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# From Land Rights to Climate Resilience: Evidence from Ethiopian Smallholders\*

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## Abstract

*Land tenure security is increasingly recognized as a critical institutional factor for enhancing climate resilience, yet evidence on how institutional and ecological factors jointly affect the adoption of diverse climate adaptation investments remains limited. We investigate the causal effects of land security on short-, medium-, and long-term climate adaptation investments among Ethiopian smallholders. Using nationally representative panel data and a correlated random effect–instrumental variable (CRE–IV) approach, we estimate the impacts of both formal and perceived land rights on various climate adaptation practices. The findings confirm that formal land rights significantly enhance investments that strengthen adaptive capacity and resilience, including crop rotation, watershed management, and agroforestry. However, these effects are substantially stronger in areas with better vegetation greenness. Gender-disaggregated analysis also reveals that both men and women holders benefit from land rights, albeit through different pathways and with varying magnitudes. Further, perceived land rights have a significant effect on agroforestry practices. Our findings conclude that secured land rights are crucial for promoting sustainable land use practices, particularly in areas with better ecological conditions.*

**Keywords:** Land security; Climate adaptation investments; Vegetation density; Agroforestry; Ethiopia

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## 1. Introduction

Climate change affects the livelihoods of billions of people, particularly in regions dependent on agriculture (Demem, 2023; Roy et al., 2024). In these countries, agriculture serves as the primary source of income and employment, yet it is also the most climate-sensitive sector due to its heavy dependence on weather patterns (Daba et al., 2025). Increasingly erratic rainfall, recurrent floods, soil degradation, and heatwaves have led rural households to adopt various climate adaptation investments (adaptation investments hereafter) (Mohamed Shaffril et al., 2024). Ethiopia is among the most climate-vulnerable countries in Africa. With over 70 percent of its population dependent on rain-fed agriculture, even minor climatic shocks can have severe implications for food security, income stability, and overall rural well-being (Assefa Tofu & Wolka, 2023). The country is already experiencing more frequent droughts, unpredictable rainfall, land degradation, and rising temperatures. Against this backdrop, climate adaptation at the local levels is a key area of policy and research focus (Zelege et al., 2021).

Investment in sustainable land management, including soil and water conservation, agroforestry, crop rotation, small-scale irrigation, and the application of organic fertilizers, can help mitigate the adverse impact of climate change and improve agricultural productivity (Abegaz et al., 2024). Such investments can contribute both to agricultural productivity and to reducing the impacts of climate change (Dinh et al., 2023). However, in Ethiopia, due to reliance on traditional subsistence agriculture and lack of structural transformation, the adoption of sustainable land use practices is low (Kidane et al., 2025). The capacity and willingness of households to undertake such long-term investments are crucially shaped by institutional conditions, particularly the degree to which land rights are recognized, formalized, and protected (Besley, 1995; Critchley et al., 2023).

The economic theory of property rights stipulates that secure, well-defined, and enforceable property rights are crucial to boost long-term agricultural investment, as they reduce the risk of expropriation and facilitate access to credit and markets (Besley, 1995). Such investments are essential not only to improve agricultural productivity but also to reduce the adverse impact of climate change. These adaptation investments often require substantial upfront capital and may take years to yield returns, making secure land tenure a critical prerequisite (Dinh et al., 2023). Without the assurance of continued land access and the right to reap future benefits, farmers are less likely to invest in such measures.

Despite a well-established theoretical base, empirical findings on the relationship between land tenure security (tenure security hereafter) and agricultural investment remain mixed and highly context-specific. While tenure security alone does not always lead to increased investment (Abab et al., 2023; Gorfu, 2016; Huntington & Shenoy, 2021; Mekonnen, 2009, 2009; Navarro-Castañeda et al., 2021; Schürmann et al., 2020), it can positively and significantly influence investment decisions (Abdulai et al., 2011; Adamie, 2021; Ali et al., 2011; Holden et al., 2009; Lin et al., 2020; Wolde, 2025; Wolde & Bertacchini, 2025). A key limitation of much of the existing literature, however, is its narrow focus on the diversity and intensity of agricultural investments adopted (Adere et al., 2022). We extend this literature by examining how secure land rights (secure rights hereafter) impact a range of adaptation investments across various time horizons, including short-, medium-, and long-term strategies.

Our paper makes several contributions to existing literature. First, we provide context-specific empirical evidence on how both formal and informal (perceived) land rights influence a range of adaptation investments, encompassing short-term, medium-term, and long-term strategies, such as crop rotation, watershed management, improved seed adoption, agroforestry, organic fertilizer use, and small-scale irrigation. This will link secure rights to diverse adaptation strategies, providing a holistic understanding of how land rights shape farmer behavior (Fedele et al., 2019). By examining not only whether households invest but also the extent of their investment, the study offers deeper insights into how and to what extent tenure security shapes farmers' adaptation behavior.

Second, we examine how vegetation density and health moderate the relationship between tenure security and climate investment. In areas with higher vegetation density, secure rights may provide stronger incentives to invest, whereas in ecologically degraded or drought-prone regions, the risks of crop failure may blunt the incentives to invest despite secure land tenure. To capture local vegetation density and health, we use satellite-derived data on the Normalized Difference Vegetation Index (NDVI), and analyze its interaction with plot certification. This approach contributes to the literature by jointly considering institutional and ecological dimensions, thereby offering insights into how environmental conditions shape agricultural investment behavior.

Our analysis also incorporates a gender-disaggregated analysis to assess how tenure security affects male and female plot holders differently. In Ethiopia, where women often face structural barriers in accessing and controlling land, understanding these gendered dimensions is vital for designing equitable land

policies and climate adaptation interventions. By highlighting the gendered impacts of land tenure reforms, the study supports the formulation of more inclusive and effective policies.

In doing so, we employ a multi-topic, multi-level, and nationally representative panel dataset from the Ethiopian Socioeconomic Panel Surveys (ESPS). Ethiopia, with its large population, vast geographic area, and diverse agroecological zones, faces pressure from climate change, tenure insecurity, and gender gaps. This study addresses ongoing issues in tenure security, climate adaptation, and agricultural investment in Ethiopia. The findings may inform policymakers, development practitioners, and international donors on promoting sustainable land use and supporting rural resilience through land governance reforms. Moreover, the findings help inform national policy in Ethiopia and offer scalable insights for other low- and middle-income countries with similar socio-economic, environmental, and institutional contexts.

## **2. Land Tenure Security and Climate Adaptation**

The intensifying impacts of climate change, especially in ecologically fragile and economically constrained settings, have made climate adaptation a central concern in development and policy discourse (Castro & Kuntz, 2022; Sinore & Wang, 2024). In agrarian economies like Ethiopia, where livelihoods are deeply tied to natural resources, adaptation is essential for maintaining livelihoods under changing climatic conditions (Sinore & Wang, 2024). While adaptation strategies in urban or high-income contexts may focus on infrastructure or insurance systems, rural adaptation in developing countries is fundamentally linked to access to and control over land (Stringer et al., 2020). As such, tenure security can influence the effectiveness and sustainability of adaptation investments (Castro & Kuntz, 2022).

This makes land policy an increasingly important tool for strengthening rural climate resilience. The nexus between land tenure and climate adaptation operates through multiple, often context-dependent pathways. On the one hand, secure land tenure can encourage climate adaptation by providing individuals and households the assurance needed to invest in long-term improvements, such as soil conservation, agroforestry, or irrigation infrastructure (Besley, 1995). Such investments typically involve upfront costs with delayed benefits, and their adoption is often higher when households perceive tenure stability and control. However, farmers may not always adopt these practices with the conscious intent of adapting to climate change. Their primary motivations often focus on increasing productivity, preserving soil

fertility, or improving long-term profitability (Grigorieva et al., 2023). As a result, many adaptation outcomes occur as secondary benefits of decisions driven by these objectives (Tilahun et al., 2023).

Theoretical foundations for the link between tenure security and investment behavior are well established in the property rights literature. According to classic economic theory, clearly defined and enforceable property rights reduce transaction costs, lower investment risks, and improve allocative efficiency (Besley, 1995; Demsetz, 1974; Redford, 2020). Applied to agriculture, these mechanisms suggest that secure tenure enhances farmers' incentives to undertake forward-looking and often capital-intensive practices, such as terracing, organic soil management, and tree planting (Deininger & Jin, 2006; Holden et al., 2009; Navarro-Castañeda et al., 2021). Furthermore, tenure security can facilitate access to credit by allowing land to serve as collateral and enabling more efficient land transfers through rental and sales markets (Bogliacino et al., 2022, 2025; Deininger & Feder, 2001).

