation, Transaction Costs, and Incentives

In the above analysis, the indirect impact of property rights on technology adoption through its impact on contract choice depended on the assumptions made about the differences in the risk preferences and the entrepreneurial abilities of the tenant and landlord. We also ignored the possibility that the landlord may not fully observe the inputs. This section relaxes these assumptions and demonstrates that there will still be an indirect impact of insecure property rights on technology adoption even when there is no difference in the risk preference and entrepreneurial skill between the landlord and the tenant.

Thus, suppose both the tenant and the landlord are risk neutral and have the same entrepreneurial skill: $A_t = A_l = \overline{A}$. Assume the landlord cannot directly observe both labor and fertilizer, and moreover cannot deduce the amount of labor and fertilizer applied to the farm by simply observing output as there is randomness in production. Following Bardhan (1984) we assume that the landlord chooses the total quantity of fertilizer to be bought, N, but she faces the possibility that the tenant may not apply all fertilizer purchased (he may re-sell some of the fertilizer for private gain or apply it on his own land, i.e., $x \leq N$).

Thus, the landlord's problem is given by:

$$\max_{\alpha,\beta,r,l,x,} (1-\tau(R))(1-\alpha)\overline{A}f(x,l)-(1-\beta)p_x N + r$$

Subject to:

$$(1-\tau(R))\alpha\overline{A}f(x,l)-\beta p_x N + p_x(N-x)-\psi(l)-r \geq \overline{w} \tag{5}$$

$$(1-\tau(R))\alpha\overline{A}\frac{\partial f}{\partial l} = \frac{\partial \psi}{\partial l} \tag{6}$$

$$(1-\tau(R))\alpha\overline{A}\frac{\partial f}{\partial x} = p_x \tag{7}$$

$\overline{w}$ denotes the expected income of the tenant from his outside option. Equations (6) and (7) represent the incentive compatibility constraints the landlord needs to consider in choosing the contract parameters. It should be clear from the incentive compatibility constraint that in the absence of any risk of expropriation the landlord can solve the incentive problem that results from inability to fully observe inputs (i.e. monitoring is costly) by choosing a rental contract i.e. $\alpha = \beta = 1$.

Now define x^* and l^* as the levels of fertilizer and labor units that solve the incentive compatibility constraints when $\alpha = \beta = 1$ i.e. rental contract is chosen. Also, define $Y_l^{share} > 0$ as the maximum expected income the landlord gets under sharecropping arrangement without subtracting transaction cost.

That is, $Y_l^{share} \equiv \max_{\alpha,\beta,r}(1-\tau(R))(1-\alpha)\overline{A}f(x,l)-(1-\beta)p_x N + r$ such that $\alpha \in (0,1)$, $\beta \in (0,1)$, and $r \geq 0$.

Denote α^* as the optimal value of α that solves the landlord's program with incentive problems.

PROPOSITION 2: If $\gamma(R,C,1)-\gamma(R,C,\alpha) > (1-\tau(R))f(x^*,l^*)-p_x x^* - \overline{w}+\psi(l*)-Y_l^{share}$ $\forall \alpha \in (0,1)$, then the landlord chooses a sharecropping contract.

<u>Proof</u>: The proof is simple and involves comparing the expected income under the three types of contracts. First note that $\alpha \neq 0$, i.e., a wage contract will not be chosen as it does not solve the incentive compatibility constraint.[9] Hence, the choice of contracts is between sharecropping and rental contracts.

Under rental contract, we can solve for r from the tenant's rationality constraint, which is binding, as:

$$r = (1-\tau(R))\overline{A}f(x^*,l^*)-p_x N + p_x(N-x^*)-\psi(l^*)-\overline{w}$$
$$= (1-\tau(R))\overline{A}f(x^*,l^*)-p_x x^* -\psi(l^*)-\overline{w}$$

Incorporating transaction cost in rental market, the expected income of the landlord if she chooses rental contract is given by:

$$Y_l^{rental} = Max\{(1-\tau(R))f(x^*,l^*)-p_x x^* - \overline{w}+\psi(l^*)-\gamma(R,C,1),0\}$$

That is, the landlord will not participate in the rental market if $Y_l^{rental} < 0$. Furthermore, if $Y_l^{share} - \gamma(R,C,\alpha) > Max\{(1-\tau(R))f(x^*,l^*)-p_x x^* - \overline{w}+\psi(l^*)-\gamma(R,C,1),0\}$, then $\alpha^* \in (0,1)$ i.e., the landlord will choose the sharecropping arrangement: Proposition 2 follows immediately.

Proposition 2 says is that significant transaction costs exclude rental contract, which is the optimal contract when the returns of the new technology are uncertain and both the landlord and the tenant are risk neutral.

[9] No fertilizer and labor will be applied under wage contract, and hence output would be zero.

Once again, what is the implication of this on the adoption of technology? First note that under no risk of expropriation and transaction cost, the Pareto-optimal condition is $\overline{A}\frac{\partial f}{\partial x} = p_x$: fertilizer will be used until its value of marginal product is equal to its price. Nevertheless, if significant land transfer costs prevent the landlord from participating in the land rental market, and sharecropping contracts are chosen, then the first order conditions of the incentive compatibility constraint will be given by:

$$(1-\tau(R))\alpha\overline{A}\frac{\partial f}{\partial x} = p_x. \tag{8}$$

Through algebraic manipulations (8) can be expressed as:

$$\underbrace{-\alpha\tau(R)\overline{A}\frac{\partial f}{\partial x}}_{\substack{\text{direct impact of expropriation}\\ \text{on fertilizer demand}}} \underbrace{-(1-\alpha)\overline{A}\frac{\partial f}{\partial x}}_{\substack{\text{the dis-incentive}\\ \text{effect}}} + \overline{A}\frac{\partial f}{\partial x} = p_x \tag{9}$$

Equation (9) says the suboptimal use of technology on the land when sharecropping is chosen can be decomposed into the direct impact of expropriation and the fact that fixed rental contract, which would solve the incentive (moral hazard) problems the landlord faces, was not chosen because of significant transaction cost in the land rental market.

2.4.1 Implication of Credit Market Imperfections

The implication of the analysis is that credible tenure reforms have the potential to promote technology adoption by altering the optimal contracts farmers choose, i.e., by promoting their participation in the rental market, which would result in gains from trade or solve the moral hazard problems that arise when the landlord cannot perfectly monitor inputs. Nevertheless, note that even when the land certification program succeeds in eliminating tenure insecurity and transfer costs, credit market imperfections can potentially exclude a rental contract. To see this suppose the tenant is credit constrained, and his credit constraint is given as:

$$\beta p_x N + r - p_x (N - x) \leq W_t ,$$

where W_t represents the tenant's wealth (or working capital). Substitute into her rationality constraint in equation (5) to get[10]

$$\alpha \leq \frac{\overline{w} + W_t + \psi(l)}{(1 - \tau(R))Af(x,l)} \tag{10}$$

Equation (10) says that severe credit constraints can potentially exclude rental contract. That is, if the tenant's wealth is very low it is possible that α is constrained to be less than 1 by his lack of access to credit.

2.5 Dynamic Considerations

This section discusses the implications of the presence of risk of expropriation on the incentive to use fertilizers in a dynamic setting using a two-period model. In particular, we will address the common argument in the literature on sharecropping that the landlord can induce more effort from the tenant using the threat of eviction if output falls below a certain level. Given that background, I make the following claim

PROPOSITION 3: The risk of expropriation reduces the ability of the landlord to induce the application of fertilizer using the threat of eviction.

Proof/Discussion:

[10] Note that the tenant's real expenditure is $\beta p_x N + r - p_x (N - x)$. Furthermore, his rationality constraint is binding.

Following Bardhan (1984), let $G \in (Q; l, x)$ represent the distribution function of $Q = \overline{A}\theta f(x,l)$, the randomness of which arises due to the randomness of θ which captures the production uncertainty in the economy. Suppose the tenant is risk averse, and the landlord is risk neutral. Lets fix $\overline{A} = 1$

First consider a two-period general principal agent problem with no risk of expropriation, but with the presence of weather risk. In the second period the landlord's problem is given by

$$\max_{\alpha,\beta,r,l,x,N} (1-\alpha) f(x,l) - (1-\beta)PN + r$$

subject to:

$$EU\left(\alpha Q - \beta p_x N + p_x(N-x) - r\right) - \psi \geq U(\overline{w})$$

$$EU'\theta\alpha \frac{\partial f}{\partial l} - \psi' = 0$$

$$EU'\left(\alpha\theta\frac{\partial f}{\partial x} + p_x\right) = 0$$

Suppose the solution to this maximization problem exists and the level of the tenant's expected utility is $V^* > U(\overline{w})$.[11] Now assume the landlord specifies $Q_{\min}$ so that if output falls below this level in the first period, she will fire the tenant and hire another tenant from a pool of identical tenants. Thus, the tenant's expected utility from the two-period contract is given by

$$EU\left(\alpha Q - \beta p_x N + p_x(N-x) - r\right) - \psi(l) + \mu V^*(1 - G(Q_{\min}; l, x)$$

[11] As Bardhan (1984) argues, this condition is necessary for the threat of eviction to be real i.e. the tenant must be made worse off by being dismissed. This happens when the tenant is strictly better off by working for the landlord in the second period and thus his expected utility under this contract should be higher than his outside option.

where μ is the tenant's discount factor. The first order conditions of an interior solution for the tenant's problem are given by:

$$EU'\theta\alpha f_l - \psi'(l) - \mu V^* G_l(Q_{\min}; l, x) = 0 \tag{11}$$

$$EU'\theta\alpha f_x - EU' p_x - \mu V^* G_x(Q_{\min}; l, x) = 0 \tag{12}$$

Since the probability of output falling below $Q_{\min}$ is decreasing in applications of fertilizer and labor, G_l and G_x are both negative. Thus, it follows that the sum of the first two terms in both equations is negative. Hence, given the concavity of the production function, the tenant would apply more labor and fertilizer under a threat of eviction for any contract (α, β, r). See Bardhan (1984) for a similar discussion.

Now consider the second period game described as above but in the presence of risk of expropriation. Suppose once again the solution to this maximization problem exists and that the level of the tenant's expected utility is $V^{**} > U(\overline{w})$. Note that expected utility of the tenant with both production and tenure risk cannot exceed than the case where there is only production risk. That is, $V^{**} \leq V^*$.

Therefore, given the landlord faces risk of expropriation in the first period with probability $\tau(R) \in (0,1)$, the tenant's expected utility in the two period contract is given by:

$$\begin{aligned} EU &= (1-\tau(R))\left[EU(\alpha Q - \beta p_x N + p_x(N-x) - r)\right] + \tau(R)\left[EU\left(-\beta p_x N + p_x(N-x) - r\right)\right] - \psi(l) \\ &+ \mu V^{**}(1 - G(Q_{\min}; l, x))(1-\tau(R)) \end{aligned}$$

Note that the tenant now realizes the second period interaction will only take place if output does not fall below $Q_{\min}$ and the landlord is not evicted from the land herself. Hence, the probability that the second period game will be played is $(1 - G(Q_{\min}; l, x))(1-\tau(R))$. Define the first period income of the tenant under the good state (no expropriation) and bad state (with expropriation) in respectively as:

$$Y_t^G = \alpha Q - \beta p_x N + p_x(N-x) - r \quad \text{and} \quad Y_t^B = -\beta p_x N + p_x(N-x) - r$$

The first order conditions of the tenant's problem are:

$$EU'(Y_t^G)\theta\alpha f_l - \psi'(l) - \mu V^{**} G_l(Q_{\min};l,x) = 0 \qquad (13)$$

$$(1-\tau(R)EU'(Y_t^G)(\theta\alpha f_x + p_x) - \tau(R)EU'(Y_t^B)p_x - \mu(1-\tau(R)V^{**}G_x(Q_{\min};l,x) = 0 \qquad (14)$$

Rearranging (14) yields

$$EU'(Y_t^G)(\theta\alpha f_x + p_x) - \mu V^{**} G_x(Q_{\min};l,x) - \frac{\tau(R)}{(1-\tau(R)} EU'(Y_t^B)p_x = 0 \qquad (15)$$

Thus, focusing our attention on the use of fertilizer, and by comparing (15) to (12) and noting that $V^{**} \leq V^{*}$, we can see that for any given contract (α, β, r), less units of fertilizer would be applied on the plot of land even under the threat of eviction if the landlord faces risk of expropriation. The intuition of this claim is clear. If the landlord faces possible expropriation herself, her threat of eviction would not have the same impact in inducing the application of fertilizer by the tenant. The implication is that the disincentive effect of risk expropriation that we discussed in the static model and its implication on technology adoption is still valid in long term contracts.

2.6 Conclusion

The theoretical framework developed in this chapter shows that improved land rights influences farmers' choice of land and labor contracts by reducing the risk of expropriation and transaction costs. The first proposition shows that even in absence of imperfect information and incentive problems, reduced risk of expropriation can potentially increase the use of chemical fertilizers directly by reducing production uncertainty and indirectly by allowing the transfer of land to tenants who are better farm managers. We later extend this analysis by incorporating imperfect information into the model and demonstrate that by reducing land transfer costs, improved land rights encourages farmers' adoption of rental contracts which solve the moral hazard problems associated with sharecropping and wage contracts, thereby promoting the use of chemical fertilizers. Finally, we present a model that analyzes the impact of risk of expropriation in a dynamic context in the presence of other production risk. We argue that expropriation risk reduces the ability of the landlord to induce the application of fertilizer using the threat of eviction, demonstrating that the disincentive effect of risk expropriation that we analyzed in the static model and its implication on technology adoption persists even in long-term contracts.