However, despite strong theoretical claims, empirical findings on the relationship between tenure security and investments remain inconsistent. While some studies report positive impacts of tenure security on long-term land management practices (Abdulai et al., 2011; Adamie, 2021; Ali et al., 2011), others find its effects on agricultural investment to be insignificant or highly context-specific (Dinh et al., 2023; Schürmann et al., 2020). In contrast, studies from Sub-Saharan Africa, including Ghana and Ethiopia, highlight the importance of perceived tenure security rather than formal titles in shaping investment behavior, often influenced by local institutions and political affiliations (Asaaga et al., 2020; Gorfu, 2016; A. Mekonnen, 2009). This reflects the reality that land tenure is not only a legal issue but also a deep social and political construct.

Such divergent findings suggest that formal land tenure reforms are necessary but not always sufficient to promote agricultural investment. The strength of tenure rights, as perceived and enforced locally, can significantly influence investment decisions. Moreover, the effectiveness of land rights in driving adaptation may depend heavily on ecological context. Farmers operating in more fertile or ecologically favorable regions may be more responsive to tenure security due to higher expected returns. Conversely, in degraded regions, where returns to land-based investment are uncertain, tenure security alone may not be enough to encourage adaptive behavior (Rampa & Lovo, 2023; Teklu et al., 2023). As far as our knowledge is concerned, there is no empirical evidence examining how environmental condition mediates the tenure-investment relationship, especially using high-resolution satellite-based proxies such

as the NDVI. Integrating spatial analysis into land tenure research can reveal important location-specific dynamics that influence investment decisions.

Another significant gap in the literature relates to the gender-differentiated impacts of land reforms. Although women constitute a substantial share of the agricultural labor force in many developing countries, they often face systemic barriers to accessing, owning, and controlling land (Meinzen-Dick et al., 2019). These barriers are particularly acute in Ethiopia, where customary norms and institutional biases frequently undermine women's land rights. When women have secure tenure, either through formal titles or perceived rights, they are more likely to invest in sustainable land management practices (Doss et al., 2018). Nonetheless, gender-disaggregated analyses remain scarce, and the intersection of gender, tenure security, and climate adaptation is still poorly understood (Meinzen-Dick et al., 2019).

Taken together, these insights reveal that while tenure security may have the potential to catalyze adaptation investments, its actual impact depends on a confluence of institutional, ecological, and social factors. Moreover, the effect of secure rights is unlikely to be uniform across different types of investment. Short-term practices may respond differently to tenure security than long-term investments. Therefore, exploring the effects of secure rights on various forms of adaptation investments is essential. Addressing these knowledge gaps requires an integrated analytical approach that simultaneously considers secured land rights, environmental condition, and gender dynamics. Our study contributes to this literature by empirically assessing the effects of secure rights on a broad spectrum of adaptation investments in Ethiopia, ranging from short-term actions, such as organic fertilizer application, to long-term strategies, including agroforestry. By incorporating vegetation density and gender-disaggregated analysis, it offers insights into how tenure security interacts with ecological and social variables to influence adaptation behavior.

### **3. Methods and Materials**

#### **3.1 Data and Sources**

This study utilizes rich, internationally standardized, and nationally representative socioeconomic panel surveys jointly administered by the Ethiopian Statistical Service (ESS) and the World Bank—Living Standards Measurement Study (LSMS). The study leverages the latest four waves (ESPS2—2013/14, ESPS3—2015/16, ESPS4—2018/19, and ESPS5—2021/22). All survey rounds constitute a nationally representative household panel spanning both rural and urban areas and covering all regional states and

the two administrative cities. The only exception is ESPS-5, which was not conducted in the Tigray region because of security concerns. ESPS samples were selected using a two-stage stratified probability sampling method. In the first stage, enumeration areas (EAs—villages) were determined through simple random sampling. In the second stage, households within each EA were selected using systematic random sampling. ESPS2 and ESPS3 were carried out in 433 EAs (290 rural), surveying 5,262 (3,323 rural) and 4,954 (3,272 rural) households, respectively. ESPS4 interviewed 6,770 households in 535 EAs (291 rural). ESPS5 covered 435 EAs (220 rural) and surveyed 4,959 households (2,285 rural). [Figure 1](#) shows the geographic distribution of sample villages.

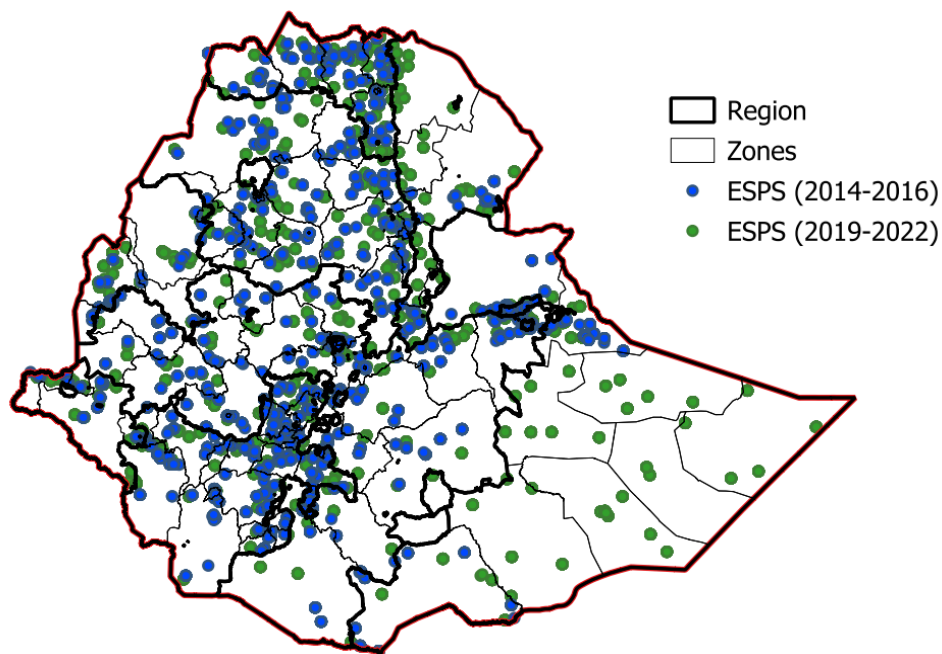


**Figure 1:** The geospatial distribution of sample villages in ESPS surveys

In this paper, we focus on rural land certification programs, using samples from rural and small-town areas. From these surveys, we obtain plot-level data on land registration and certification, and different adaptation investments. We then integrate the survey data with satellite-based information on the Normalized Difference Vegetation Index (NDVI), which measures vegetation density and greenness and is commonly used as a proxy for vegetation health and local environmental conditions (see [Figure 2](#)). The NDVI data is extracted from Google Earth Engine Data Catalog, provided by NASA's Land Processes Distributed Active Archive Center (LP DAAC). The NDVI data are produced at 250m spatial resolution and computed from atmospherically corrected reflectance, masked for water, heavy aerosols, and cloud shadows ([Didan, 2021](#)). Given the Ethiopian Socioeconomic Panel Surveys (ESPS) are geo-coded at the community (village) level, we extract mean NDVI values for each survey period by spatially

matching satellite observations to the GPS coordinates of the surveyed communities. We then aggregate these village-level NDVI measures to a larger administrative (zonal) level, as neighboring villages are expected to share very similar vegetation conditions (comparable agroecological conditions) and therefore exhibit limited within-zone variation in NDVI.

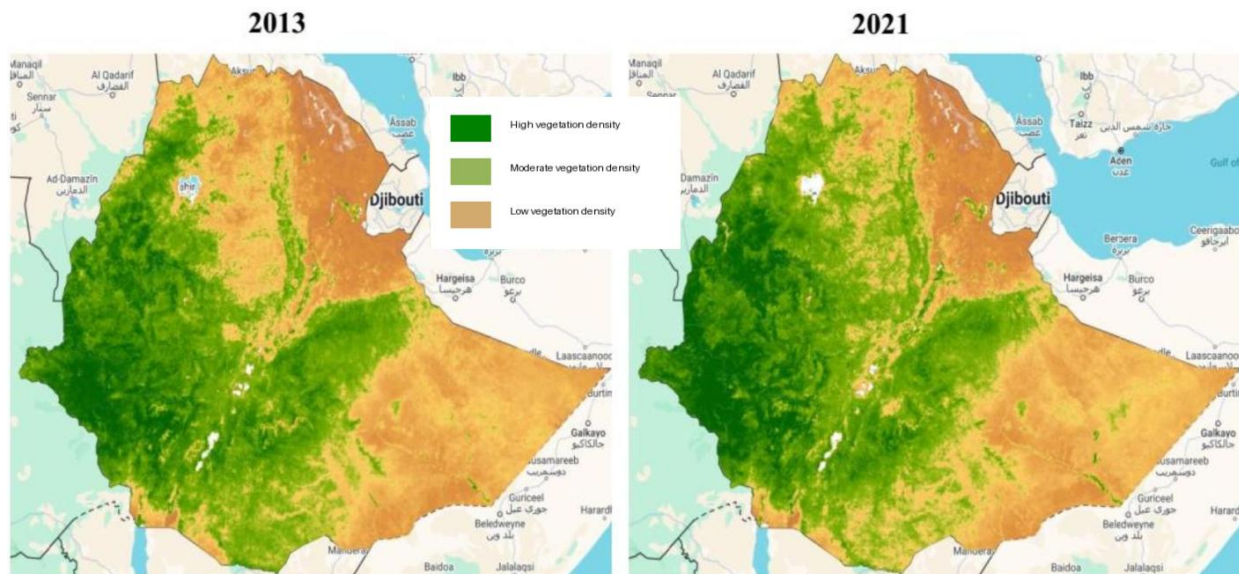


**Figure 2:** Vegetation Density and Health in Ethiopia

### 3.2 Empirical Strategies:

The land certification process does not follow any predefined economic criteria, and certificates were distributed to households in program villages in a relatively egalitarian manner, suggesting that the absence of plot certificates is not due to systemic factors (Deininger et al., 2008; Adamic, 2021). As such, depending on the nature of the outcome variables, we begin our estimation using Random effects (RE) regression models—linear, and probit—as baseline estimation methods. Random effects models utilize both within- and between-plot variation, making them particularly suitable for our data structure, which consists of short panels with a large number of plots (see Wolde, 2025). The above models assume that the land certification process is exogenous. However, the issue of endogeneity remains a key identification challenge due to reverse causality between land security and adaptation investments, omitted variable biases, and measurement errors.

We then applied the Correlated Random effects (CRE) regression model (also known as the Mundlak approach), which relaxes the standard RE assumption of strict exogeneity by including the group-means of time-varying variables as additional controls. This specification accounts for potential correlation between covariates and unobserved unit effects, thereby mitigating potential endogeneity concerns and

yielding consistent estimates (see [Mundlak, 1978](#); [Wooldridge, 2019](#)). The CRE model can be specified as:

$$Y_{ijt} = \alpha + \beta LC_{ijt} + \delta X_t + \theta \bar{X} + \varphi_t + \varepsilon_{ijt} \quad (1)$$

Where  $Y_{ijt}$  refers to adaptation investments in a given plot  $i$  at year  $t$  in community  $j$ ;  $LC_{ijt}$  is land (plot) certification ( $LC_{ijt}$ ) in community  $j$ .  $X_t$  is a vector of covariates capturing plot-level, holder-level, household, and community-level characteristics, while  $\bar{X}$  is the group mean of the time-varying variables:  $\bar{X} = \frac{1}{T} \sum X_t$ . The coefficient of interest ( $\beta$ ) captures the within-unit effect (variation within the same plot over time), while the coefficient on the group-means ( $\theta$ ) indicates the between-unit effect (differences across plots). An important advantage of the Mundlak approach is that it gives the same within-unit estimates as the fixed effects (FE) model<sup>1</sup> for time-varying regressors, while also allowing the estimation of time-invariant variables.

The RE and CRE models may not address possible endogeneity, particularly from feedback effects (i.e., reverse causality) between tenure security and the outcome variables, which could bias the estimates. To address this and provide more robust evidence on the causal impact of land security on adaptation investments, we also employ the CRE-instrumental variable (CRE-IV) approach, controlling for a set of household, plot, and community-level characteristics, as well as geospatial variables. The CRE-IV approach combines CRE and IV to address endogeneity from multiple sources. CRE controls time-invariant unobserved heterogeneity, while the IV component mitigates bias from omitted time-varying factors. This allows us to consistently estimate the causal impact of tenure security on adaptation investments.

Mathematically, the following CRE-IV regression model is specified to estimate the causal effects of land security on adaptation investments:

$$\text{(First stage)} \quad LC_{ijt} = \sigma + \delta Z_{ijt} + \gamma X_t + \vartheta \bar{X} + \varphi_t + u_{ijt} \quad (2)$$

$$\text{(Second stage)} \quad Y_{ijt} = \alpha + \beta \widehat{LC}_{ijt} + \delta X_t + \theta \bar{X} + \varphi_t + \varepsilon_{ijt} \quad (3)$$

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<sup>1</sup>In our case, a plot-level fixed effects (FE) model is not appropriate and performs poorly because the data contain very little within-plot variation as many plots are observed only once, leaving a large number of singleton observations. Since FE estimation relies only on plots where variables change over time, resulting in very low within  $R^2$ , and generally insignificant coefficients. In most specifications, even the overall F-test is insignificant, reinforcing that FE is not suitable for our dataset. In short, the lack of sufficient within-plot variation in our data limits the applicability and reliability of FE models.

We employ two instruments for land certification status: (i) the mode of land acquisition (granted by the local leader or inherited), and (ii) the share of certified plots within the community. ). It is common to use such a kind of instruments (Besley, 1995; Adamie, 2021; Wolde, 2025). These instruments satisfy the relevance condition, as they are expected to be strongly correlated with the plot certification. For instance, the mode of land acquisition is relevant because plots granted by local authorities or inherited may follow distinct administrative procedures or eligibility criteria that systematically increase the likelihood of certification. Community-level certification rates also capture centralized implementation and local spillover effects, making landholders in highly certified communities more likely to receive certification. The exogeneity condition requires that the instruments influence the outcome only through their effect on plot certification. That is, exogeneity is plausible because, conditional on observed household, plot, and community characteristics, instruments should not directly affect land-related investments except through plot certification. A valid instrument should be strongly correlated with the instrumented variable, but uncorrelated with the error term:  $\text{Cov}(LC_{ijt}, Z_{jt}) \neq 0$  and  $\text{Cov}(Z_{jt}, \varepsilon_{ijt}) = 0$ . Finally, to check the credibility of these instruments, we conduct under- and weak identification tests.

### 3.3. Description of main variables

Table 1 presents the list of our main variables used in the empirical analysis, along with their description. Specifically, we consider three variables as proxies for tenure security, capturing both formal and informal dimensions. We also consider six adaptation investments as outcome variables in our estimations. The variables listed in the second panel of Table 1 represent a diverse set of strategies widely recognized in the literature as key adaptation investments in smallholder agricultural systems (Incoom et al., 2025). Each of these measures may not necessarily reflect households' conscious intent to insure against climate change, but they are also designed to improve productivity and generate long-term returns (Belay et al., 2017; Gashure, 2024). Detailed descriptions of the six outcome variables are provided in the appendix.

**Table 1:** List and description of main variables

| <b>Land security variables</b>      |                                                                                           |
|-------------------------------------|-------------------------------------------------------------------------------------------|
| Land certification                  | Does the holder have a document for his parcel (plot)                                     |
| Right to sell                       | Does anyone in the household have the right to sell the parcel or use it as collateral?   |
| Right to bequeath                   | Does anyone in the household have the right to bequeath the parcel?                       |
| <b>Climate adaptation practices</b> |                                                                                           |
| Crop rotation                       | Practice of crop rotation on landholding (1 if Yes)                                       |
| Improved seed                       | The use of improved seeds on any one of the plots (1 if Yes)                              |
| Organic fertilizer                  | The adoption of organic fertilizer (such as manure, compost) at the plot level (1 if yes) |
| Irrigation                          | Irrigated plot during the current agricultural season (1 if yes)                          |
| Watershed                           | Participation in watershed activities in the community (1 if yes)                         |
| Agroforestry                        | The total number of fruit-bearing trees at the plot level                                 |

**Note:** These questions were taken from the original survey.

## 4. Results and discussion

### 4.1 Summary statistics

[Table 2](#) presents the statistical distribution of formal and perceived land rights (perceived rights hereafter) during the study period. The share of plots (parcels) with certification (formal land rights) increased from 51 percent in 2013 to 57 percent in 2015, reaching a peak of 66 percent in 2018. However, the proportion of certified plots slightly declined to 65 percent in 2021, primarily attributed to a smaller sample size resulting from the exclusion of the Tigray region, due to security concerns. Overall, the summary statistics indicate substantial progress in formal land certification over the years, which may be driven by strong support from donors, enhanced administrative efforts, and strong demand for tenure security among landholders ([Bezu & Holden, 2014](#)). Nevertheless, the average rate of formal land certification across all survey years remains at 58.5 percent, highlighting the continued prevalence of uncertified plots in Ethiopia.

On the other hand, perceived rights (mainly the right to sell) remained consistently high throughout the study period. A high proportion of landholders perceive they have the right to sell their land, with mean values ranging from 87 to 92 percent. This indicates that perceived land security (at least in terms of transferability through sale) has remained widespread regardless of formal documentation. This may reflect strong informal tenure systems that effectively convey secure transfer rights and underscore the importance of distinguishing between formal and perceived rights in empirical analysis ([Alhola & Gwaindepi, 2024](#)).