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Chapter 3

Property Rights, Contract and Technology Adoption: Evidence from Ethiopia

3.1 Introduction

This chapter focuses on the econometric analysis of the impact of improved land rights on the adoption probability and the intensity of use of chemical fertilizers by farmers in rural Ethiopia. Our approach empirically disentangles the direct impact of improved tenure security on technology adoption, via a reduced risk of expropriation, from the indirect impact it has by altering farmers' optimal contractual arrangement. To estimate the indirect impact of improved tenure security on technology adoption, we proceed in two steps. (1) Link contract types to the decisions to adopt fertilizers and to the intensity of fertilizer use. To this end, after running initial household fixed-effects regressions, we employ the inverse-probability weighted regression adjustment method to control for the potential endogeneity of contracts. (2) Link property rights with contract choice using the semi-parametric tobit fixed effects estimator, again controlling for the potential endogeneity of tenure security at the household level. Finally, we employ the difference-in-difference estimator to obtain the direct impact of improved tenure security on technology adoption. The econometric results demonstrate that the main channel through which improved land rights promotes the adoption of chemical fertilizers is by transforming the contractual structure in the agricultural sector by encouraging the switch towards fixed rental contracts that allow the transfer of land to farmers who are more likely to use chemical fertilizers, in addition to solving the moral hazard problems associated with the other contracts.

This chapter is organized as follows. Section 3.2 briefly reviews the land policy and land certification program in Ethiopia. Section 3.3 discusses the data used in the study. Section 3.4 presents the empirical strategy adopted in the paper and the econometric results. Section 3.5 concludes the paper.

3.2 Institutional Background and Land Certification Program

All land in Ethiopia is under public (government) ownership. Article 40, No. 3 of the Constitution of the country that has been adopted since 1994 stipulates:

"the right to ownership of rural and urban land, as well as of all natural resource, is exclusively vested in the State and in the peoples of Ethiopia. Land is a common property of the Nations, Nationalities and Peoples of Ethiopia and shall not be subject to sale or to other means of exchange"

A similar land policy was in place under the socialist military government that ruled Ethiopia during 1974-1991 that came to power after overthrowing the Imperial government of Haile Selassie, which allowed private ownership of land, although most of the land was owned by absentee landlords during that time. The military government swiftly abolished private ownership of land, took the land from landlords without compensation, and gave peasants the right to use their farmland indefinitely.[12]

The current government, which ousted the military government in 1991 after a protracted civil war, continued with the same land policy, and has steadfastly resisted calls by international donors to privatize land despite undertaking significant structural adjustment and market reforms in other

[12] Proclamations No. 31, 1975 and No. 47, 1975 nationalized all rural and urban land (including extra houses), respectively.

sectors of the economy, including the privatization of public companies and opening of the economy to private investment.[13]

In what seems to be a compromise to the mounting pressure by donors that provide significant development aid to the country, the government started a land certification program that is aimed at eliminating possible tenure insecurity faced by farmers. This program gives farmers perpetual land-use rights to cultivate their land without fear of eviction. Under this program, which is administered by the regional governments' lowest level of administration (Kebeles), farmers can also rent out their land or engage in sharecropping arrangements, although perpetual land lease is prohibited (Deininger et al., 2007).[14] Descendants of the farmers also enjoy the right to inherit the land-use rights of their parents. Nevertheless, farmers are not allowed to sell the land they cultivate or use it as collateral to obtain credit.

In this study, we explore the impact of the land certification program on technology adoption by influencing farmers' choice of land and labor contracts. Clearly, for the program to have any impact, the following two conditions must hold: (1) there ought to be real or perceived risk of expropriation to begin with (2) the program should be credible.[15] So, how real was the risk of land expropriation in Ethiopia? To answer this question, looking at the frequency of land expropriation in the past and existing laws is instructive. In addition to the nationalization of all private land that took place under the military government, regional governments under the current regime have also have redistributed land in the past, usually citing rising number of landless people in rural

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[13] The government contends that privatization of land, the most important means of production in a predominantly agrarian economy, will eventually lead to a skewed concentration of land in the hands of the wealthy, in addition to the possible mass migration of peasants that may occur beyond what the modern/urban sector can potentially absorb.
[14] Ethiopia is a federal republic with 7 regional states and 2 chartered cities.
[15] A lot of factors may affect the credibility of these title reforms including effectiveness of legal institutions in enforcing the law of the land.

areas as a reason. For instance, according to Deininger et al. (2007), in 1997 the Amhara regional government, the second largest state in the country, confiscated and redistributed land, although some contend that this was politically motivated rather than a response to population pressure.

In addition, the constitution of Ethiopia still gives the government the power to hold land it deems is in the interest of the public. Article 89, No. 5 of the constitution reads:

"Government has the duty to hold, on behalf of the People, land and other natural resources and to deploy *them for their common benefit and development*"

This provision gives the government the authority to acquire land from farmers at will. An example of this is the recent large-scale land acquisitions by firms and foreign governments in Ethiopia in deals they entered with the government, which resulted in the displacement of small-scale farmers in some regions. By some estimates these land deals account for around 8% of the total agricultural land in Ethiopia.[16]

Thus, it is fair to say that the risk of expropriation is real and, as long as the government maintains the right to take land for the 'public good', and tenure insecurity may still exist even after the introduction of the land certification program. Our empirical analysis examines the credibility of the program indirectly by exploring its impact on farmers' participation in the rental market after the introduction of the land certification program.[17]

[16] http://www.bbc.com/news/world-africa-17099348. Many organizations like Oxfam have termed these large-scale acquisitions in Ethiopia and other parts of Africa as outright land grabs by foreign entities at the expense of small-scale farmers.

[17] If the land certification program is not credible, then we should not find any impact on the contractual structure in agriculture. The converse, however, is not true. The lack of any impact of the program on farmers' rental market participation can be due to other factors, such as credit market imperfections, which can significantly limit the impact of the policy.

3.3 Data and Descriptive Statistics

The data for the study were obtained from household surveys conducted by the World Bank (WB) and Ethiopian Economic Association (EEA) in 2006 and 2010. These surveys cover over 2300 households that are randomly selected from 115 rural Ethiopian villages in four regional states in Ethiopia: Amhara, Oromia, Southern Nations, Nationalities and Peoples (SNNP), and Tigray regional states.[18] According to the Ethiopian Statistical Authority, the population in these regions accounted for 86% of the estimated 75.1 million and 79.7 million population of Ethiopia in 2006 and 2010, respectively.[19] We obtained rainfall data for about 184 stations in the country from the Ethiopian National Meteorology Agency.[20]

Table 1 presents comparison of the characteristics of households with and without land certificate in 2006 and 2010. In 2006, 47% households did not have certificates on their land holdings. The figure dropped to 26% in 2010, as the land certification program expanded in the regional states. There does not seem to be a strong correlation between the likelihood of obtaining land certificates and household size or the literacy levels of the household head. The average household size of both sets of households was roughly around 7 in both years.[21] While half of the household heads who did not possess a land certificate were illiterate in both years, the corresponding figures were only slightly lower for households with land certificate (48% in 2006 and 49% in 2010), and the difference is not statistically significant.

[18] Ethiopia is a federal republic with 7 regional states and 2 chartered cities.
[19] Currently, the population of Ethiopia is estimated to be around 94.1 million, making the country the second most populous country in Africa after Nigeria.
[20] Based on the geographic coordinates of the villages and stations, I computed the distance between each station and the villages in the sample and assigned the rainfall data of the nearest station to each village.
[21] Although the difference in average household size for the two groups of households is statistically different in 2006, that magnitude is not meaningfully significant (6.5 vs. 6.9).

In addition, although households without land certificates appear to be relatively wealthy, the difference in wealth is not statistically significant. In 2006, the average values of farm and household assets were Birr 749 and Birr 851 for households with and without land certificates, respectively.[22] This rose to Birr 2302 for households with land certificate and Birr 2861 for those without certificate in 2010. The significant increase in the value of household assets is partly due to the very high inflation the country experienced during the period.[23] A more accurate depiction of the dynamics of value of assets is reflected if we convert the figures into US dollars using the annual exchange rate. Accordingly, the value of farm and household assets for households with no certificate increased from USD 96.7 in 2006 to USD 173.1 in 2010. The increase in household and farm assets for households with land certificate during this period was from USD 85 to USD 139.6, which is consistent with the macroeconomic figures that show that country has achieved rapid economic growth during that period. Furthermore, there is no statistically significant difference in the average size of land holdings by both groups of households.

To look at the gender dimension of the implementation of the land certification program, we compare the composition of female-headed households among households with and without land certificate. Specifically, we tested if the gender composition of household heads with and without land certificates is different but did not find any statistically significant systematic difference. Female-headed households accounted for 13% and 15% of households with land certificate in 2006 and 2010, respectively. Among households without land certificate 12% and 18% were female headed in 2006 and 2010, respective.

[22] Birr is the local currency. In the fiscal year 2006/2007, the annual average official exchange rate was Birr 8.7943/USD while in 2010/11 the figure was Birr 16.5292/USD.

[23] According to the data from the Central Statistical Agency of Ethiopia, the national annual average inflation during 2006-2010 was 15.5%.

Both sets of households are predominantly farmers and there does not appear to any structural shift in their occupational choice during 2006-2010. 87% of household heads with land certificate reported that farming as their major occupation both in 2006 and 2010. The figure is slightly higher for households without land certificate (88-90%) but the difference is statistically insignificant. Overall the two groups of households possess comparable observable characteristics (See Table 1).

Table 2 presents descriptive statistics on how technology choice is linked to the choice of land and labor contracts. The proportion of plots that are cultivated using modern seeds is higher under a rental contract than under sharecropping contracts or plots farmed by households using their own family labor alone (autarky).[24] Specifically, 19% of parcels under fixed rental contract were farmed using modern seeds in 2006. The corresponding figure is 10% for parcels under share contracts and 13% under autarky. In 2010, 18% parcels under fixed rental contracts were farmed by employing modern seeds as opposed to 14% and 21% under share and wage contracts, respectively.[25] In the same year, 15% for plots of land under autarky were farmed using modern seeds.

[24] We say a farmer has used modern seed on the parcel if he plants one or more crops using a high-yield variety.
[25] I consider all plots where the use of hired labor is greater than family labor to be under wage contracts.

Table 1 – Household Characteristics by Treatment

Variables	2006		2010	
	Has Certificate	**No Certificate**	**Has Certificate**	**No Certificate**
Number	1079 (53.3%)	1236 (46.7%)	1701 (73.7%)	606(26.3%)
Household Size	6.47	6.87***	7.21	7.22
Head is Illiterate (%)	51	47	49.3	49.6
Value of Farm and Household Asset in Birr	749.1	851.9	2302.89	2861.84
Age of Household Head	47.6	47.8	50.94	51.56
Female Headed Household (%)	13.3	12.6	15	18
Male Adult Labor in Household	1.70	1.84*	2.01	2.05
Female Adult Labor in Household	1.62	1.67	1.93	1.86
Roof is corrugated metal (%)	58.6	56.3	68	70
Number of Rooms	2.26	2.00***	2.27	2.40**
Farming is head's major occupation (%)	87.8	89.4	87	88
Borrowing Capacity in Birr (self-reported)	2242.48	2343.87	7492.88	7664.68
Total Land Size (in hectare)	1.87	1.75	1.82	1.88

*** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation from WB/EEA survey

The descriptive statistics also show that the probability of adopting chemical fertilizers is highest under rental contract. Chemical fertilizers were applied to 68% of parcels under rental contracts in 2006. The analogous figure is 37% for plots under wage contracts, 42% under share contracts, and 28% under autarky. In 2010, 72% of parcels under fixed rental contracts had modern fertilizers as opposed to only 39% under autarky. Chemical fertilizers were applied to 59% of plots under share contracts and wage contracts in 2010. This high use of fertilizers under share contracts was mainly driven by high fertilizer use under input-output sharing contracts.

The intensity of fertilizer use is also the highest under fixed rental contracts. In 2006, chemical fertilizer use was 104 kg per hectare for plots under fixed rental contracts as opposed to 54.7 kg per hectare and 59.8 kg per hectare under autarky and share contracts, respectively. The figure was 69 kg per hectare for wage contracts. The same pattern is observed 2010; the intensity of fertilizer use on plots of land under fixed rental and wage contracts was 96.2 kg per hectare and 64 kg per hectare, respectively. The corresponding figures are 80 kg per hectare for share contracts and 58.7 kg per hectare for plots of land under autarky.

Although the probability of adopting modern seeds and fertilizer and the intensity of fertilizer use is relatively higher under rental contracts, it is important to observe that households who adopt these two type of contracts tend to be much wealthier and more educated. This implies we cannot readily ascribe the choice contracts as the causal factor that influences the technology adoption decision of farmers. But an important observation can be made here. That is, land title reform can potentially promote technology adoption by allowing the transfer of land to farmers who are more likely to adopt new technology for various reasons. This is particularly true if land title reforms succeed in encouraging the transfer of land to wealthier and more educated farmers, and if wealth and education are believed to promote technology adoption as many studies on technology adoption show. This may be crucial if new technology is risky and wealthier farmers tend to be less risk averse.

In addition, our analysis only looks at how property rights influence the type of contract chosen, not the length of the contract. This, however, may be important in the context of learning about new technology. If reduced tenure insecurity gives landlords the incentive to rent out land for a longer period of time, this may give the opportunity for the tiller to learn more about the optimal use of the fertilizer on that specific plot of land, an opportunity he may not have under short-term contracts with different landlords, hence different plots of land.

3.4 Empirical Strategy

The econometric strategy aims at disentangling the direct impact of tenure reform on technology adoption from its indirect impact on the latter by transforming the contractual structure in agricultural production. Estimating the indirect effect of property rights on technology through its effect on contact choice involves two steps. In the first stage, we link property rights with contract choice. Here we use a semi-parametric fixed-effect estimator developed by Honore (1992). In the second stage, contract choice is linked with the decision to adopt new technology. At this stage, after estimating household fixed-effects and tobit regressions, we estimate the impact of contract choice on technology adoption employing inverse-probability weighted regression adjustment to control for the endogeneity of contracts.

To estimate the direct impact of improved property rights on technology adoption, we focus on the plots that are owned and cultivated by the household and examine if having a land certificate promotes the use of technology using the difference-in-difference estimator.

There are essentially four contract types we consider in the empirical analysis: wage contract, fixed rental contract, output-sharing contract, and input-output sharing contracts. The base category is autarky where the household uses only family labor to farm its plots.[26]

[26] Note that it is important to make a distinction between a household that does not hire labor because it is optimal to do so and a household that does not hire labor due to labor and credit market imperfections. Thus, it is important to control for adult family labor and household assets in our analysis.

Table 2 – Technology Use by Contract Type

Variable	2006				2010			
	Autarky	Wage Contract	Share Contract	Fixed Rental Contract	Autarky	Wage Contract	Share Contract	Fixed Rental Contract
Use of modern seeds	0.13	0.19	0.10	0.19	0.15	0.21	0.14	0.18
Use of modern fertilizers	0.39	0.37	0.42	0.68	0.43	0.33	0.59	0.72
Intensity of Fertilizer Use (kg/ha)	54.68	68.74	59.76	104.00	58.7	64.1	77.03	97.13
Good soil quality	0.58	0.66	0.51	0.48	0.62	0.67	0.57	0.69
Medium Soil quality	0.30	0.25	0.33	0.43	0.30	0.25	0.31	0.24
Flat Sloped	0.75	0.72	0.78	0.83	0.77	0.72	0.79	0.90
Slightly Slanted	0.20	0.25	0.19	0.14	0.20	0.24	0.19	0.09
Household Size	7.06	6.46	6.86	7.61	7.5	7.2	7.61	8.33
Head is illiterate	0.47	0.35	0.31	0.31	0.48	0.33	0.35	0.24
Female-headed household	0.09	0.17	0.03	0.05	0.11	0.10	0.03	0.04
Value of asset in Birr	828.33	1089.74	1037	1369	2503.94	3809.43	3414.61	6767.60

Source: Author's computation from WB/EEA survey

3.5 Estimating the Impact of Tenure Security on Technology Adoption through Contract Choice

This section is devoted to demonstrating how improved land rights affects technology adoption by influencing the contract choice of farmers. This involves two stages: in the first step, we examine how obtaining a land certificate affects the participation of the farmer in the land rental market. In the second stage, we investigate how the choice of land and labor contracts by the farmers influences the decision to adopt and use new technology. The section explores the impact of contracts both on the probability of adopting chemical fertilizers as well as the intensity of the use of chemical fertilizers. We first present the second stage results before discussing the results from the first stage regressions.

3.5.1 Linking Contracts and Technology Adoption

A. The Impact of Contracts on the Probability and Intensity of Technology Adoption

This section presents regression estimates of the probability of using modern fertilizers conditional on household and plot characteristics and the choice of crops. We run three initial regressions: linear probability, linear probability fixed effects model, and logit model, controlling for observable household and plot characteristics, as well as the type of crop produced by the farmer. Table 3 presents the regression results. The base outcome for contract choice is autarky. The dependent variable is a dummy variable that indicates whether the farmer used chemical fertilizers on the plot. All the regression models provide evidence that the household is more likely to use modern fertilizers under fixed rental contracts and input-output sharing contracts than under autarky and pure output sharing arrangement. In addition, as predicted by theory, all three regression results provide evidence that farmers are less likely to use modern fertilizers on plots under wage contracts.

The linear probability and logit models predict that a household is more than 20% more likely to adopt modern chemical fertilizers than under autarky. This effect goes down to 12.4% under the linear probability household fixed effects model, which controls for any time-invariant household characteristics. Since there are no moral hazard effects in both rental contracts and autarky, and we controlled for plot characteristics such as soil quality and the slope of the plot, this difference is likely from unobserved household characteristics. This is consistent with the theoretical argument presented in the previous chapter that if a land certification program is credible it has the potential to promote technology by altering the optimal contract (to rental contract) by reducing the marginal risk premium of the tenant, which results in the transfer of land to the tenant who is more efficient and will use more units of chemical fertilizer.

Next we explore how contract choice influences the intensity of fertilizer use. The results from OLS, household fixed effects, and tobit random effects regressions are reported in Table 4. We run the tobit regressions because of left censoring in the dependent variable, fertilizer use per hectare. Three robust results emerge from these regressions: (1) there is significantly higher intensity of fertilizer use under fixed rental than any other contracts (by around 30 kg per hectare than under autarky); (2) there is no evidence that the intensity of fertilizer use under output-sharing contract and input-output is different than under autarky; (3) under all contracts, the value of household and farm assets positively influences the intensity of technology use. The last observation indicates that households either have to rely on their own financial resources or use their assets to obtain credit to access technology, suggesting potential credit market imperfections in the economy.[27] The estimates of the impact of a fixed rental contract on technology adoption (relative to autarky) from the tobit random effects and ordinary least squares regression are comparable (around 35.5 kg per hectare) and higher than under the fixed effects model (30 kg per hectare) which controls for unobserved time-invariant household characteristics. Other notable results from these regression include: (1) there is positive association between mean rainfall income at village level and the use chemical fertilizers, (2) farmers seem to apply fewer units of chemical fertilizer on plots with good soil quality, suggesting a possible substitution between soil quality and chemical fertilizers,[28] (3) households headed by illiterate farmers are less likely to use chemical fertilizers, and (4) the gender and age of the household head do not seem to have any significant impact on technology adoption. These results suggest that, apart from transferring land to tenants who may

[27] In the perfect world, productions decisions should not be influenced by the household's level of wealth i.e. production decisions should be separate from consumption decisions or variables that exclusively affect consumption such as wealth.
[28] This substitution is in essence between inputs that can potentially increase soil quality (like long term use of manure) and chemical fertilizers.

be have higher entrepreneurial skill than the landlord, the land certification can promote technology adoption by allowing the transfer of land to more educated or are less risk averse farmers. In addition, while we may expect that a household is more likely to rent in a more fertile piece of land, which, if not controlled, may bias the impact of rental contract on technology use, the bias appears to be negative. Finally, holding other factors constant, intergenerational or gender-biased transfer of land, if it exists, does not seem to affect technology use. Nevertheless, the validity of the results hinges on the assumption that we have controlled for all factors that influence the choice of contracts in these regressions. Therefore, we proceed to use inverse-probability weighted regression adjustment to control for selection into different types of contracts at household level.

Table 3 – The Impact of Contract Choice on the Probability of Using Chemical Fertilizers

Variables	Linear Probability(LP)	Logit	LP Fixed Effects)
Wage contract	-0.130***	-0.163***	-0.0341**
	(0.0183)	(0.0252)	(0.0168)
Output sharing contract	0.00603	0.0128	0.0189*
	(0.0130)	(0.0161)	(0.0114)
Input-output sharing contract	0.138***	0.166***	0.119***
	(0.0267)	(0.0355)	(0.0242)
Rental contract	0.210***	0.265***	0.124***
	(0.0180)	(0.0250)	(0.0161)
Annual rainfall	0.000167***	0.000195***	9.70e-05***
	(1.25e-05)	(1.65e-05)	(1.64e-05)
Good soil quality	-0.0294**	-0.0378**	-0.0279**
	(0.0123)	(0.0156)	(0.0115)
Medium soil quality	0.00535	0.00703	-0.00576
	(0.0128)	(0.0164)	(0.0117)
Flat slope	0.0341	0.0471*	0.0240
	(0.0217)	(0.0286)	(0.0192)
Slightly slanted slope	-0.0239	-0.0308	0.0184
	(0.0226)	(0.0299)	(0.0200)
Value of farm and household assets in thousands of birr	0.00828***	0.0130***	0.00198**
	(0.000868)	(0.00138)	(0.000988)
Household head is illiterate	-0.0596***	-0.0716***	-0.0501***
	(0.00782)	(0.0102)	(0.0103)
Dummy for use of hired labor	0.159***	0.197***	0.122***
	(0.00900)	(0.0118)	(0.00840)
Female-headed household	0.0109	0.0120	-0.0150
	(0.0122)	(0.0157)	(0.0184)
Age of household head	0.000337	0.000343	-0.000456
	(0.000290)	(0.000380)	(0.000472)
Dummy for vegetables	0.0811***	0.156***	0.0385***
	(0.0147)	(0.0208)	(0.0133)
Dummy for fruits	-0.0826***	-0.0944***	-0.0844***
	(0.0218)	(0.0325)	(0.0192)
Dummy for spices	0.0577	0.0948*	0.0415
	(0.0413)	(0.0549)	(0.0350)
Dummy for tree c	-0.167***	-0.267***	-0.0994***
	(0.0116)	(0.0173)	(0.0111)
Dummy for oilseeds	-0.00685	0.00922	-0.0384**
	(0.0218)	(0.0321)	(0.0189)
Dummy for beans	0.0387***	0.0864***	0.00804
	(0.0104)	(0.0144)	(0.00917)
Dummy for cereals	0.441***	0.633***	0.394***
	(0.00975)	(0.0158)	(0.00882)
Constant	-0.175***		-0.0691*
	(0.0315)		(0.0385)
Observations	15,576	15,576	15,576
R-squared	0.241		

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 4 – The Impact of Contract Choice on the Intensity of Fertilizer Use (in kg/hectare)

Variables	(OLS)	(Fixed Effects)	(Tobit Random Effects)
Wage contract	-7.208	-7.638	-14.58***
	(10.46)	(6.567)	(4.762)
Output sharing contract	-0.310	-0.0752	2.349
	(6.024)	(4.628)	(3.202)
Input-output sharing contract	-0.179	1.006	14.33**
	(10.55)	(9.590)	(6.121)
Rental contract	35.13***	29.99***	35.50***
	(8.940)	(6.436)	(4.089)
Annual rainfall	0.0305	0.0267***	0.0272***
	(0.0184)	(0.00480)	(0.00312)
Good soil quality	-7.993	-6.296	-8.097***
	(9.486)	(4.433)	(3.022)
Medium soil quality	-1.409	-0.841	-0.368
	(7.606)	(4.604)	(3.171)
Flat slope	11.17	9.724	9.346*
	(8.748)	(7.715)	(5.495)
Slightly slanted slope	-0.277	1.538	-3.587
	(7.269)	(8.042)	(5.757)
Value of farm and household assets in thousands of birr	1.486**	1.207***	1.471***
	(0.604)	(0.332)	(0.205)
Household head is illiterate	-3.736	-3.929	-9.074***
	(4.759)	(3.019)	(1.962)
Dummy for use of hired labor	31.46***	29.21***	31.03***
	(7.081)	(3.233)	(2.159)
Female-headed household	-3.398	-3.629	0.159
	(4.906)	(4.711)	(3.051)
Age of household head	0.000453	0.000936	0.0408
	(0.163)	(0.114)	(0.0736)
Dummy for vegetables	3.213	1.893	25.42***
	(7.282)	(5.187)	(3.863)
Dummy for fruits	-19.08**	-17.54**	-14.71**
	(7.810)	(7.653)	(6.440)
Dummy for spices	-7.606	-7.604	12.80
	(8.222)	(14.44)	(10.19)
Dummy Tree crops	-31.17***	-29.22***	-50.64***
	(6.920)	(4.165)	(3.370)
Dummy for oilseeds	-23.40*	-22.99***	-10.96*
	(11.79)	(7.667)	(6.091)
Dummy for beans	-20.00***	-20.60***	1.312
	(5.701)	(3.669)	(2.658)
Dummy for cereals	45.24***	44.31***	100.5***
	(5.507)	(3.465)	(2.897)
Constant	-29.62	-25.95**	
	(22.14)	(11.64)	
Observations	15,576	15,576	15,576

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

B. Endogenous Contracts –Inverse-Probability Weighted Regression Adjustment

In this section, we control for selection into different contract types and estimate the average treatment effect of each contract type on the intensity of fertilizer use. This involves two steps. In the first stage we estimate a multinomial logit model to obtain the probability of adopting a specific type of contract type t, $p(z,t,\gamma)$.

$$p(z,t,\gamma) = \frac{\exp(z\gamma_t)}{1+\sum_{k=1}^{q} z\gamma_k} \quad \text{and} \quad \gamma' = (\gamma'_1, \gamma'_2, ..., \gamma'_q), \tag{16}$$

where z represents household, plot, and village characteristics including whether the land certification program has started in the village which determine selection to specific contract type (t) and γ_t represents the regression parameters in the multinomial logit model. The inverse-probability weighted regression adjustment uses weighted regression coefficients to estimate the average treatment effect. The weight of each person, w_i in the treatment level (type) t is computed using the inverse probabilities of treatment as:

$$w_i(t) = \frac{t_i(t)}{p(z,t,\hat{\gamma})}\left(\frac{t_i(t)}{p(z,t,\hat{\gamma})} - 1\right) \tag{17}$$

That is, the weight attached to a specific plot owned by a household with given characteristics is inversely proportional to the probability of selection in to a specific contract. The average treatment effects (ATE) of contract choice on technology use is defined as:

$$ATE_t = E(y_t - y_0), \text{for } \ t \in \{\text{wage}_c, \text{rental}_c, \text{output} - \text{sharing}_c, \text{input} - \text{outputsharing}_c\} \tag{18}$$

where y_t is the potential outcome of intensity of technology use under contract t, and y_0 is the potential outcome of technology use under autarky. The average treatment effects estimated using inverse-probability weighted regression adjustment is presented in Table 5.

Accordingly, using autarky as control group, we find an average treatment effect of 34 kg per hectare for rental contract, slightly lower than the OLS and tobit random effects estimates we obtained earlier. Nevertheless, we do not find differences in the intensity of fertilizer use among other types of contracts.

The results suggest the land certification program promotes technology adoption by encouraging land transfer to farmers who are more likely to use chemical fertilizers. Therefore, to link with the theory, the higher use of chemical fertilizers is mainly due to gains from trade rather than incentive effect i.e. the absence of moral hazard problem in rental contract. The lack of any significant difference in the intensity of use of technology between sharecropping contracts versus farmers who cultivate their farm using family labor also supports this argument.[29]

Table 5 – The Impact of Contract Choice on Intensity of Fertilizer Use: Inverse-probability weighted regression adjustment ***(dependent variable is fertilizer use in kg/hectare)***

VARIABLES	Average Treatment Effect	Potential Outcome Mean
Output sharing vs. control group	4.926	
	(7.982)	
Input-Output Sharing vs. control group	9.660	
	(9.430)	
Rental contract vs. control group	34.45***	
	(8.538)	
Wage contract vs. control group	-6.659	
	(6.698)	
Autarky (Control group)		63.74***
		(6.580)

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

[29] If the tenant manages the farm under sharecropping contract, the results potentially mean that the gains from trade and incentive effects cancel each other, i.e., while under sharecropping land is potentially transferred to tenants who may be more likely to use fertilizer but the contract is plagued by moral hazard problems that discourage the use of chemical fertilizers.