**Table 2:** Summary of formal and perceived land rights (at plot level)

| Formal land rights |       |        | Perceived rights—the right to sell |        |
|--------------------|-------|--------|------------------------------------|--------|
| Year               | Mean  | Freq.  | Mean                               | Freq.  |
| 2013               | 0.511 | 10,671 | 0.907                              | 10,780 |
| 2015               | 0.570 | 11,175 | 0.917                              | 11,154 |
| 2018               | 0.659 | 8,174  | 0.869                              | 7,048  |
| 2021               | 0.648 | 5,683  | 0.885                              | 4,997  |
| <b>Total</b>       | 0.585 | 35,703 | 0.899                              | 33,979 |

As shown in [Figure 1](#), significant regional disparities exist in the proportion of parcels with certification in Ethiopia. Regions such as Amhara (76 percent), Tigray (71 percent), and Oromia (62 percent) exhibit high certification rates. In contrast, notably lower levels of certification are observed in Afar (12 percent), Somali (11 percent), and Dire Dawa (10 percent). These variations indicate substantial differences in the implementation of land certification programs across Ethiopian regional states. Large-scale land certification programs have been more actively implemented in larger regions, including Amhara, Oromia, the Southern Nations, Nationalities, and Peoples' Region (SNNP), and Tigray. These regions have benefited from stronger institutional capacity, active donor engagement, and administrative focus, which have facilitated broader coverage and more consistent enforcement of land formalization. In contrast, other regions, particularly Afar, Somali, and Dire Dawa, have received limited attention and priority in the implementation process. These differences may be further explained by the decentralized structure of Ethiopia's land governance system. Since 2002, regional governments have been granted autonomy to design and implement their land-related policies and programs, resulting in significant heterogeneity in land administration efforts ([Adamie, 2021](#)).

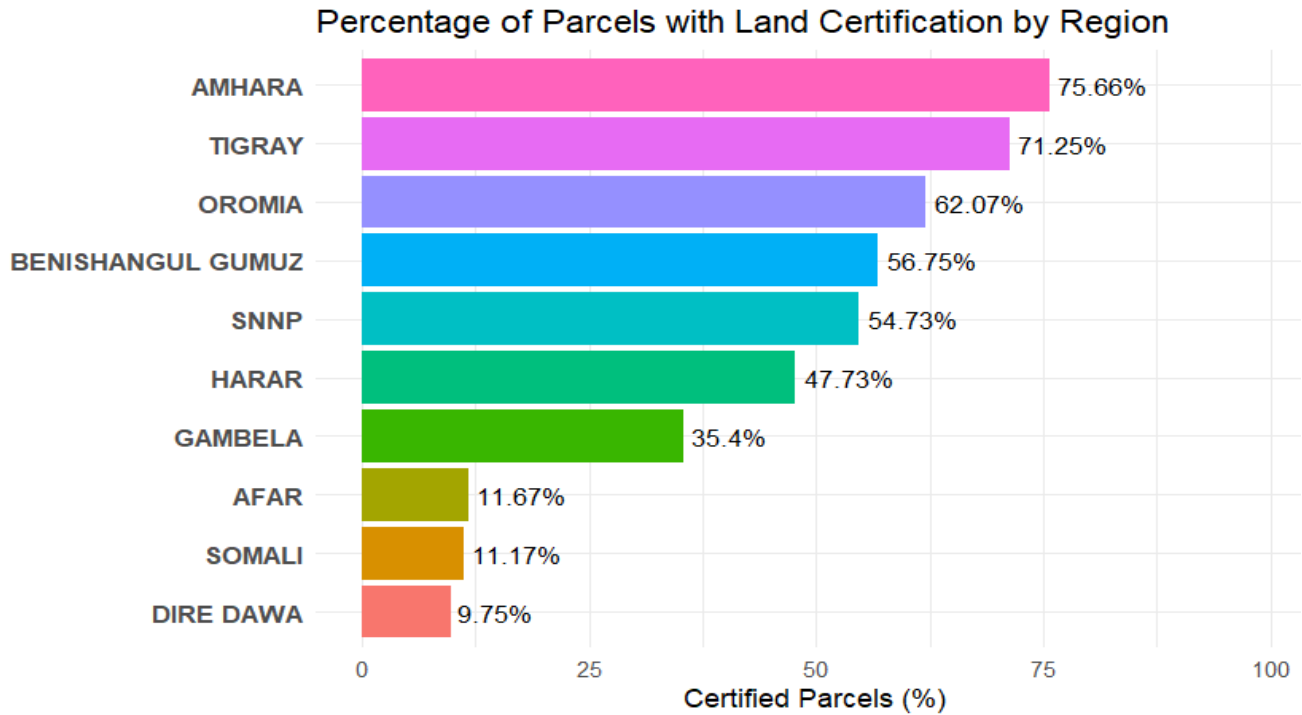


**Figure 3:** Land certification across regions

Figure 2 illustrates the association between formal land documentation and perceived rights, particularly the right to sell plots. The results reveal two key insights. First, there is a strong positive relationship between having formal land documentation and perceiving the right to sell. Notably, the largest group in the sample (57 percent) consists of landholders who possess both formal land certificates and perceive they have transfer rights. This indicates that formal land certification plays a crucial role in improving the perceived security of land by providing greater legal recognition and confidence in their ability to transfer their plots. Several findings suggest that formal land certification reinforces and legitimizes perceptions of informal land rights (Gedefaw et al., 2020; Tesfaye et al., 2023; Wolde, 2025).

Second, a considerable share (33 percent) of plot holders report having the right to sell their land without formal documentation, suggesting that customary tenure systems still hold significant legitimacy among rural communities. This pattern highlights that both formal and informal (customary or perceived) land tenure systems play a critical role in shaping farmers' perceptions of land rights in Ethiopia (Wolde, 2025). This also suggests that in developing countries like Ethiopia, formal land certification alone does not provide a complete picture of the tenure security system. Informal and customary land rights play an equally important role in complementing formal land rights. Hence, it is essential to consider both formal and informal land rights in the further analysis of land tenure systems.

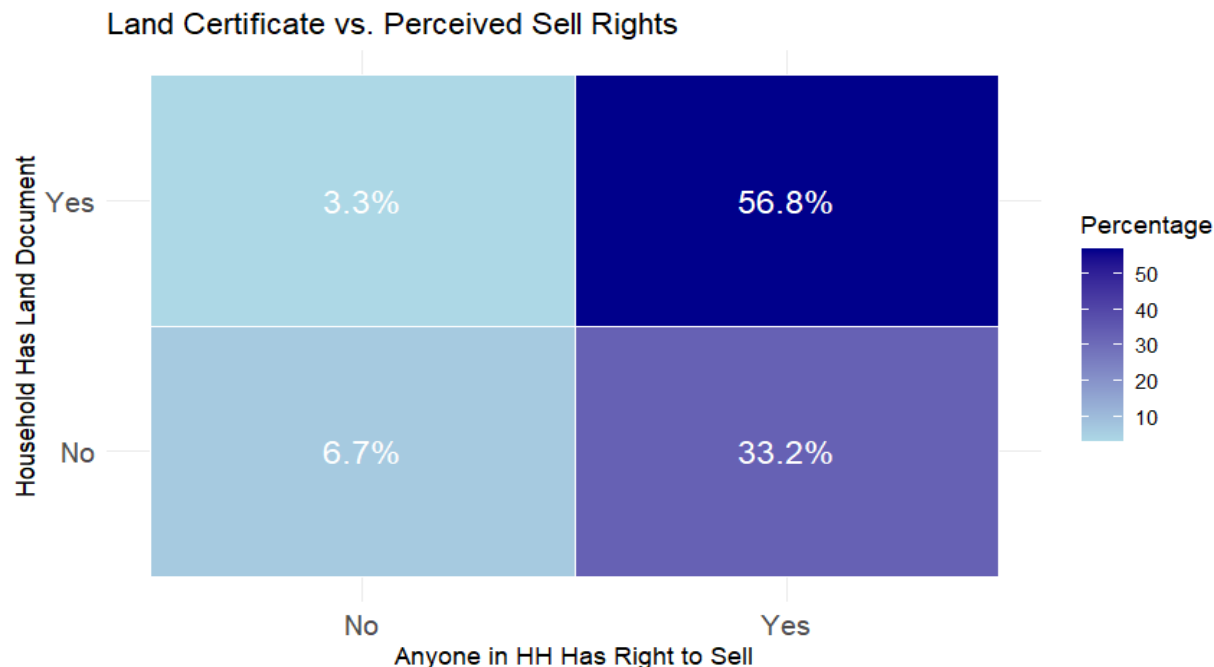


**Figure 4:** Formal and perceived land rights

#### 4.2. Difference-in-means between certified and uncertified groups

[Table 3](#) presents a comparison of average outcomes related to adaptation investments between landholders with and without a formal land certification, along with the associated statistical significance. The results highlight differences in land use behavior across the two groups during the survey period, with potential implications for the effectiveness of tenure security in promoting adaptive responses to climate change. For instance, the likelihood of crop rotation practices on certified plots was 83 percent during the 2013-2021 period, compared to 61 percent on uncertified plots. Certified plots also demonstrate higher rates of improved seed adoption and organic fertilizers. In the pooled sample, 24 percent of certified plots adopted improved seed compared to 19 percent of uncertified plots.