3.5.2 Linking Property Rights and Contract Choice

This section examines the factors that influence the choice of contracts using the semi parametric tobit fixed effects estimator developed by Honore (1992) to link improved tenure security and participation in the rental market. The method allows us to deal with censoring of the dependent variable but also at the same time control for unobserved time-invariant household characteristics. The results of this regression are presented in Table 6. The dependent variable is the ratio of land that is either rented in or rented out by the household to the total land owned and operated by the same household, with a view to capture the participation of the household in the land rental market. Because households who have land certificates may be different in some unobservable characteristics than households who do not have certificates, and that can potentially bias the econometric results, we use whether the land certification program started in the village or not, which is exogenous to the household, to measure the level of property rights enjoyed by the household. Accordingly, we find strong evidence that shows that the introduction of the land certification program have significantly increased the participation of households in the land rental market. More specifically, on average the introduction of the land certification program is associated with an increase in the proportion of land under rental contract by more than a third of initial total household land holding, controlling for household assets, ownership of cattle, and the age and gender of the head of the household.

Table 6 – The Impact of Land Certification on Land Rental Market Participation: Semi-Parametric Tobit Fixed Estimates (dependent variable is the ratio of total land rented-in or rented-out to total cultivated land)

VARIABLES	Model 1	Model 2	Model 3
Certification program started in village	0.304*	0.274*	0.386**
	(0.156)	(0.148)	(0.184)
Values of farm and household assets			5.87e-06
			(1.02e-05)
Total land holdings	-0.622**	-0.672**	-0.744**
	(0.297)	(0.338)	(0.354)
Female-headed household		-2.778	-2.813
		(4.590)	(3.273)
Age of Household Head		0.0566	0.0484
		(0.0677)	(0.0568)
Household Size		0.0379	0.0536
		(0.116)	(0.118)
Household owns cattle			-0.126
			(0.262)
Observations	2315	2315	2315

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

3.6 Estimating the Direct Impact of Tenure Security on Technology Adoption

This section presents empirical evidence on the relationship between the household's choice of contract and the decision to adopt technology. We run a difference-in-difference estimator given by the following equation

$$y_i = \beta_0 + \beta_1 year_{2010} + \beta_2 * treated_i + \delta year_{2010} * treated_i + \beta'_k Z_{k,i} + e_i$$

where y_i denotes fertilizer use (in kg per hectare) by household i, $treated_i$ is a dummy variable that takes 1 if the household has certificate on the land it cultivates and 0 otherwise. $Z_{k,i}$ represents a vector of household and plot characteristics. The results of the regression are presented in Table 7. I include regional dummies to control for land scarcity and differences in administrative capacity in implementing the land certification program among the different regional states in the country. Accordingly, we do not find any statistically significant impact of improved tenure security on technology adoption. This, however, is not surprising for the following reasons: (1) the land certification program does not allow farmers to use their land as collateral, and thus does not improve their access to credit; (2) investment in chemical fertilizer, unlike in organic fertilizer, does not have any positive long-lasting impact on soil quality. Therefore, unless the risk of expropriation is very extreme, one may not expect improved tenure security to significantly boost the use of chemical fertilizers in a given production cycle. As can be seen in Table 7, and consistent with the previous regression results, we find that the value of household and farm assets play a significant role in influencing the intensity of the use of chemical fertilizers. Thus, the results suggest that the fact that farmers are not allowed to use their land as collateral has limited the direct impact of the land certification program on technology adoption.

The statistical analyses in the above two sections demonstrate that the main channel through which improved property rights promotes the adoption of chemical fertilizers is by transforming the contractual structure in the economy.

Table 7 – Estimating Direct Impact of Land Certification on Intensity of Fertilizer Use:-Difference-in-Difference Estimators *(Dependent Variable is Fertilizer Use in kg per hectare)*

VARIABLES	(Model)	(Model 2)	(Model 3)
Dummy for year 2010	-1.026	-4.197	-1.265
	(11.21)	(10.10)	(10.11)
Obtained certificate in 2006	-8.450***	-13.00***	-15.86***
	(3.273)	(3.003)	(3.025)
Difference-in-Difference estimator	**0.397**	**4.420**	**3.735**
	(11.11)	(10.00)	(10.01)
Total land holding	-5.498***	-5.914***	-7.653***
	(2.083)	(1.881)	(1.870)
Land rented or shared out	-4.931	-3.332	-2.005
	(3.501)	(3.188)	(3.370)
Land rented in or shared in	4.401**	1.978	-1.266
	(1.970)	(1.825)	(1.845)
Female-headed household		3.591	3.806
		(3.970)	(3.991)
Age of household head		-0.0995	-0.148
		(0.105)	(0.105)
Plot's distance from home			-0.0115
			(0.0319)
Proportion of flat slope land			-0.343
			(6.229)
Proportion of land slightly slanted slope			-17.31***
			(6.700)
Value of farm and household assets in thousands of birr			1.046***
			(0.321)
Household size		1.907***	1.893***
		(0.470)	(0.473)
Household head is illiterate		-5.671**	-4.085*
		(2.442)	(2.431)
Farming is head's major occupation		-1.046	-0.750
		(4.055)	(4.090)
Roof is corrugated sheet		16.55***	15.86***
		(2.478)	(2.552)
Number of rooms		-0.950	-1.816*
		(0.892)	(1.083)
Received credit		3.218*	3.019*
		(1.677)	(1.679)
Annual rainfall			0.0321***
			(0.00397)
Proportion of land with good soil quality	-6.366	-4.226	-4.964
	(5.019)	(4.628)	(4.713)
Proportion of land with medium soil quality	4.301	3.464	2.747
	(5.418)	(4.972)	(4.991)
Land is irrigated	-12.74*	-14.83**	-9.868*
	(6.541)	(5.961)	(5.973)
Constant	31.89***	15.76*	-19.09
	(7.461)	(9.578)	(11.93)
R-squared	0.059	0.097	0.144

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.7 Conclusion

Cross-country empirical studies in economic growth identify technological progress as the single most important determinant of long-run economic performance. Because advances in cutting-edge technology by and large take place in developed countries, many argue that the success of developing economies in raising overall productivity, including in the agricultural sector, depends on their ability to import and adapt existing technology from developed countries to their local conditions. Given this premise, it follow that investigating factors that influence technology adoption in the agricultural sector in developing economies is indispensable to understanding the determinants of productivity in the sector and from the standpoint of designing economic policy. In addition, because a significant section of the population in developing economies derives its livelihood from the agricultural sector directly or indirectly, and that sector is the major source of savings and foreign exchange earnings in these economies, understanding the process of technology adoption in the agricultural is very crucial to understanding the process of overall economic growth in developing countries.

The present study attempts to directly link property rights and technology adoption at the microeconomic level and carefully identify the specific mechanisms through which improved property rights influence the adoption of new technology in Ethiopian agriculture. We argue that an important channel through which improved land rights influences technology adoption is by altering the optimal contractual arrangement economic farmers enter into. The research shows that improved land rights promotes technology adoption by altering the agrarian contractual structure by lowering land transfer costs and reducing the risk of expropriation which in turn influences the land and labor contracts farmers choose. These contracts in turn affect technology adoption by influencing the incentive structure and creating opportunities for trade. The econometric results demonstrate improved property rights in Ethiopia have their greatest effect on the adoption of chemical fertilizers by transforming the agrarian contractual structure. The empirical results suggest that the direct impact of tenure security on technology adoption is limited because the specific tenure reform considered here does not allow farmers to use their land as collateral, and hence its impact on technology adoption by improving farmers' access to credit is limited.

Unlike previous studies on technology adoption, the study goes beyond the proximate determinants of technology adoption, and offers microeconomic evidence supporting the view that property rights institutions are the underlying determinants of technology adoption. In addition, the paper identifies an important mechanism, contract choice, through which property rights institutions influence technology adoption, and by doing so it promotes our understanding on the interaction between property rights institutions and contracting institutions.

At a policy level, the results suggest that the impact of land reforms on agricultural productivity is pronounced if these reforms address imperfections in the credit and land rental market, and if tenure reforms allow farmers to use their land as collateral.

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Chapter 4

Agricultural Extension and Technology Adoption: Evidence from Ethiopia

4.1 Introduction

The Ethiopian agricultural sector accounts for roughly 43% the country's GDP and contributes to over 90% its total export earnings. However, the sector is marked by abysmal levels of productivity, and millions of rural households in the country are chronically food insecure. For instance, the Ethiopian government estimates that around 3 million people in the country needed emergency food relief assistance this year (Disaster Prevention and Preparedness Commission, 2015).

Many observers argue that limited technical progress in the agricultural sector, which is largely dominated by small farms owned by households, explains the observed low productivity in the sector. It is with this understanding that the current government of Ethiopia designed and implemented the extension program with the primary objective of promoting productivity mainly through the transfer of modern technology to farmers.

The Ethiopian agricultural extension program receives the lion's share of total government expenditure in the agricultural sector, and it is backed by several multinational development organizations and bilateral donors, as the agricultural sector provides the livelihood for over 80% of the estimated 94 million people in the country and is considered a priority sector in the fight against poverty.

In this chapter we employ propensity score matching and inverse probability weighting methods to evaluate the impact of the Ethiopian agricultural extension program in promoting the adoption of chemical fertilizers. Our empirical results show that the Ethiopian extension program increases both the likelihood of chemical fertilizer adoption and enhances the intensity of fertilizer use by farmers, but the impact is heterogeneous across households

The chapter is organized as follows. In section 4.2, we provide background and institutional context to the Ethiopian agricultural extension program. Section 4.3 offers a simple theoretical framework that guides the empirical research. In Section 4.4, we describe the data and provide descriptive statistics. Section 4.5 outlines the empirical strategy for the study. Section 4.6 presents the econometric results and analysis of the results. Section 4.7 concludes the paper.

4.2 The Ethiopian Agricultural Extension Program: Background and Institutional Context

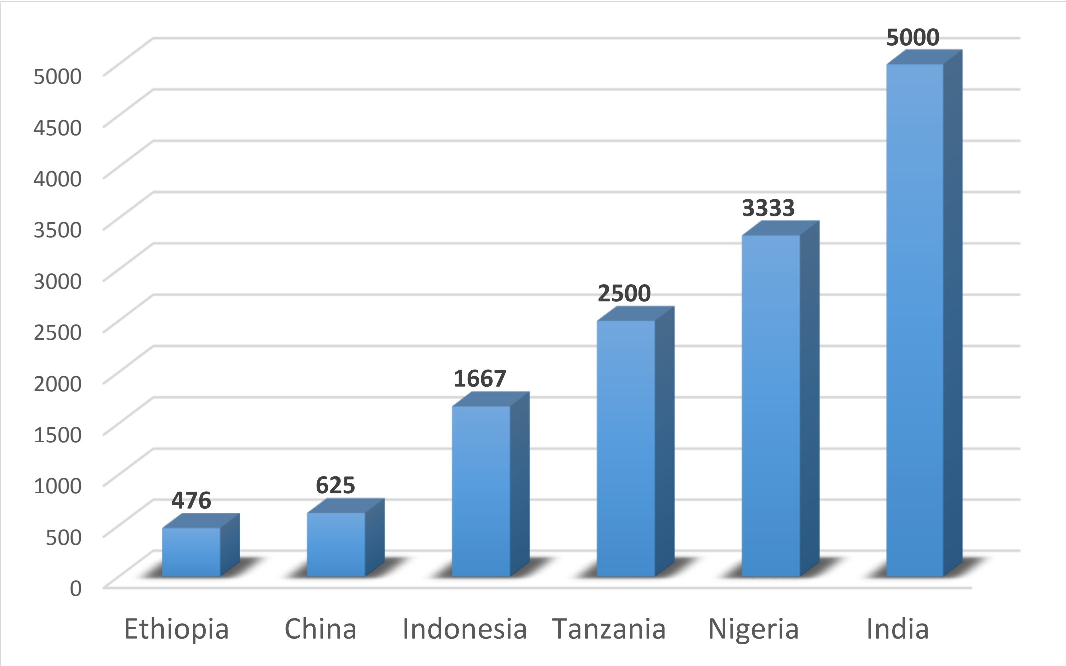
The official goal of the Ethiopian Extension Program is to improve farmers' welfare and accelerate growth in the agricultural sector by promoting the transfer and continued adoption of modern technologies and best farming practices. The program provides extension services in crop and livestock production, as well as in the management of natural resources.

Technology transfer is mainly done through extension agents known as Development Agents (DAs), who provide home visit services and at the same time demonstrate technology in Farmer Training Centers (FTCs). In 2010 there were on Average 21 DAs per 10,000 farmers. DAs operate throughout the country in over 10,000 FTCs. A typical FTC consists of a building with a training room and DA offices, a demonstration plot and in some instances DA housing. The program envisions having three DAs deployed to an FTC, who provide advice and services to groups of farmers, although the number is usually lower in practice. A survey by Gebresilasie (2014) in Northern Ethiopia shows that 66% of the surveyed DAs made weekly or bi-weekly visits to farmers participating the extension program, while the rest DAs reported their visits are less frequent than that.

The technologies and practices the DAs try to popularize include inputs (e.g., seed, fertilizer and pesticides), agronomic practices (e.g., method and time of planting, rate and type of fertilizer application, weeding and time and method of harvesting) and mechanization (e.g. sowing or row planting machines and threshers).

Because of the key role played by DAs in the dissemination and popularization of technologies, the government has also launched the Agricultural Technical and Vocational Education and Training (ATVETs) to strengthen the human resource capacity of the extension system. In 2013, twenty-five ATVETs and seven Higher Learning Institutes (HLIs) were giving agriculture-related training to meet the human resource needs of the extension system. Gebresilasie (2014) shows that 42% of the DAs in Northern Ethiopia have bachelor degrees and the remaining have diplomas in various agriculture related disciplines including plant science, animal science and natural resource management.

Figure 2 – Number of Farmers Per Extension Worker in Selected Countries



Source: Davis et al., 2010

Currently, there are 10,400 FTCs, and the Government is planning is to build a total of 18,000 FTCs in the country. About 73,000 DAs have been trained as of 2013 and about 46,000 are deployed to FTCs in different regions of the country. Davis et al. (2010) report that Ethiopia has one of the highest DA-farmer ratios in the world, with roughly one DA for every 476 farmers (figure 2), Currently about 95% of the employed DAs are deployed in four regions of the country: Oromia, Southern Nations, Nationalities and Peoples (SNNPR), Amhara and Tigray, on which this study focuses.

Official documents show that Ethiopian agricultural extension system is broken down into three major components: field-level execution, higher-level organization, and institutions that are designed to provide an enabling environment. At the field level, extension is provided through FTCs, which serve as information, training and demonstration centers.

The Ministry of Agriculture, with its regional and woreda structures, directs and oversees the overall implementation of the extension program by developing guidelines and manuals in the country-wide execution of the program.[30] The woreda is the administrative structure where extension services are designed, financed, delivered. Woredas also help synchronize regional and local level planning of the extension program. Regional Bureaus of Agriculture develop packages and provide support to woreda offices of agriculture in delivering extension services. In some regions, zonal offices of agriculture provide coordination and technical support role for woreda offices of agriculture.[31]

[30] These represent local administrative structures; there are around 740 administrative woredas in the country.
[31] There are nine regional administrations and 69 zones in the country.

FTCs are managed at the kebele level with funding for capital items, operations and DA salaries coming from the woreda level.[32] The government guidelines stipulates that FTCs should be led by management committees (MCs), which consist of a kebele administrator, DAs residing at the kebele, women representatives, and farmer representatives. However, the government's own reports indicate that only 42% of the FTCs reported to have MCs that are responsible for overall management and operations of the training centers, and from the total established MCs only about 21% were operational, which limit active participation of farmers in the decision making process in the execution of the extension program.

In addition to these problems, Lemma et al. (2011) report that that only 56% of the demonstration plots were suitable, 19% of the FTCs did not have demonstration plots at all, and the remaining 25% of the FTCs had unsuitable plots. Davis et al. (2010) also report that a significant number of FTCs were not functional in the four regional states we study (See Table 1).

Table 8 – Number and Status of Established FTCs in Regional States

Region	Established FTCS	Functional FTCs	Number of DAs
Tigray	588	55(9.4%)	2,067
Oromiya	2549	1147(45%)	19,654
Amhara	1725	318(18.4%)	10196
SNNPR	1610	857(53.2%)	11,061

Source: Davis et al., 2010

Farmer organizations, particularly cooperatives, play a major role in the supply of inputs. There are around 10,000 primary agricultural cooperatives and 160 agricultural cooperative unions in the country, serving as distribution outlets for public and private seed producers. In addition, Non-

[32] Kebeles are the lowest forms of government in the country.

Governmental Organizations (NGOs) such as Oxfam America and SG 2000 partake in agricultural extension programs in strengthening FTCs. Agriculture Development Partners Linkage Advisory Council (ADPLAC) offers as linkage forum for the actors in the technology system. In addition to the federal level, ADPLAC offices are set up in 55 zones of the country and 302 woredas as of 2012.

Finally, the National Agricultural Research System (NARS) plays an important role in the extension system by developing new technologies and improved practices that are multiplied and delivered to farmers. The NARS is comprised of Ethiopian Institute for Agricultural Research (EIAR), Regional Agricultural Research Institutes (RARIs) and HLIs. There are 55 research centers, sub-centers and testing sites located at different agro-ecologies of the country.

Although there are several players in the extension system whose performance may affect the effectiveness of the extension program, our empirical analysis only looks at whether a household's participation in the extension program increases the use of chemical fertilizer on the plot the household cultivates.[33]

4.3 A Simple Theoretical Framework

Consider a farmer who cultivates a fixed plot of land using labor, l, and chemical fertilizer, x. Suppose the production function of the farmer is given by $Q(l, Ax)$, where $A > 0$ represents the human capital that the farmer possesses in utilizing the technology (chemical fertilizers), which partly depends on public investment in agricultural extension programs, I, and other individual characteristics of the farmer, Z. We assume technical training and demonstrations the farmer receives from agricultural extension agents increase her human capital, A, but the impact

[33] Although there is a strategy in place by the government to encourage private sector participation in the extension program, currently the government is the only provider of extension services in the country.

decreases as investment in the program expands. That is, $\frac{\partial A(I,Z)}{\partial I} > 0$ and $\frac{\partial^2 A(I,Z)}{\partial I^2} < 0$. (This assumption is consistent with some of the evidence in the literature that that shows the impact of extension programs is greater at initial stages where information disequilibrium is high.)

The objective of the farmer is to maximize her farm profit, which is given by:

$\pi = Q(l, A(I,Z)x) - wl - p_x x$, where w and p_x represent the price of labor and fertilizer, respectively. For convenience, we normalize the price of output to 1.

The first order conditions of the farmer's profit maximization are:

$$\frac{\partial \pi}{\partial x} = A(I,Z)\frac{\partial Q}{\partial x} - p_x = 0 \qquad (1)$$

$$\frac{\partial \pi}{\partial l} = \frac{\partial Q}{\partial l} - w = 0 \qquad (2)$$

Let's denote $x^* = x(p, w, A(I,Z))$ and $l^* = l(p, w, A(I,Z))$ as the solutions of the farmer's optimization problem. To understand how the increase in public investment in agricultural extension influences the demand for chemical fertilizers, we differentiate the fertilizer demand function with respect to I. This yields,

$$\frac{\partial x^*}{\partial I} = \frac{\partial x^*}{\partial A}\frac{\partial A(I,Z)}{\partial I}$$

Where, $\frac{\partial A(I,Z)}{\partial I}$ is positive by assumption. Hence, the sign of $\frac{\partial x^*}{\partial I}$ depends on the sign of $\frac{\partial x^*}{\partial A}$.

This can be obtained by totally differentiating (1) and (2) with respect to A. This yields:

$$\frac{\partial Q}{\partial x} + A\left(\frac{\partial^2 Q}{\partial x^2}\frac{\partial x^*}{\partial A} + \frac{\partial^2 Q}{\partial x \partial l}\frac{\partial l^*}{\partial A}\right) = 0$$

$$\frac{\partial^2 Q}{\partial l \partial x}\frac{\partial x^*}{\partial A} + \frac{\partial^2 Q}{\partial l^2}\frac{\partial l^*}{\partial A} = 0$$

Rearranging terms we get and expressing the system of equation in matrix notation yields,

$$\begin{bmatrix} \frac{\partial^2 Q}{\partial x^2} & \frac{\partial^2 Q}{\partial x \partial l} \\ \frac{\partial^2 Q}{\partial l \partial x} & \frac{\partial^2 Q}{\partial l^2} \end{bmatrix} \begin{bmatrix} \frac{\partial x^*}{\partial A} \\ \frac{\partial l^*}{\partial A} \end{bmatrix} = \begin{bmatrix} -\frac{\partial Q}{\partial x} / A \\ 0 \end{bmatrix}$$

Solving for $\frac{\partial x^*}{\partial A}$ using Cramer's rule yields:

$$\frac{\partial x^*}{\partial A} = \frac{\begin{vmatrix} -\frac{\partial Q}{\partial x} / A & \frac{\partial^2 Q}{\partial x \partial l} \\ 0 & \frac{\partial^2 Q}{\partial l^2} \end{vmatrix}}{H} = \frac{\left(-\frac{\partial Q}{\partial x} / A \right) \left(\frac{\partial^2 Q}{\partial l^2} \right)}{H} > 0 \tag{3}$$

Where $H = \begin{vmatrix} \frac{\partial^2 Q}{\partial x^2} & \frac{\partial^2 Q}{\partial x \partial l} \\ \frac{\partial^2 Q}{\partial l \partial x} & \frac{\partial^2 Q}{\partial l^2} \end{vmatrix} > 0$ (i.e. positive definite) and $\frac{\partial^2 Q}{\partial l^2} < 0$ as the production function is assumed to be strictly concave.

Therefore, $\frac{\partial x^*}{\partial I} = \frac{\partial x^*}{\partial A} \frac{\partial A(Z, I)}{\partial I} > 0$. Note that the magnitude of the impact of investment in public extension programs on the demand for chemical fertilizers also depends on a vector of individual characteristics, Z, signifying the possible heterogeneous impact of agricultural extension programs on farmers with different characteristics.

To see the impact of the extension program on the farmer's income, we differentiate the profit function at the optimum with respect to I. We get,

$$\frac{\partial \pi^*}{\partial I} = \frac{\partial Q}{\partial l} \frac{\partial l^*}{\partial I} + \frac{\partial Q}{\partial x} \left(\frac{\partial A(\bullet)}{\partial I} x^* + A \frac{\partial x^*}{\partial I} \right) - w \frac{\partial l^*}{\partial I} - p \frac{\partial x^*}{\partial I} \tag{4}$$

Rearranging (4) and using (1) and (2) in equation (4) yields,

$$\frac{\partial \pi^*}{\partial I} = \left(\frac{\partial Q}{\partial l} - w \right) \frac{\partial l^*}{\partial I} + \left(A \frac{\partial Q}{\partial x} - p \right) \frac{\partial x^*}{\partial I} + \frac{\partial Q}{\partial x} \frac{\partial A(\bullet)}{\partial I} x^* = \frac{\partial Q}{\partial x} \frac{\partial A(\bullet)}{\partial I} x^* > 0. \tag{5}$$

Therefore, (4) and (5) show that if the technical training received through the extension program enhances the farmer's human capital, it will increase her demand for chemical fertilizers and ultimately raise her income. Nevertheless, the magnitude of the impact also depends on the individual characteristics of the farmer.

4.4 Data and Descriptive Statistics

The data for the study were obtained from household surveys conducted by the World Bank (WB) and Ethiopian Economic Association (EEA) in 2010. These surveys cover 2308 households that are randomly selected from 115 rural Ethiopian villages in four regional states in Ethiopia: Amhara, Oromia, Southern Nations, Nationalities and Peoples (SNNP), and Tigray.[34] The population in these regions accounted for 86% of the estimated 79.7 million population of Ethiopia in 2010.[35] We obtained rainfall data for about 184 stations in the country from the Ethiopian National Meteorology Agency.[36]

In 2010, around 40% of households in the four regional states participated in the Ethiopian agricultural extension program. Table 9 compares the characteristics of households who have participated in the Ethiopian agricultural extension program against non-participating households in 2010. This reveals a stark difference in observable characteristics between the two groups. With an average value of farm and household assets worth Birr 3534, households participating in the extension program are relatively wealthier than non-participants, who reported a corresponding asset value of Birr 1751. This is also consistent with the fact that the a higher percentage of extension participants live in houses with a roof made of corrugated sheet, a sign of wealth and status in rural Ethiopia (as opposed to living in grass-roofed huts). In addition, the heads of household who participated in the Ethiopian agricultural extension program are relatively more

[34] Ethiopia is a federal republic with 7 regional states and 2 chartered cities.
[35] Currently, the population of Ethiopia is estimated to be around 94.1 million, making the country the second most populous country in Africa after Nigeria.
[36] Based on the geographic coordinates of the villages and stations, I computed the distance between each station and the villages in the sample and assigned the rainfall data of the nearest station to each village.

literate (around 40 % of participating household heads are illiterate as opposed to 55% among non-participants). Furthermore, a higher percentage of households who have not participated in the extension program are female-headed. In terms of access to credit, only 3.6% non-participants received some kind of credit during 2010 as opposed to 9.5% of households who participated in the extension program. Regarding occupational choice, while both sets of households are predominantly farmers, a relatively higher percentage of participant households (90%) reported farming as their major occupation in 2010. The figure is lower for non-participants at 85%.

Table 9 – Household Characteristics By Treatment

Variables	Extension	No Extension
Number	918 (39.8%)	1390(60.2%)
Household Size	**7.42**	**7.07*** **
Head is Illiterate (%)	**40.7**	**55.1*** **
Value of Farm and Household Asset in Birr	**3536.4**	**1750.9*** **
Age of Household Head	**50**	**51.9*** **
Female Headed Household (%)	**11.4**	**18.3*** **
Male Adult Labor in Household[37]	**2.14**	**1.95*** **
Female Adult Labor in Household	**1.95**	**1.88**
Roof is corrugated metal (%)	**74.3**	**65.3*** **
Number of Rooms	**2.54**	**2.14*** **
Farming is head's major occupation (%)	**90.0**	**85.2*** **
Received Credit (%)	**9.5**	**3.6*** **

*** p<0.01, ** p<0.05, * p<0.1
Source: Author's computation from WB/EEA survey

Table 10 presents descriptive statistics on the choice of technology and plot characteristics by treatment. Among participants, 77% have used chemical fertilizers on their plots as opposed to only 50.1% for non-participating households. Similarly, only 18% of non-participants have used a high-yield variety crop while 50% of households who participated in the extension program have

[37] Male and Female adult labor simply represent the number of male and female adults in the household.

done so. There is also statistically significant difference in the intensity of fertilizer use among the two groups; fertilizer use among extension participants is around 62.5 kg per hectare compared to 45 kg per hectare by non-participants. In terms of land holdings, the average size of land among participants is higher (2.24 hectare) when compared to that of non-participants (1.68 hectare). Interestingly, the proportion of land with good soil quality among non-participants is higher among non-participating households. Finally, Table 10 shows that non-participating households on average tend live in villages with lower average annual rainfall.