This finding suggests that land certification is associated with a higher likelihood of adopting improved agricultural inputs, which are essential for enhancing climate resilience and adaptation. Similarly, certified plots had greater participation in watershed management and increased agroforestry activities. Conversely, small-scale irrigation appears to be more prevalent on uncertified plots, likely due to contextual factors such as proximity to water sources and communal access arrangements that reduce the relevance of formal land rights.

In general, the observed differences-in-means reported in [Table 3](#) indicate notable variations between certified and uncertified parcels, particularly in terms of crop rotation, improved seed adoption,

watershed management, and agroforestry practices. These differences highlight the role of land certification in promoting adaptive land use behaviors and farmers' willingness to invest in sustainable agricultural practices. Yet, it is essential to move beyond descriptive comparisons and rigorously assess the extent to which the observed differences in adaptation investments can be causally linked to tenure security.

**Table 3: Difference-in-means between certified and uncertified groups**

| Outcome Variables  | Pooled panel<br>(2013/14-2021/22) |           |                                         | Panel 1<br>(2013/14-2015/16) |           |                                         | Panel 2<br>(2018/19-2021/22) |           |                                         |
|--------------------|-----------------------------------|-----------|-----------------------------------------|------------------------------|-----------|-----------------------------------------|------------------------------|-----------|-----------------------------------------|
|                    | Uncertified                       | Certified | H <sub>0</sub> : Diff. = 0<br>[P-value] | Uncertified                  | Certified | H <sub>0</sub> : Diff. = 0<br>[P-value] | Uncertified                  | Certified | H <sub>0</sub> : Diff. = 0<br>[P-value] |
| Crop rotation      | 0.614                             | 0.830     | [0.000]                                 | 0.612                        | 0.862     | [0.000]                                 | 0.617                        | 0.784     | [0.000]                                 |
| Improved seed      | 0.186                             | 0.240     | [0.000]                                 | 0.073                        | 0.108     | [0.000]                                 | 0.434                        | 0.414     | [0.080]                                 |
| Organic fertilizer | 0.422                             | 0.439     | [0.023]                                 | 0.592                        | 0.516     | [0.000]                                 | 0.232                        | 0.377     | [0.000]                                 |
| Irrigation         | 0.077                             | 0.044     | [0.000]                                 | 0.078                        | 0.039     | [0.000]                                 | 0.073                        | 0.051     | [0.000]                                 |
| Watershed          | 0.606                             | 0.699     | [0.000]                                 | 0.641                        | 0.759     | [0.000]                                 | 0.517                        | 0.616     | [0.000]                                 |
| Agroforestry       | 72.02                             | 97.94     | [0.002]                                 | 78.69                        | 84.88     | [0.435]                                 | 57.42                        | 115.23    | [0.001]                                 |

### 4.3. Empirical Results

#### 4.3.1. Formal land rights and Climate adaptation investments: Estimation results

In this section, we present the regression results on the impacts of land certification on different adaptation investments —crop rotation, use of improved seeds, organic fertilizer application, irrigation, watershed management, and agroforestry practices.

Table 4 reports the baseline results from random effects (RE) and RE-probit regression models. The results indicate that land certification is positively and significantly associated with **five (out of six)** adaptation investments. Specifically, land certification increases the likelihood of practicing crop rotation by 2-3 percent, the use of improved seeds by 4-5 percent, and the adoption of organic fertilizer by 2 percent. Formal certification is also positively associated with watershed management and agroforestry (fruit tree cultivation) practices, with holders of certified plots being 4 percent more likely to engage in watershed management activities, while fruit-bearing tree plantations increase by 8 percent with formal certification. The results from the correlated random effects (CRE) model, which accounts for time-invariant unobserved heterogeneity, further confirm the robustness of the baseline findings across all outcome variables, except for improved seed.

**Table 4: RE, probit, and CRE Estimation results (formal land rights)**

|                              | Crop rotation | Improved seed | Organic fertilizer | Irrigation | Watershed | Agroforestry |
|------------------------------|---------------|---------------|--------------------|------------|-----------|--------------|
| Plot                         | 0.028***      | 0.050***      | 0.019**            | -0.004     | 0.037***  | 0.080***     |
| Certification_ <b>RE</b>     | (0.008)       | (0.008)       | (0.009)            | (0.004)    | (0.010)   | (0.026)      |
| Plot                         | 0.023***      | 0.036***      | 0.021***           | -0.004     | 0.041***  | -            |
| Certification_ <b>probit</b> | (0.007)       | (0.008)       | (0.009)            | (0.004)    | (0.010)   |              |
| Plot                         | 0.024***      | 0.007         | 0.017**            | -0.005     | 0.035***  | 0.075***     |
| Certification_ <b>CRE</b>    | (0.008)       | (0.008)       | (0.009)            | (0.004)    | (0.010)   | (0.025)      |
| Control                      | Yes           | Yes           | Yes                | Yes        | Yes       | Yes          |
| Region-dummy                 | Yes           | Yes           | Yes                | Yes        | Yes       | Yes          |
| year-dummy                   | Yes           | Yes           | Yes                | Yes        | Yes       | Yes          |
| Observations                 | 33,806        | 22,867        | 19,028             | 25,400     | 33,806    | 22,830       |

**Note:** Figures in parentheses are robust standard errors clustered at the landholder level. **RE** denotes random effects. In the RE and CRE regressions, agroforestry is measured as the natural logarithm of the number of fruit-bearing trees. The control variables included in the regression are listed in [Table A1](#) (appendix). We also include spatial leave-one-out variables as controls in regressions (particularly for agroforestry) to account for local spillover effects.

However, the results in [Table 4](#) may be influenced by potential endogeneity concerns, particularly arising from reverse causality between tenure security and the outcome variables, which could lead to biased estimates. To address these concerns, validate our baseline findings, and provide a causal interpretation, we apply the CRE-IV approach. As noted earlier, CRE-IV accounts for both time-invariant and time-varying sources of endogeneity. Accordingly, our interpretations primarily rely on the CRE-IV results.

[Table 5](#) presents the results of CRE-IV regression estimating the impacts of formal land rights on various adaptation investments. The model of plot acquisition and the share of certified plots within the community are used as instruments for plot-level certification. The first-stage regression results indicate that these instruments are strong predictors of formal land rights, with positive and highly significant coefficients across all specifications. Moreover, both the under-identification and the F-test of excluded instrument (weak identification test) confirm the relevance and strength of the instrument, thereby supporting the validity of our IV estimation strategy.

The CRE-IV results in the first column of [Table 5](#) provide robust evidence that formal land rights significantly encourage investments in different adaptation investments. The IV estimates are qualitatively consistent with the baseline results reported in [Table 4](#), emphasizing the robustness of the positive impact of land certification on adaptation investments. In particular, land certification appears to induce landholders to exercise crop rotation in their plots. Using the first instrument, the mode of land acquisition, we find a 23 percent higher likelihood of practicing crop rotation in certified plots compared

to uncertified plots. In contrast, when using the second instrument, the community-level share of certified plots, the estimated effect corresponds to a 6 percent increase in the adoption of crop rotation. Similarly, formal land certification is found to increase the adoption of improved seeds (statistically significant only when using the second instrument) and organic fertilizers. Specifically, holders of certified plots appear to be 12 percent more likely to use improved seeds and 5-19 percent more likely to adopt organic fertilizers.

The effects of land certification on watershed management are also positive and statistically significant. Holders with land certificates are 4-9 percent more likely to engage in watershed management practices compared to those without formal certification. This finding is similar to previous studies such as [Adamie \(2021\)](#); [Hailay Tesfay & Machethe \(2024\)](#), which emphasize the role of tenure security in promoting soil and water conservation measures. A similarly significant and positive impact is observed between land certification and agroforestry practices. This suggests that the cultivation of fruit-bearing trees tends to be 11-28 percent higher on certified plots. This is consistent with other studies showing that formal rights encourage agroforestry activities ([Mekonnen, 2009](#); [Mengesha et al., 2019](#); [Wolde, 2025](#)).