Table 10 – Plot Characteristics and Technology Choice

Variables	2010	
	Extension	**No Extension**
Use of modern seeds (%)	50	18.4***
Use of modern fertilizers (%)	76.8	50.1***
Intensity of Fertilizer Use (kg/ha)	62.5	45***
Proportion of Land with good soil quality	56	62.2***
Proportion of Land with medium Soil quality	32.4	23.9***
Proportion of land Flat Sloped	74.9	73.6**
Proportion of Slightly Slanted	20.1	15.5***
Annual Rainfall(in mm)	710.6	622***
Total Land Size (hectares)	2.24	1.68***

*** p<0.01, ** p<0.05, * p<0.1
Source: Author's computation from WB/EEA survey

4.5 Empirical Strategy

We employ the propensity score matching and inverse probability weighting methods to estimate the average treatment effect and the average treatment effect of the extension program on the treated. The propensity score matching method involves two steps: (1) estimate the conditional probability of participating in the extension program (the propensity score), and (2) compute the difference in the average value of the outcome of interest between participant and non-participant households who have equal probability of being selected into the program. The inverse probability weighting method also relies on estimating the propensity score for each household but the weight assigned to the outcome of interest in computing the average treatment effect is inversely proportional to the estimated propensity score of each household.

Both methods employ the counterfactual framework to estimate the causal effect of the program on the outcome of interest. Thus, denote $Y_i(1)$ and $Y_i(0)$ as the potential fertilizer use per hectare for household i if the household participates and does not participate in the Ethiopian agricultural extension program, respectively. Furthermore, we denote the vector of household and plot characteristics (or pretreatment variables that influence selection into treatment) by X_i. The treatment status of household i is denoted by W_i such that $W_i = 1$ if the household participated in the extension program and $W_i = 0$ otherwise. Therefore, we can describe realized fertilizer use per hectare, Y_i, as :

$$Y_i \equiv Y_i(W_i) = \begin{cases} Y_i(0) \text{ if } W_i = 0 \\ Y_i(1) \text{ if } W_i = 1 \end{cases}$$

Our objective is to estimate two parameters: the average treatment effect, τ, and the average treatment effect on the treated, τ_t. Formally,

$$\tau_t = E[Y_i(1) - Y_i(0)] \text{ and } \tau_t = E[Y_i(1) - Y_i(0) \mid W_i = 1]$$

The fundamental estimation problem in this counterfactual framework is that we only observe the household in one state, i.e., either as a participant in the extension program or not.

Now let's define the propensity score, $e(X_i)$, as the conditional probability of receiving treatment: $e(X_i) = \Pr(W_i = 1 \mid X_i = x) = E(W_i \mid X_i = x)$. Rosenbaum and Rubin (1983) and Rosenbaum

(2002) show that the treatment assignment and observed pretreatment covariates are independent given the propensity score. That is, $X_i \perp W_i \mid e(X_i)$.[38]

In addition, the results of Rosenbaum and Rubin (1983) show that the average difference of fertilizer use per hectare between participant and non-participant households is an unbiased estimate of the average treatment effect of the extension program at the propensity score under the following two assumptions:

<u>Assumption 1</u>: Ignorable Treatment Assignment: $\left(Y_i(0), Y_i(1)\right) \perp W_i \mid X_i$

This assumption says the potential fertilizer use per hectare is independent of selection into the agricultural extension program conditional on pretreatment covariates.

If Assumption 1 holds Rosenbaum and Rubin show that $\left(Y_i(0), Y_i(1)\right) \perp W_i \mid e(X_i)$. That is the potential fertilizer use per hectare is independent of selection into the agricultural extension program conditional on the propensity score. This result allows us to estimate the average treatment effect of the extension program by matching based on the propensity score instead of matching by pre-treatment covariates, thus solving the dimensionality problem one would face if matching is to be done based on multiple covariates.

<u>Assumption 2</u>: Overlap: $0 < \Pr(W_i = 1 \mid X_i) < 1$.

The assumption states the requirement that each household has a positive probability of being selected into the treatment group, i.e., in the extension program.

We follow Abadie and Imbens (2015) to estimate the average treatment effect by matching households by their estimated propensity score. This estimator is given as:

[38] The sign $\perp$ is read as "orthogonal to", signifying independence between the variables.

$$\hat{\tau} = \frac{1}{N}\sum_{i=1}^{N}(2W_i - 1)\left(Y_i - \frac{1}{M}\sum_{j\in\Gamma_M(i,\hat{\theta}_N)} Y_j\right)$$

Where θ is the estimated parameters in the propensity score model $\hat{e}(X) = F(X'\hat{\theta})$, M is the number of matches per unit and $\Gamma_M\left(i,\hat{\theta}\right)$ is the set of matches for household i

We use the logit model to estimate the propensity score. That is, $F(X'\hat{\theta}) = \dfrac{\exp(X'\hat{\theta})}{1+\exp(X'\hat{\theta})}$

Thus, the average treatment effect on the treated is given as: $\hat{\tau}_{ate} = \dfrac{1}{N}\sum_{i=1}^{N} W_i\left(Y_i - \dfrac{1}{M}\sum_{j\in\Gamma_M(i,\hat{\theta}_N)} Y_j\right)$

The average treatment effect of the extension program using the inverse probability weighting method is computed as:

$$\tau = \frac{\sum_{i=1}^{N}\frac{W_i Y_i}{\hat{e}(X_i)}}{\sum_{i=1}^{N}\frac{W_i}{\hat{e}(X_i)}} - \frac{\sum_{i=1}^{N}\frac{\left(1-W_i\right)Y_i}{1-\hat{e}(X_i)}}{\sum_{i=1}^{N}\frac{W_i}{1-\hat{e}(X_i)}}$$

Here, the outcome variable (fertilizer use per hectare) for households who are more likely to participate in the extension program, i.e., with higher estimated propensity score $\hat{e}(X_i)$ is given relatively less weight in estimating the average treatment effect.

4.6 Initial Regressions

We first run a set of logistic, OLS, and tobit regressions to explore the impact of the extension program on technology adoption. Table 11 reports the results of a logistic regression estimating the probability of using modern fertilizers conditional on household and plot characteristics and the choice of crops. The unconditional logistic regression predicts that households who participated in the Ethiopian agricultural extension program are on average 26% more likely to use chemical fertilizers, allowing for correlation in the error terms across household in the same village. When we control for household's characteristics such as the education level, the value of household assets, household size, access to credit, availability of male labor in the household, and the gender of household head, this figure declines to 21%. Next, we control for plot characteristics such as soil quality, the slope of the plot, and the annual rainfall in the production cycle, along with household characteristics mentioned above, and find that a household participating in the extension program is 17.3% more likely to adopt fertilizers. Finally, we control for the type of crop the household produces in addition to household and plot characteristics. Accordingly, a household is 16% more likely to adopt chemical fertilizers when the household participates in the Ethiopian agricultural extension program. Other notable results from these initial regressions include that wealthier and more literate households are more likely to use chemical fertilizers. In addition, higher probability of use of chemical fertilizers is also reported in the production of cereals (such as teff, corn, wheat) and beans.

Next we proceed to look at the impact of the extension program on the use of high-yield variety seeds using the logit regression model, again allowing for correlation among error terms among households in the same village. Accordingly, the logistic regression without other controls predicts that a household participating in the extension program is about 28% more likely to use a high yield variety crop. When we control for household characteristics such as the education level, the gender and major occupation of the household head, the value of household assets, household size and the availability of male and female adult labor in the family, the figure drops to 24.8%. Next, we added plot characteristics such as the size of the cultivated land, soil quality, and slope of the plot, along with rainfall in that season, and the results show that participation in the extension leads to a 26% increase in the probability of using modern seeds. Finally, we added the crop choice as additional control but the probability of use of a high yield variety associated with the household's participation in the extension program did not change significantly (See Table 12).

Next we run initial OLS and tobit regressions to explore if participation in the agricultural extension program is correlated with higher intensity of fertilizer use after controlling for household and plot characteristics, along with the choice of crop by the household (See Table 13). Once again all regressions allow for correlation in the error term among households living in the same village. The first model, an OLS regression that controls for household characteristics, namely the head's literacy status and gender, coupled with the value of household assets and household size, predicts participation in the extension program increases chemical fertilizer use on average by 13.8 kg per hectare. When we control for plot characteristics, such as the quality of soil, the size and slope of the plot and the average rainfall in the village, the figure slightly drops to 13.1 kg per hectare. Controlling the choice of crop as an additional control does not significantly change the estimated increase in the intensity of technology use due to participation in the extension program. Finally, we run a tobit regression because of left censoring in the dependent variable, i.e., fertilizer use per hectare. Similar to the full OLS regression model, the tobit model shows that the impact on the intensity of the use of chemical fertilizers associated with participation in the agricultural Extension program is around 13.4 kg per hectare, controlling for observable household and plot characteristics and the type of crop the household produces.

Table 11 – The Impact of Extension Program on the Probability of Using Chemical Fertilizers: Logistic Regression

VARIABLES	(Model 1) .	(Model 2) .	(Model 3) .	(Model 4) .
dummy for participation in extension	0.264***	0.208***	0.173***	0.160***
	(0.0444)	(0.0426)	(0.0426)	(0.0407)
value of household assets		0.0186**	0.0138*	0.0214**
		(0.00846)	(0.00741)	(0.00939)
household head is illiterate		-0.0992***	-0.0854***	-0.0862***
		(0.0293)	(0.0289)	(0.0300)
age of household head		0.000630	2.18e-05	0.000118
		(0.00113)	(0.00109)	(0.000953)
dummy for access to credit		0.0483	0.0507	0.0400
		(0.0572)	(0.0617)	(0.0660)
male adult labor		0.0245**	0.0113	0.00884
		(0.0111)	(0.00997)	(0.0104)
female adult labor		0.0153	0.0110	0.0146
		(0.0134)	(0.00958)	(0.00919)
female-headed household		-0.0356	-0.0157	-0.00705
		(0.0289)	(0.0285)	(0.0292)
household size		0.00885	0.00965	0.00628
		(0.00931)	(0.00744)	(0.00779)
farming is head's major occupation		0.0413	0.0150	-0.0219
		(0.0401)	(0.0338)	(0.0322)
roof is made of corrugated sheet		0.0911*	0.0581	0.0535
		(0.0494)	(0.0424)	(0.0405)
proportion of land with good soil quality			-0.0346	-0.0170
			(0.0709)	(0.0664)
proportion of land with medium soil quality			-0.0362	-0.0328
			(0.0665)	(0.0582)
proportion of flat slope land			0.163***	0.0364
			(0.0630)	(0.0666)
proportion of land slightly slanted slope			0.0537	-0.0545
			(0.0654)	(0.0705)
total size of cultivated land			0.0528***	0.0279**
			(0.0177)	(0.0137)
annual rainfall			0.000199**	0.000175*
			(9.69e-05)	(9.10e-05)
dummy for cereals				0.328***
				(0.0779)
dummy for beans				0.115***
				(0.0420)
Observations	2,308	2,308	2,308	2,308

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12 – The Impact of Extension Program on the Probability of Using Modern Seeds: Logistic Regression

VARIABLES	(Model 1) .	(Model 2) .	(Model 3) .	(Model 4) .
dummy for participation in extension	0.283***	0.248***	0.260***	0.260***
	(0.0318)	(0.0317)	(0.0261)	(0.0256)
value of household assets		0.00840**	0.00955**	0.0102**
		(0.00342)	(0.00386)	(0.00421)
household head is illiterate		-0.0783***	-0.0790***	-0.0786***
		(0.0267)	(0.0257)	(0.0260)
age of household head		-0.00124	-0.000939	-0.000696
		(0.00108)	(0.00102)	(0.000979)
dummy for access to credit		0.0139	0.0203	0.0269
		(0.0462)	(0.0412)	(0.0440)
male adult labor		0.00694	0.00351	0.00376
		(0.00806)	(0.00766)	(0.00807)
female adult labor		0.00608	0.00354	0.00540
		(0.00984)	(0.00951)	(0.00950)
female-headed household		-0.0801**	-0.0807**	-0.0688*
		(0.0383)	(0.0384)	(0.0383)
household size		0.00703	0.0127**	0.0123**
		(0.00470)	(0.00502)	(0.00535)
farming is head's major occupation		0.0896**	0.0773**	0.0513
		(0.0380)	(0.0376)	(0.0379)
roof is made of corrugated sheet		-0.0149	-0.0244	-0.0192
		(0.0403)	(0.0344)	(0.0347)
proportion of land with good soil quality			0.120**	0.112**
			(0.0495)	(0.0545)
proportion of land with medium soil quality			0.00252	-0.000803
			(0.0426)	(0.0472)
proportion of flat slope land			0.0352	-0.0243
			(0.0512)	(0.0576)
proportion of land slightly slanted slope			-0.0250	-0.0799
			(0.0677)	(0.0712)
total size of cultivated land			-0.0133	-0.0150
			(0.0102)	(0.0109)
annual rainfall			4.70e-05	6.10e-05
			(7.62e-05)	(7.60e-05)
dummy for cereals				0.233***
				(0.0614)
dummy for beans				-0.0784**
				(0.0350)
Observations	2,308	2,308	2,308	2,308

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13 – The Impact of Extension Program on the Intensity of Using Chemical Fertilizers: (in Kg per hectare)

VARIABLES	(OLS) Model 1	(OLS) Model 2	(OLS) Model 3	(Tobit)
dummy for participation in extension	13.84***	13.13***	13.43***	13.43***
	(2.963)	(2.929)	(2.869)	(2.749)
value of household assets	0.816*	0.484	0.510	0.510
	(0.473)	(0.460)	(0.464)	(0.539)
household head is illiterate	-2.178	-1.562	-1.526	-1.522
	(2.664)	(2.606)	(2.607)	(2.498)
dummy for access to credit	1.861	0.742	1.290	1.289
	(3.750)	(3.284)	(3.210)	(3.128)
age of household head	0.0119	-0.0167	-0.0438	-0.0437
	(0.128)	(0.113)	(0.103)	(0.0938)
male adult labor	0.292	0.306	0.242	0.240
	(1.018)	(0.964)	(0.968)	(0.927)
female adult labor	0.248	-0.725	-0.426	-0.427
	(1.032)	(1.150)	(1.149)	(1.134)
female-headed household	-2.829	-2.686	-1.911	-1.918
	(3.635)	(3.422)	(3.310)	(3.684)
household size	0.0761	0.863	0.617	0.617
	(0.632)	(0.603)	(0.586)	(0.570)
farming is head's major occupation	-1.191	1.979	0.728	0.729
	(5.331)	(4.448)	(4.903)	(4.749)
roof is made of corrugated sheet	9.065**	5.755**	5.259**	5.262***
	(4.465)	(2.186)	(2.122)	(1.898)
proportion of land with good soil quality		7.152	6.382	6.390
		(7.347)	(7.046)	(6.494)
proportion of land with medium soil quality		5.581	4.875	4.892
		(7.566)	(7.592)	(6.619)
proportion of flat slope land		-2.797	-2.048	-2.088
		(12.24)	(11.98)	(8.440)
proportion of land slightly slanted slope		-2.038	-1.378	-1.417
		(12.36)	(12.28)	(9.399)
total size of cultivated land		-3.582***	-4.095***	-4.095***
		(1.057)	(1.213)	(1.221)
annual rainfall		0.143***	0.153***	0.153***
		(0.0317)	(0.0242)	(0.0239)
dummy for cereals			20.24***	20.24***
			(7.228)	(7.018)
dummy for beans			-2.208	-2.216
			(4.196)	(3.616)
Constant	61.26***	28.70***	11.46	11.48
	(7.644)	(10.53)	(14.46)	(14.16)
Observations	2,308	2,308	2,308	2,308
R-squared	0.408	0.445	0.451	
	.	.	.	.