In contrast, land certification does not appear to influence small-scale irrigation, implying that tenure security alone may not be sufficient to drive irrigation activities. The result is not quite unexpected, as irrigation in Ethiopia remains limited in both scale and accessibility, given that it requires substantial financial resources, access to water sources, supportive infrastructure, and technical expertise. Consequently, the marginal impacts of tenure security on irrigation are relatively weak in the Ethiopian context. Different studies also pointed out that tenure security may not be a standalone driver of agricultural investments in certain contexts ([Dinh et al., 2023](#); [Lin et al., 2020](#); [Schürmann et al., 2020](#)).

**Table 5: CRE-IV regression results (formal land rights)**

|                             | Crop rotation       |                     | Improved seed      |                     | Organic fertilizer  |                     | Irrigation         |                     | Watershed          |                    | Agroforestry        |                    |
|-----------------------------|---------------------|---------------------|--------------------|---------------------|---------------------|---------------------|--------------------|---------------------|--------------------|--------------------|---------------------|--------------------|
| <b>Plot certification</b>   | 0.233***<br>(0.036) | 0.055***<br>(0.014) | 0.006<br>(0.025)   | 0.124***<br>(0.012) | 0.193***<br>(0.031) | 0.053***<br>(0.015) | -0.020<br>(0.017)  | 0.021***<br>(0.007) | 0.090**<br>(0.042) | 0.036**<br>(0.018) | 0.283**<br>(0.122)  | 0.107**<br>(0.045) |
| IV: plot acquisition        | ✓                   | -                   | ✓                  | -                   | ✓                   | -                   | ✓                  | -                   | ✓                  | -                  | ✓                   | -                  |
| IV: share of certified      | -                   | ✓                   | -                  | ✓                   | -                   | ✓                   | -                  | ✓                   | -                  | ✓                  | -                   | ✓                  |
| Control                     | Yes                 | Yes                 | Yes                | Yes                 | Yes                 | Yes                 | Yes                | Yes                 | Yes                | Yes                | Yes                 | Yes                |
| Region-dummy                | Yes                 | Yes                 | Yes                | Yes                 | Yes                 | Yes                 | Yes                | Yes                 | Yes                | Yes                | Yes                 | Yes                |
| year-dummy                  | Yes                 | Yes                 | Yes                | Yes                 | Yes                 | Yes                 | Yes                | Yes                 | Yes                | Yes                | Yes                 | Yes                |
| First-stage Regression      | 0.21***<br>(0.010)  | 0.97***<br>(0.010)  | 0.23***<br>(0.011) | 0.99***<br>(0.011)  | 0.33***<br>(0.017)  | 0.99***<br>(0.011)  | 0.22***<br>(0.010) | 0.99***<br>(0.011)  | 0.26***<br>(0.014) | 0.97***<br>(0.010) | 0.296***<br>(0.016) | 0.99***<br>(0.012) |
| Under-ident. test [p-value] | 368.5<br>[0.000]    | 1506.9<br>[0.000]   | 356.8<br>[0.000]   | 1319.2<br>[0.000]   | 244.4<br>[0.000]    | 1196.6<br>[0.000]   | 371.1<br>[0.000]   | 1324.8<br>[0.000]   | 265.9<br>[0.000]   | 1511.1<br>[0.000]  | 239.9<br>[0.000]    | 1131.8<br>[0.000]  |

|                 |         |         |         |         |         |         |         |         |         |         |         |         |
|-----------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| weak inst. test | 426.3   | 9387.2  | 437.4   | 8804    | 379.6   | 7629.3  | 456.0   | 8523.8  | 370.7   | 9395.6  | 343.1   | 6995.7  |
| [p-value]       | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| Obs.            | 33,806  | 33,806  | 22,867  | 22,867  | 19,028  | 19,028  | 25,400  | 25,400  | 33,806  | 33,806  | 22,830  | 22,830  |

**Note:** figures in round brackets are heteroscedastic-robust standard errors. The mode of plot acquisition and the share of certified plots in the community are used as instruments. The under-identification test, with the null hypothesis that the model is under-identified and the alternative that it is identified (the excluded instrument is relevant, meaning correlated with land certification). The F-test of excluded instruments (weak identification test) assesses the strength of the instrument, with a null hypothesis of a weak instrument. Agroforestry is measured as the natural logarithm of the number of fruit-bearing trees. The control variables included in the regression are listed in [Table A1](#) (appendix). We also include spatial leave-one-out variables as controls in the regressions (particularly for agroforestry) to account for local spillover effects.

Overall, our regression results highlight the critical role of land certification in enhancing tenure security and promoting sustainable land use and adaptation investments. Formal land rights also appear to incentivize long-term investments such as agroforestry, which may offer multiple co-benefits, including improved household nutrition, income diversification, and environmental sustainability through enhanced biodiversity and soil conservation.

#### 4.2.2. Impacts of tenure security across different Vegetation density and health

As shown in [Figure 3](#), the relationship between tenure security and the adoption of adaptation investments varies across areas with differing vegetation density and health, as proxied by NDVI values. Our CRE-IV results reveal substantial heterogeneity in the effects of tenure security depending on ecological context, highlighting that land certification has differentiated impacts across areas with low and high vegetation density.

In areas with better vegetation density (more fertile and green environments), formal land certification is positively and significantly associated with crop rotation (6-21 percent), indicating that secure tenure encourages landholders to engage in crop diversification and intensification where returns are likely higher. That is, in environmentally conducive areas, secure land tenure greatly enhances crop rotation practices. In contrast, this relationship is weaker and even statistically insignificant (when using the second instrument) in low vegetation density areas, reflecting a more limited role of tenure security as an incentive for adopting such practices in low fertile areas. Regarding improved seed adoption, the impact of land certification is considerably stronger in high-NDVI regions—particularly when using the second instrument—where certification increases adoption by 15 percent, compared to only 6 percent in low-NDVI areas. This finding suggests that secure land tenure is more effective in promoting the use of productivity-enhancing inputs in ecologically favorable environments. However, when using the first instrument, the estimated effects are statistically insignificant in both high- and low-NDVI regions.

On the other hand, the results for organic fertilizers appear to be mixed. When using the first instrument, land certification has a significant positive effect in both high- and low-NDVI areas, with a substantially larger impact in high-NDVI regions—approximately double the effect observed in low-NDVI regions. However, when using the second instrument, the impact is significant only in low-NDVI areas. This may imply that in less fertile and degraded areas, secure tenure may play a more crucial role in motivating farmers to adopt fertility-enhancing practices as a means to improve soil fertility and sustain productivity.

In the case of watershed management and agroforestry practices, the results appear interesting as more pronounced effects are observed in areas with high NDVI values (better vegetation density). In particular, land certification increases the likelihood of engaging in watershed management by 12-14 percent in high NDVI regions. This indicates that in more fertile areas and water availability, secure rights encourage landholders to participate in soil and water conservation practices, as the expected returns from such activities are relatively high. Conversely, in drier and less ecologically favorable areas, these practices may be less feasible or yield lower benefits, thereby weakening the influence of tenure security.

Similarly, formal land rights significantly increase agroforestry (fruit tree cultivation) by 20-55 percent in high NDVI areas. These findings suggest that secure tenure promotes long-term, tree-based investments in areas with favorable agroecological conditions. In contrast, the relationship between land certification and agroforestry is statistically insignificant in low NDVI areas. As such, farmers may perceive limited profitability and viability of tree-based agricultural investments, even when land rights are secure, possibly due to a high risk of crop failure in more arid environmental constraints.



**Figure 3:** The CRE-IV estimates of tenure security across different NDVI values: The upper panels show the CRE-IV estimates using the mode of plot acquisition as the instrumental variable, while the lower panels display estimates based on the share of certified plots within the community as the instrument.

Overall, these findings emphasize the importance of ecological context in shaping the effectiveness of tenure security policies on adaptation investments. In areas characterized by better ecological conditions, secure tenure consistently promotes sustainable, climate-resilient, and long-term land use practices such as agroforestry, watershed management, and crop rotation. In contrast, in low NDVI regions, where climatic and soil constraints reduce expected returns, the influence of tenure security on such investments is limited. These findings are in line with prior works of [Besley \(1995\)](#) and [Wolde \(2025\)](#), who highlight that the effectiveness of tenure security in stimulating land-related investments is conditional on the broader ecological and economic context.

#### 4.2.3. Impacts of tenure security and gender differences

[Figure 4](#) presents the CRE-IV estimates showing the gender-disaggregated impacts of land certification on adaptation investments among female and male landholders. Accordingly, land certification

significantly increases the likelihood of crop rotation exercises for both genders, with comparable impacts. Certification is also strongly associated with the use of improved seed (when using the second instrument) and organic fertilizer for both. Furthermore, certification positively influences watershed management practices, particularly among male landholders, whereas it substantially promotes agroforestry (fruit tree cultivation) among female landholders. In contrast, consistent with earlier findings, land certification does not significantly affect the adoption of small-scale irrigation for either group. These findings highlight important gender-specific insights into how tenure security responds to adaptation investments.



**Figure 4:** Impacts of tenure security and gender differences: The upper panels show the CRE-IV estimates using mode of plot acquisition as the instrumental variable, while the lower panels display estimates based on the share of certified plots within the community as the instrument.

#### 4.2.4. Perceived land rights and climate adaptation investments

Given the significant role of perceived rights in shaping land use decisions in developing countries such as Ethiopia, we further examine the impacts of perceived rights—the right to sell and the right to bequeath—on the adoption of adaptation investments. [Tables 6 and 7](#) present the regression results.

[Table 6](#) shows the relationship between the perceived right to sell and adaptation investments. The findings indicate that landholders who perceive having the right to sell their land are associated with a 2–3 percent higher likelihood of practicing crop rotation and a 5–6 percent higher likelihood of adopting watershed management practices, compared to those who do not perceive such rights. Similarly, the perceived right to sell is related to a 15 percent increase in agroforestry practices. These results are consistent with our earlier findings based on formal land certification and confirm the role of tenure security in incentivizing sustainable land use and adaptation investments. Prior studies also found similar results (see [Adamie, 2021](#); [Gedefaw et al., 2020](#); [Hailay Tesfay & Machethe, 2024](#); [Mengesha et al., 2019](#); [Wolde, 2025](#); [Wolde & Bertacchini, 2025](#)).

However, the coefficients for perceived rights to sell are found statistically insignificant for the adoption of improved seeds, small-scale irrigation, and organic fertilizer. This suggests that the influence of perceived rights may vary depending on the type of investment, particularly those requiring upfront financial or technological inputs.

**Table 6: Perceived land security and climate adaptation investments (the right to sell)**

|                        | Crop rotation       | Improved seed       | Organic fertilizer | Irrigation       | Watershed           | Agroforestry        |
|------------------------|---------------------|---------------------|--------------------|------------------|---------------------|---------------------|
| Right to sell (RE)     | 0.032***<br>(0.011) | -0.014<br>(0.011)   | 0.010<br>(0.012)   | 0.003<br>(0.006) | 0.056***<br>(0.014) | 0.140***<br>(0.035) |
| Right to sell (Probit) | 0.024**<br>(0.010)  | -0.021**<br>(0.010) | 0.009<br>(0.012)   | 0.005<br>(0.006) | 0.058***<br>(0.014) | -                   |
| Right to sell (CRE)    | 0.028**<br>(0.011)  | -0.018*<br>(0.010)  | 0.013<br>(0.012)   | 0.005<br>(0.006) | 0.051***<br>(0.014) | 0.146***<br>(0.035) |
| Control                | Yes                 | Yes                 | Yes                | Yes              | Yes                 | Yes                 |
| Region-dummy           | Yes                 | Yes                 | Yes                | Yes              | Yes                 | Yes                 |
| year-dummy             | Yes                 | Yes                 | Yes                | Yes              | Yes                 | Yes                 |
| Observations           | 32,280              | 21,485              | 17,572             | 24,030           | 32,280              | 21,449              |

**Note:** Figures in parentheses represent robust standard errors clustered at the landholder level. **RE** denotes random effects. In the RE and CRE regressions, agroforestry is measured as the natural logarithm of the number of fruit-bearing trees. The control variables included in the regression are listed in [Table A1](#) (appendix).

The relationship between the right to bequeath and adaptation investments is reported in [Table 7](#). Overall, the results do not reveal a consistently strong association between the right to bequeath and most

adaptation practices. One notable exception is that the right to bequeath is positively and significantly associated with agroforestry practices. Landholders who perceive they have the right to transfer their land to heirs increase agroforestry by about 12 percent, suggesting the potential of inheritance-related tenure security in promoting long-term land use investments.

**Table 7: Perceived land security and adaptation investments (the Right to bequeath)**

|                               | Crop rotation    | Improved seed     | Organic fertilizer | Irrigation        | Watershed        | Agroforestry       |
|-------------------------------|------------------|-------------------|--------------------|-------------------|------------------|--------------------|
| Right to Bequeath<br>(RE)     | 0.025<br>(0.018) | -0.006<br>(0.012) | -0.014<br>(0.017)  | 0.017*<br>(0.010) | 0.029<br>(0.023) | 0.129**<br>(0.062) |
| Right to Bequeath<br>(Probit) | 0.021<br>(0.016) | -0.005<br>(0.011) | -0.015<br>(0.017)  | 0.015*<br>(0.008) | 0.032<br>(0.023) | -                  |
| Right to Bequeath<br>(CRE)    | 0.019<br>(0.018) | -0.005<br>(0.012) | -0.009<br>(0.017)  | 0.018*<br>(0.010) | 0.031<br>(0.022) | 0.124*<br>(0.064)  |
| Control                       | Yes              | Yes               | Yes                | Yes               | Yes              | Yes                |
| Region-dummy                  | Yes              | Yes               | Yes                | Yes               | Yes              | Yes                |
| year-dummy                    | Yes              | Yes               | Yes                | Yes               | Yes              | Yes                |
| Observations                  | 10,584           | 7,305             | 8,363              | 8,103             | 10,584           | 7,296              |

**Note:** Figures in parentheses represent robust standard errors clustered at the landholder level. **RE** denotes random effects. In the RE and CRE regressions, agroforestry is measured as the natural logarithm of the number of fruit-bearing trees. The control variables included in the regression are listed in [Table A1](#) (appendix). Note that, because of data availability constraints, our estimation of the effects of the right to bequeath is restricted to the 2018/19–2021/22 period.

## 5. Discussion of our results

The empirical findings from this paper provide robust evidence that secure rights in both formal and perceived dimensions play a significant role in shaping landholders' decisions to adopt a wide range of adaptation investments in Ethiopia. These findings align closely with theoretical frameworks that posit enhanced tenure security as a key driver of long-term investments in sustainable land use and climate resilience ([Ali et al., 2011](#); [Besley, 1995](#); [Demsetz, 1974](#)). The analysis reveals that formal land certification is positively and significantly associated with the adoption of key sustainable agricultural practices, including crop rotation, improved seed use, organic fertilizer, watershed management, and agroforestry. These findings highlight the critical role of tenure security in fostering land-based investments that not only enhance agricultural productivity and income diversification but also strengthen smallholders' capacity to adapt to climate change ([Castro & Kuntz, 2022](#)).

In addition to formal certification, perceived rights, particularly the right to sell, also have a positive and significant impact on farmers' adaptation investments. Farmers who perceive they have the right to sell or transfer their land are more likely to engage in practices such as crop rotation, watershed management,

and agroforestry, relative to those who do not perceive such rights. This signals the importance of both de jure and de facto land security in encouraging climate-resilient investments ([Holland et al., 2022](#)).

The positive effects of secure rights on climate adaptation investment may operate through several key mechanisms. Historically, Ethiopia's land tenure system has been characterized by insecurity and weak enforcement, discouraging smallholder farmers from making long-term investments in their land ([Ayana et al., 2013](#)). Reforms that enhance tenure security, most notably through formal land certification, reduce the perceived risks of land expropriation by the state or other actors ([Besley, 1995](#)). This assurance is crucial for farmers to undertake investments like agroforestry and soil conservation, which typically yield benefits over longer time horizons. Without secure tenure, the threat of losing land rights can deter such forward-looking practices. A second important mechanism will be access to credit ([Bogliacino et al., 2025](#)). Securing land rights can improve farmers' borrowing ability, either through formal or informal lending systems. Although Ethiopia's banking sector does not widely accept land as collateral, the country has a rich tradition of informal lending. In these contexts, land ownership or perceived land security enhances a farmer's credibility and borrowing capacity. Households with either formal or perceived rights are viewed as more credible borrowers, making them more likely to access financial resources necessary for implementing adaptation investments.

Tenure security also reduces local land-related conflicts. Secure rights tend to improve farmers' control over and access to their land, which reduces disputes and enhances confidence in land use decisions. This is particularly relevant in Ethiopia, where land conflicts are common and can significantly influence household investment behaviors ([Moreda, 2023](#)). Hence, secure tenure reduces uncertainty and enables farmers to commit resources to long-term adaptation practices without fear of losing access to their plots. Furthermore, tenure security contributes to the development of land markets. In Ethiopia, land is not only an economic asset but also a symbol of social status and wealth. Secure rights facilitate land transactions, such as rental agreements or informal sales, that allow for more efficient land use and investment ([Deininger et al., 2011](#)). The growth of land markets, in turn, encourages landowners to improve their land and maintain its value, further promoting adaptation investments.