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.7 Inverse Probability Weighting and Propensity Score Matching Methods

This section presents the causal effect of the extension program on the intensity of technology use employing the propensity score matching and the inverse probability weighting methods, which control for selection problems. Before we present our results, let's first assess whether two key assumptions that greatly influence the credibility the results obtained using these methods are in fact satisfied: balance and overlap

(1) Assessing Balance

The validity the average treatment effect estimates using the propensity score depends largely on the extent that the method has succeeded in balancing the covariates between the units of analysis in both the control and treatment group. In Table 14, we present the difference in the average values of key covariates, along with the variance ratio in the matched and raw samples. Accordingly, the standardized difference between the average values of the covariates in the matched sample is close to zero in almost all covariates. In addition, the variance ratio in the matched sample is close to 1 for most of the covariates.

For a given covariate x where the pairs $(\bar{x}_{treatment}, s^2_{treatment})$ and $(\bar{x}_{control}, s^2_{control})$ represent the sample mean and the sample variance for households in the treatment and control groups, the standardized difference is computed as: $\dfrac{\bar{x}_{treatment} - \bar{x}_{control}}{\sqrt{\dfrac{s^2_{treatment} + s^2_{control}}{2}}}$

Table 14 – Assessing Covariate Balance

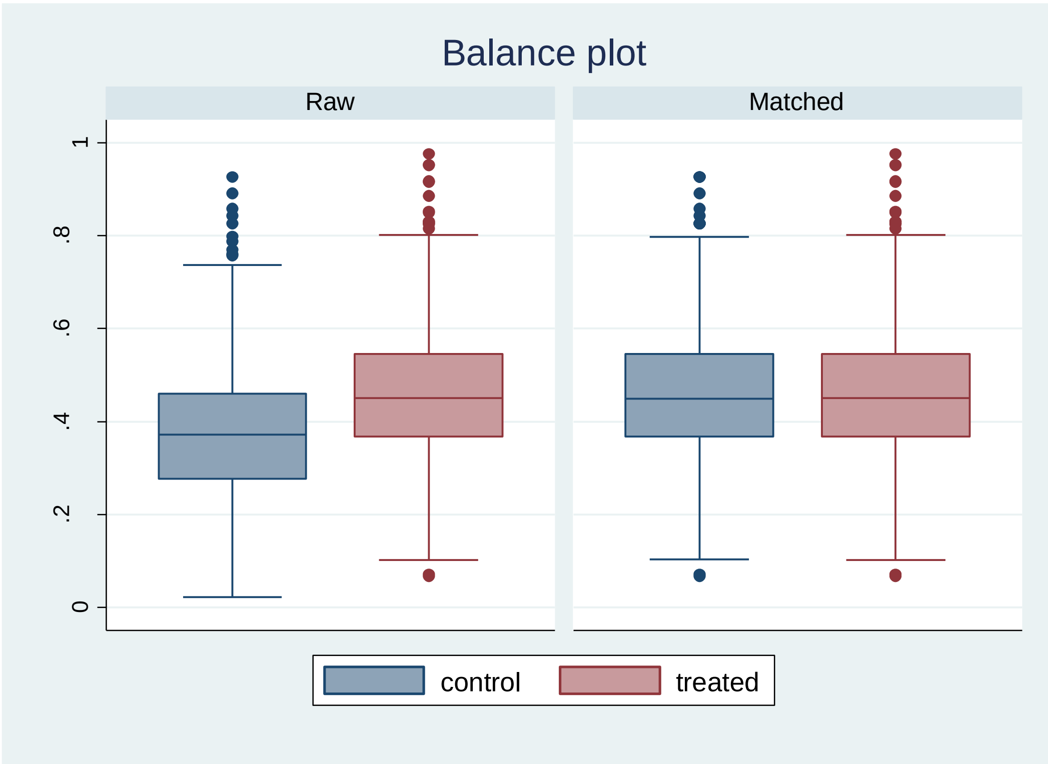
Variables	Standardized Differences		Variance Ratio	
	Raw	*Matched*	*Raw*	*Matched*
value of household assets	0.3157	0.0323	2.6865	0.9277
household head is illiterate	-0.3014	-0.0255	0.9623	0.9897
age of household head	-0.1477	-0.0207	0.8802	1.0174
male adult labor	0.1330	0.0618	0.9761	1.0202
female adult labor	0.0792	0.0169	1.0396	1.0143
female-headed household	-0.1861	-0.0258	0.6652	0.9361
household size	0.1306	0.0712	0.9539	0.9776
farming is head's major occupation	0.1301	0.0314	0.7166	0.9150
roof is made of corrugated sheet	0.1997	-0.0183	0.8390	1.0214
proportion of land with good soil quality	-0.2257	0.0297	0.9535	0.9055
proportion of land with medium soil quality	0.2000	-0.0436	0.9934	0.8628
proportion of flat slope land	-0.0583	-0.0328	0.8705	0.8992
proportion of land slightly slanted slope	0.1293	0.0205	0.9808	0.8931
total size of cultivated land	0.2780	-0.0126	0.9663	0.8214
annual rainfall	0.2523	-0.0227	1.2185	1.0855
dummy for cereals	0.3026	-0.0156	0.2646	1.1085
dummy for beans	0.1496	-0.0046	1.0702	0.9987

Source: Author's estimation

The results suggest the propensity score has largely succeeded in balancing the covariates and, in estimating the average treatment effect of the extension program using these households. That is, we are comparing households with the comparable observable characteristics except their participation in the Ethiopian agricultural extension program.

To assess if the overall balance property required for the propensity score matching method is satisfied, we present the match box plot of the propensity score in the raw and the matched data in Figure 3. The vertical axis of the box plot measures the estimated propensity score. The plot shows that while the propensity scores of household who participate in the extension program are generally higher in the raw data, overall balance is achieved in the matched sample, i.e., in estimating the average treatment effect of the program, we are comparing households who have equal propensity to participate in extension program.[39]

Figure 3 – Assessing Overall Balance



The above analyses, while informative, are not formal tests that the balancing property is satisfied. Therefore, we conduct a formal over-identification test for covariance balance developed by Imai and Ratkovic (2014). The result of the test is presented in Table 15. Accordingly, we fail to reject the null hypothesis that covariates are balanced.

[39] The band inside the boxes represent the median propensity score for the group, while the top and the bottom of the boxes represent the third and first quartiles of the estimated propensity score.

Table 15 – Formal Overidentification test for covariate balance

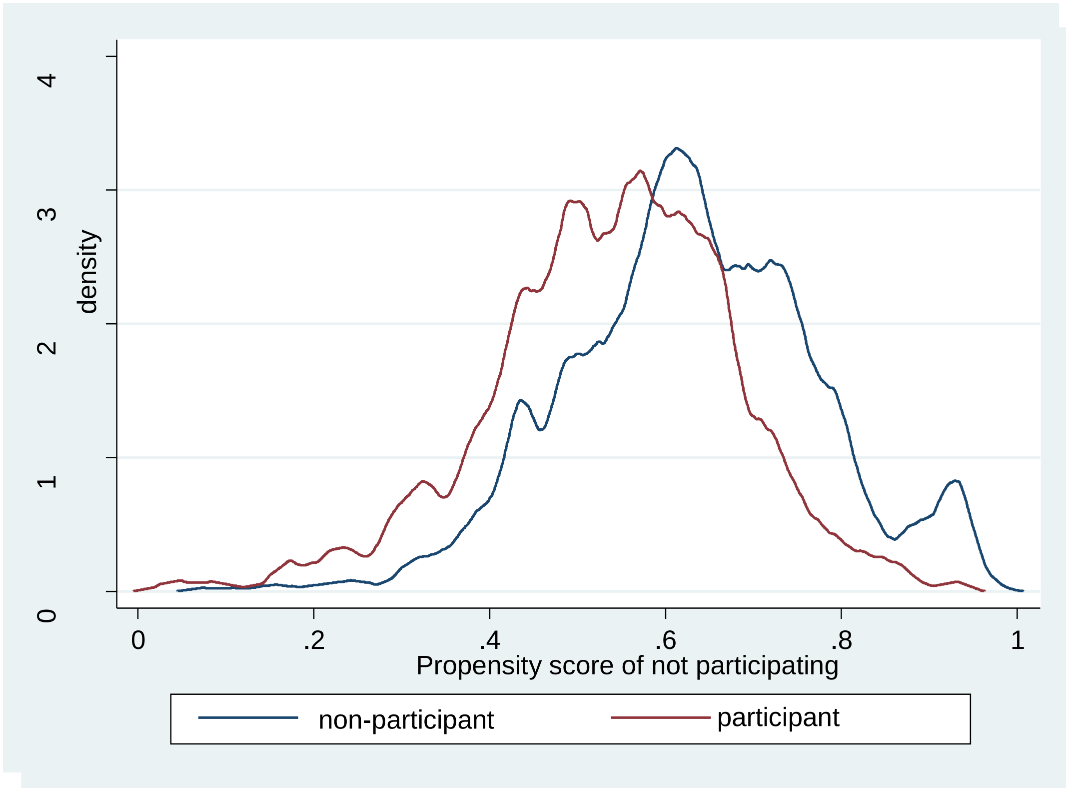
Overidentification test for covariate balance
Null Hypothesis: Covariates are balanced:
$\chi^2_{critical}$ **= 16.4882**
p-value= 0.5585

Source: Author's estimation

(2) Assessment of Overlap

Another critical assumption of methods that employ the propensity score is that what is known as the overlap assumption, which requires that each individual has a positive probability of being selected into the treatment group (in the extension program). A traditional approach employed to assess if this assumption is violated is to look at the estimated probabilities of not receiving treatment both by that treated and non-treated individuals. Thus, Figure 4 displays the predicted probabilities of not participating in the extension program by participating and non-participating households. We can see that the densities for the two groups have most of their masses in the regions they overlap and neither density has too much probability mass around 0 or 1. This shows that there is no evidence the overlap assumption is violated.

Figure 4 – Graphical Assessment of Overlap



Source: Author's estimation

(3) Average Treatment Effect Estimates

Table 16 presents the average treatment effect and average treatment effect on the treated estimates using the inverse probability weighting and propensity score matching estimators discussed in Section 4.5. The inverse probability weighting estimator of the average treatment effect of the extension program on technology adoption is around 9.1 kg per hectare. The corresponding average treatment effect estimate obtained using the propensity score matching method is slightly higher at 9.8 kg per hectare. The respective average treatment effect on the treated using the inverse probability weighting and propensity score matching methods are 7.3 and 8.3 kg per hectare, both lower than their corresponding average treatment effect estimates. We also present average treatment effect estimates using the related augmented inverse probability weighting and inverse probability weighted regression adjustment methods that yield similar estimates of the average treatment effect of the extension program.

Table 16 – Estimates of the Average Treatment Effect and Average Treatment Effect on the Treated

	Average Treatment Effect	**Average Treatment Effect on the Treated**
Propensity Score Matching	9.8123*** (3.5877)	8.3640*** (4.1830)
Inverse Probability Weighting	9.0719*** (3.0124)	7.2931*** (3.3374)
Augmented Inverse Probability Weighting	9.5754*** (3.0287)	N/A
Inverse Probability Weighted Regression Adjustment	9.3539*** (3.0134)	7.6954*** (3.2232)

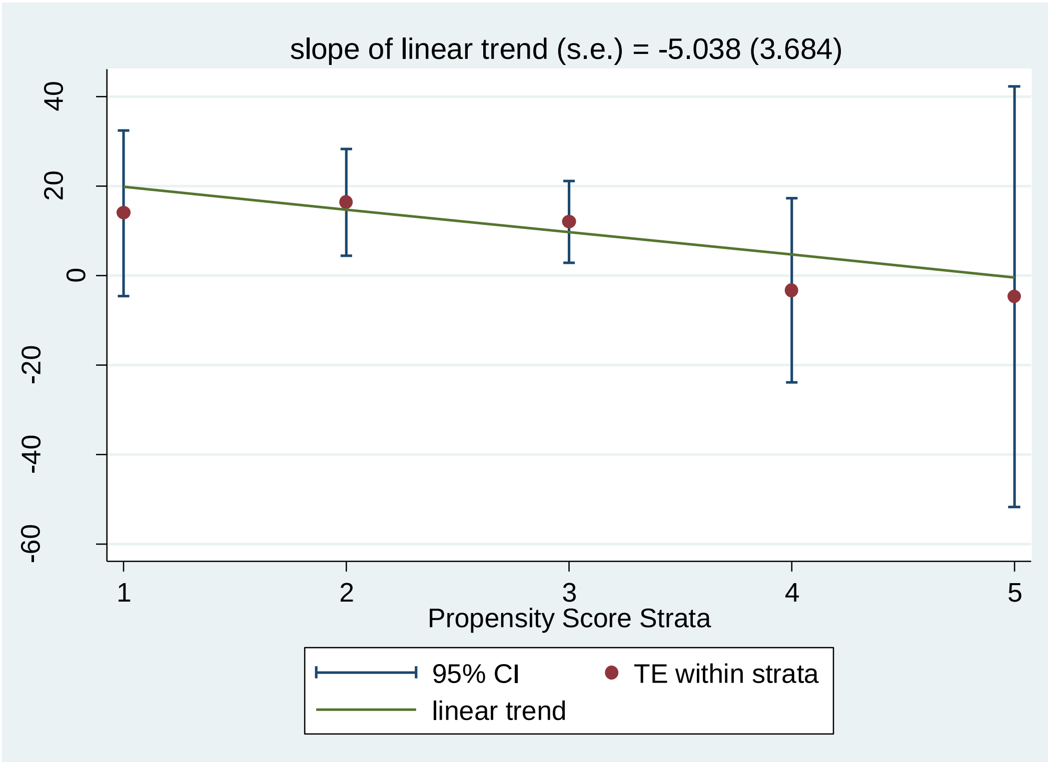
*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses

All the methods provide evidence that the Ethiopian extension program has indeed succeeded in raising the intensity of chemical fertilizer use by participating farmers by around 9 kg per hectare. In the next section, we explore if the impact of the program is heterogeneous across households.

4.8. Heterogeneous Treatment Effects

We follow Xie et al. (2012) who propose a stratification method to estimate heterogeneous average treatment effects among units of analysis. This method involves four steps (1) estimate the propensity score method using logit or probit regression models; (2) construct balanced propensity score strata which do not have significant differences in the average values of the propensity score and covariates; (3) estimate the average treatment effect for each stratum, and (4) evaluate a trend across the strata using variance-weighted least square regression of the strata-specific treatment effects computed in stage 3.

Figure 5 – Heterogeneous Treatment Effects of Ethiopian Extension Program (KG per hectare)



Note : TE and CI stand for treatment effect and confidence intervals, respectively..

Figure 5 presents the results obtained using this approach where households are categorized into five strata based on their estimated propensity score; the number of the stratum is indicated on the horizontal axis where households in first stratum have the lowest propensity score, which increases as we move across the strata. The dots represent the average treatment effect within each stratum. The figure shows the impact of the Ethiopian extension program is indeed heterogeneous across households who have different propensities of participating in the program. The analysis also appears to show that the impact of the program is higher among households in the first three strata with statistically negligible effects on households in the last two strata, implying that that the impact of the program is generally higher among household who are less likely to participate in the extension program. The results reveal that the impact of the extension program is heterogeneous among households but also that the impact is negligible among households who are more likely to participate in the program.[40] This provides a suggestive evidence that an approach in the design and implementation of the Ethiopian agricultural extension program targeted to low propensity users may potentially have larger effects.

Nevertheless, to better understand the implication of the results, it is instructive to investigate the characteristics of households that determine the likelihood of participating in the extension program. To achieve this, we run a logistic model where the dependent variable is a binary variable indicating whether the household head participates in the extension program or not and present the results in Table 17.

[40] Note that although the trend line is negative, it is not statistically significant. However, the average treatment effect for the top two strata are statistically zero (they are slightly negative but statistically insignificant). The average treatment effect estimates for the first two strata are positive, although the effect is statistically significant only for the second and third strata.

Table 17 – Estimating the Probability of Participating in the Extension Program: Logistic Regression

VARIABLES	(Model 1)	(Model 2)	(Model 3)
value of household assets	0.0179***	0.0150***	0.0170***
	(0.00338)	(0.00337)	(0.00353)
household head is illiterate	-0.0773***	-0.0714***	-0.0786***
	(0.0224)	(0.0222)	(0.0223)
dummy for access to credit	0.236***	0.221***	0.221***
	(0.0409)	(0.0402)	(0.0410)
age of household head	-0.00138*	-0.00175**	-0.00170**
	(0.000817)	(0.000811)	(0.000830)
male adult labor	0.0123	0.00923	0.00772
	(0.00929)	(0.00923)	(0.00934)
female adult labor	0.00952	0.00975	0.0127
	(0.0105)	(0.0104)	(0.0105)
female-headed household	-0.0545	-0.0313	-0.0381
	(0.0353)	(0.0349)	(0.0368)
household size	-0.00467	-0.00716	-0.00736
	(0.00572)	(0.00572)	(0.00582)
farming is head's major occupation	0.0470	0.0417	0.0421
	(0.0366)	(0.0366)	(0.0390)
roof is made of corrugated sheet	0.0587***	0.0386*	0.0328
	(0.0223)	(0.0224)	(0.0227)
proportion of land with good soil quality		-0.125***	-0.118**
		(0.0460)	(0.0475)
proportion of land with medium soil quality		-0.0201	-0.0125
		(0.0491)	(0.0502)
proportion of flat slope land		0.225***	0.228***
		(0.0554)	(0.0616)
proportion of land slightly slanted slope		0.278***	0.298***
		(0.0594)	(0.0650)
total size of cultivated land		0.0189***	0.0156***
		(0.00592)	(0.00595)
Annual rainfall		0.000106***	8.95e-05***
		(2.99e-05)	(3.08e-05)
dummy for cereals			0.268***
			(0.0544)
Observations	2308	2308	2308

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The logistic regression model predicts that wealthier households and farmers with access to credit are more likely to participate in the Ethiopian agricultural extension program, while households with illiterate heads are less likely do so. In addition, farmers with larger size of cultivated land and higher proportion of flat or only slightly sloped slope are more likely to participate in the program. Furthermore, farmers who produce cereals and live in villages with relatively higher mean annual rainfall are likely to participate in the extension program.

Although there is only suggestive evidence, the results seem to show that farmers who are generally likely to participate in the program are also more likely to use higher units of chemical fertilizer regardless of their participation in the extension program. Hence, the impact of the extension program on technology adoption is higher among households who would not have otherwise participated in the program.

4.9 Conclusion

The paper evaluates the impact of the largest public agricultural extension program in Sub-Saharan Africa, the Ethiopian agricultural extension program, in promoting the use of chemical fertilizers among farmers in four major regional states of the country. The program is aimed at increasing farmer's welfare and accelerating growth in the agricultural sector by promoting the transfer and continued adoption of modern technologies among farmers. It is also a key pillar to the current Ethiopian government's overall development strategy, the Agricultural Development Led Industrialization, that is designed to reduce poverty and achieve overall structural transformation in the Economy by boosting productivity in the agricultural sector, which employs over 80% of the workforce and contributes to over 40% the country's GDP.

By employing inverse probability weighting and propensity score matching methods, we find that the Ethiopian extension program increases the probability of adoption of chemical fertilizers and enhances the intensity of their use but the impact is heterogeneous among households. The results appear to show that impact of the program is generally higher among households that have lower propensity to participate in the program. This suggests a targeted approach in the design and implementation of the Ethiopian agricultural extension program may potentially have larger effects in promoting technology adoption and boosting agricultural productivity in one of the poorest countries in the world.

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Chapter 5
Concluding Remarks

"Nations fail today because their extractive economic institutions do not create the incentives needed for people to save, invest, and innovate." (Acemoglu and Robinson, 2012, p.372).

The difference in standard of living across countries is astounding. The annual earnings of the average American is close to 40 times than that of the average person in Ethiopia, a country we closely study in this dissertation.[41] And despite the recent progress made in reducing global poverty, particularly in East Asia, recent estimates show that over one billion people across the world still live under $1.25 a day. Thus, understanding the fundamental reasons as to why some countries are poor is still one of the most important and fascinating research areas in social science.

A dominant view in economics is that the destiny of nations is not in their natural endowment or history or culture, but rather in the economic and political institutions they choose. Leading examples of important economics institutions are property rights institutions which protect ordinary citizens and firms from direct expropriation by the government and powerful elites. In the first two essays of the dissertation, we combine this view with the results from cross-country growth regressions that show technological progress to be the key driver of economic growth, which explains the divergence in economic performance across nations. The fundamental logic underlying these two studies is that if institutions, as widely believed, are the fundamental determinants of economic performance, and much of the variation in standard of living among countries is explained by the different levels of technology, then a major channel through which

[41] The per capita income of the United States as of 2013, adjusted for purchasing power parity stood at USD 53, 575 as compared to USD 1380 in Ethiopia.

institutions affect productivity ought to be through their effect on technology adoption and innovation.

In these essays we explore the interaction between property rights and technology adoption at the microeconomic level, which, unlike studies at the macro level, allows us to carefully examine the important mechanisms through which property rights institutions influence technology adoption. The main argument we provide is that property right institutions affect technology adoption by altering the optimal choice of contracts (land and labor contracts) by economic agents, but their effect may be limited by the degree of market imperfections prevailing in the economy. We study this is in the agricultural sector using data from Ethiopia which introduced legislation aimed at strengthening the tenure security of its farmers.

The choice of agriculture to study the interaction between institutions and technology adoption is well placed, not only because agriculture provides the major source of livelihood for a significant portion of the population in many developing countries, but also because part the motivation for the sustained interest in research on the economics of technology adoption comes from the empirical puzzle of low adoption of modern agricultural technologies in the developing world, particularly in Sub-Saharan Africa, despite the perceived high returns of these technologies. Nonetheless, careful econometric studies such as by Suri (2011) show that while the return of investment in new agricultural technologies may be heterogeneous across farmers, their low adoption by a sizable section of farmers can be simply explained by their small net return.[42] This suggests that a fruitful line of research aimed at understanding why technology adoption is low in

[42] Suri (2011) shows this may be due to high cost due to supply bottlenecks.

African agriculture needs to focus on identifying the underlying factors that determine the rate of return of investment in modern technology.

The results from our research suggest that in order to understand the fundamental causes of low net return of modern agricultural technologies in developing economies, one may need to look beyond market failures, and explore the role that government failures play. An important example of government failures is weak formal property rights institutions that could potentially limit investment in technology by lowering the expected private rate of return.

Traditional analysis of property rights and investment, however, is mainly focused on examining the direct uncertainty-reducing effect of the latter on long-term investment. The first two essays of the dissertation take a different perspective and identify two important roles of property rights institutions in promoting investment in new technology:

(1) **market-supporting role of institutions**: strong property rights institutions promote technology adoption by providing the underlying basis for market participation by economic agents, resulting in gains from trade through increased specialization.

(2) **contract-supporting role of institutions**: strong property rights institutions allow agents the freedom to devise efficient mechanisms, such as contracts, to solve incentive problems (such as moral hazard) that may arise when they interact in the marketplace, leading to a more efficient use of resources such as land.

We specifically argue that improved land rights promote technology adoption by lowering land transfer costs and reducing the risk of expropriation, which in turn influences the land and labor contracts farmers choose. Because these contracts embody different incentives and risk-sharing mechanisms, they influence farmers' technology choices, particularly when the returns of the new technology are uncertain.

We provide evidence supporting this hypothesis using panel data from Ethiopia. Our empirical approach allows us to separate the direct impact of improved tenure security on technology adoption, by reducing the risk of expropriation, from its indirect impact through its effect on the optimal choice of land and labor contracts. The results show improved property rights in Ethiopia have their greatest effect on the adoption of chemical fertilizers by transforming the agrarian contractual structure.

Our results underline the importance of understanding the interactions between market and government failures, as the effectiveness of correcting government failures can be limited by the magnitude of market failures in the economy, and vice versa. These results also suggest the possible interaction between property rights institutions with contracting institutions, i.e., institutions designed to enforce contracts made among individual economic agents.

Our analysis shows that future research aimed at offering deep and actionable insights on the role of institutions in determining economic performance should sufficiently address the following three questions: (1) which institutions are important, (2) what are the mechanisms through which institutions influence economics performance (or proximate determinants of economic performance such as investment and technology adoption), (3) what are the interactions between these institutions (within and across economic and political institutions)? In addition, going forward, endogenizing these institutions in economic analysis and examining how societies come to acquire (or fail to acquire) institutions conducive to economic growth may get us closer to answering why there is so much poverty in some parts of the world. Thus we may need to explicitly incorporate political decision making directly into the economic analysis of development. As Acemoglu and Robinson argue:

"…*poor countries are poor because those who have power make choices that create poverty. They get wrong not by mistake or ignorance but on purpose." (Acemoglu and Robinson, 2012, p.62).*

In the fourth chapter, we turn our attention to examining another important mechanism through which institutions influence economic performance: by determining the level of investment countries make in their human capital which in turn promotes innovation and facilitate the adoption of advanced technology in these economies, which ultimately raises their productivity and standard of living. This is consistent with the view long held by some economists that because advances in frontier technology typically occur in developed economies, the success of developing economies in raising overall productivity depends much on their ability to import and adapt existing technology from developed countries to their local conditions, and this ability to a large extent depends on the quality of their work force which is a function of the level of investment these countries make in their human capital (Gerschenkron, 1962; Nelson and Phelps, 1966).

We study the role of human capital in the adoption of new technology by evaluating the impact of the Ethiopian agricultural extension program, the largest agricultural extension program in Sub-Saharan Africa, in promoting the adoption of chemical fertilizers by farmers in four major regional states in the country. Our results show that investment in farmers' human capital may play an important role in promoting technology adoption in Africa but the impact is heterogeneous across households. This suggests that a targeted approach in the design and implementation of public policies aimed at promoting technology adoption may be more cost effective. Finally, it is important to note that, while evaluating the impact of the stated goals of these programs is essential, the effectiveness of these programs should be weighed against their cost, which is a crucial determinant of the sustainability of these interventions.[43] In particular, future research needs to look at the cost-effectiveness of alternative modes of information delivery to farmers, including the use of modern information technology and the participation of private firms as an alternative to government-run home-visits by extension agents or the construction of Farmer Training Centers, which are very costly and may not be sustained on a long-term basis.[44]

Finally, an important extension to the studies included in this dissertation would be to explore the general equilibrium effects of these nationwide policies, as there can be potentially considerable productivity spillovers from agriculture to other sectors of the economy.

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[43] These also help us compare alternative interventions aimed at promoting technology adoption.

[44] A good example is the initiative by Digital Green where farmers share their experiences about new technology through the use of short videos.