In general, we argue that formal and perceived rights foster climate adaptation through a range of interlinked mechanisms, including reduced risk of expropriation, improved access to credit, decreased land conflicts, and enhanced land market activity ([Castro & Kuntz, 2022](#)).

The findings reveal that the impact of secure rights on climate adaptation investment is not uniform across regions (Kurbanov et al., 2025), emphasizing that there is no ‘one-size-fits-all’ approach to leveraging land rights for climate resilience. In this regard, another key contribution of this paper shows how agroecological conditions moderate the effects of tenure security. The findings show the significance of considering local contexts that potentially shape the impact of secure rights on adaptation investments. In better vegetation areas, land certification has a strong and significant positive effect on multiple practices, including crop rotation, improved seeds, watershed management, and agroforestry. These areas offer greater potential returns, making secure tenure more impactful in promoting adaptive behaviors (Besley, 1995; Wolde, 2025). In contrast, in areas with low low vegetation density, the impact of land rights is weaker, statistically insignificant, or even negative. This suggests that tenure security alone may not be sufficient to motivate climate adaptation in degraded or arid areas. In such environments, ecological limitations may overshadow the potential benefits of secure tenure. This highlights the importance of contextual factors in shaping how and to what extent land rights affect farmers’ adaptation decisions.

The gender-disaggregated results also reveal that while both male and female landholders benefit from formal land certification, the pathways and magnitude of these effects differ. Notably, male landholders are more likely to invest in watershed management following certification, suggesting that men may respond more strongly to tenure security in practices that are labor- or resource-intensive. Conversely, certification has a particularly pronounced effect on agroforestry adoption among female landholders, indicating that secure tenure may empower female landholders to make long-term, sustainability-oriented investments. These gender-differentiated outcomes underscore the need for climate and land policy interventions to be gender-responsive, ensuring that land tenure reforms are designed and implemented in ways that address the constraints and opportunities facing female farmers.

The findings appear to have important policy implications for enhancing adaptation investments in Ethiopia. Strengthening the land certification system is a critical strategy for promoting climate-resilient agriculture, particularly in more productive regions with higher ecological and economic returns on agricultural investments. This requires reducing the cost and improving the accessibility of land certification, as well as addressing bureaucratic obstacles that hinder implementation. In particular, expanding certification efforts in underserved regions such as Afar, Somali, Dire Dawa, and Gambella is essential to stimulate investment and ensure a more equitable distribution of the benefits associated with land tenure reforms.

The positive effects of perceived rights, particularly on agroforestry practices, highlight the importance of providing comprehensive and transferable land rights for long-term agricultural investments. Allocating broader bundles of rights, including the rights to sell, rent, and bequeath, can significantly enhance the effectiveness of property rights reforms. Given that Ethiopia has not yet implemented full private land ownership, this remains a critical area for policy improvement. Moreover, a context-specific approach is essential. Land tenure interventions should be tailored to the local agroecological conditions. In areas with harsh environmental conditions, complementary interventions such as extension services, reforestation initiatives, credit, and market access may be necessary to enhance the impact of tenure security on climate adaptation investment. Finally, integrating secure rights with other support mechanisms, such as access to formal credit, is likely to generate the most substantial and sustainable outcomes.

## **6. Concluding Remarks**

We investigate the impact of secure rights on adaptation investments in Ethiopia and found strong empirical evidence underscoring the crucial role of tenure security in encouraging such investments among smallholder farmers. Using nationally representative panel data and a range of econometric models, including correlated random-effects and panel instrumental variable (CRE-IV), the analysis shows that secure rights, measured through both formal land certification and perceived land tenure, significantly enhance the adoption of key climate-adaptive agricultural practices. Formal land certification is particularly associated with increased uptake of agroforestry, crop rotation, improved seed use, organic fertilizer application, and watershed management.

In addition to formal documentation, perceived rights, mainly the rights to sell land, also positively influence farmers' adaptation decisions, reinforcing the complementarity of both legal and perceived tenure security for enhancing adaptation investments. These results confirm theoretical expectations from the property rights literature and highlight that secure tenure encourages short-, medium-, and long-term agricultural investments, thereby improving farmers' climate resilience and adaptation practices.

In addition, the study reveals substantial regional heterogeneity and moderate gender differences. In more fertile areas, land rights exert a stronger influence on adaptation behavior. In contrast, in ecologically constrained, low-fertility regions, the effect of tenure security is weaker, suggesting that land rights alone are insufficient where environmental and economic constraints are more severe. This highlights the need

for a context-specific approach to land and climate adaptation policies. Strengthening land certification, particularly in agriculturally productive regions, can be an effective strategy for enhancing climate resilience. Policymakers should prioritize making certification affordable, accessible, and administratively efficient. Furthermore, expanding the legal recognition of broader bundles of land rights can enhance farmers' confidence and willingness to invest.

In conclusion, this study underscores the critical role of tenure security in driving agricultural investments that support climate change adaptation. It also highlights the need for an integrated and context-specific policy agenda that combines tenure reform with complementary interventions to enhance rural climate resilience and promote sustainable land use.

While this study makes important contributions, several avenues for future research remain. First, because the analysis is confined to Ethiopia, comparative studies in other low-income or land-insecure settings would help substantiate the generalizability of these findings. Second, employing experimental and quasi-experimental designs with more advanced methodologies would allow for a more rigorous identification of the causal mechanisms linking land rights to adaptation investments. Unpacking these pathways could inform more targeted and effective policy interventions. Third, the effects of land rights on adaptation investments may vary over time. While some effects may appear relatively quickly, others are likely to unfold more gradually due to the long-term nature of certain practices. Since this study lacks data on the pace at which different adaptation measures respond to tenure security, future research should examine these temporal dynamics to better understand the timing of impacts.

## Appendix

### 1. Description of climate adaptation strategies

**Crop Rotation:** Crop rotation refers to the practice of cultivating different crops on the same plot of land across successive growing seasons. Empirical evidence indicates that crop rotation can enhance the climate resilience of farming systems by improving water dynamics, soil fertility, and biological diversity (Bowles et al., 2020; Yu et al., 2022). It represents a relatively low-cost, knowledge-based adaptation strategy that farmers utilize to mitigate climate-related risks.

**Improved Seed:** it refers to crop seed varieties that have been developed through scientific breeding methods to perform better than traditional or local varieties (Sun et al., 2024). Adoption of improved seed varieties is a promising strategy to achieve increased yields, support food security, and reduce poverty under climate change (Otieno et al., 2022). By reducing the risk of crop failure under erratic rainfall and extreme weather, improved seeds directly enhance farmers' resilience to climate variability (Thapa & Dhakal, 2024).

**Organic Fertilizer:** It is the application of compost, manure, or other organic inputs in place of chemical fertilizers to enhance soil fertility and improve agricultural productivity. Organic fertilizer enables agricultural ecosystems to better adjust to the effects of climate change and has major potential for reducing agricultural greenhouse gas emissions (He et al., 2023).

**Irrigation:** Irrigating plots during the agricultural season is one of the most direct measures of adaptation to rainfall variability and drought (Olayide et al., 2016). Irrigation reduces dependence on unpredictable rainfall and helps farmers stabilize production in the face of climatic shocks (Ward, 2022). Irrigation is widely recognized as a potential adaptation strategy to climate variability, as it enhances resilience by buffering crop production against drought shocks and reducing yield losses associated with extreme temperature events (Taylor, 2023).

**Integrated Watershed Management:** it is an approach that promotes the sustainable management of watershed areas through coordinated and holistic practices addressing land, water, and related resources (Wolka et al., 2023). Studies have documented the positive contributions of watershed management activities, such as soil and water conservation, to climate change adaptation by reducing surface runoff, improving soil moisture retention, and enhancing crop productivity (Mekonnen et al., 2021; Wolka et al., 2023).

**Agroforestry:** it is the deliberate incorporation of trees or shrubs into crop and livestock production systems (Quandt et al., 2023). As an adaptation measure, it contributes to enhancing ecological functions and improving the resilience of agricultural systems to climate variability and risk (Zeratsion et al., 2024). Agroforestry is widely recognized as a nature-based adaptation strategy with long-term resilience benefits (Dhyani et al., 2021). In addition to mitigating climate change, agroforestry plays a vital role in enhancing food security and improving household income.

## 2. Control variables

**Table A1:** List of control variables

| Covariates      | Description                                                           |
|-----------------|-----------------------------------------------------------------------|
| Num fields      | Number of Fields (sub-parcels) in a parcel (plot)                     |
| Soil type       | The soil type of the parcel (1 if Vertisol)                           |
| Credit          | Does the holder get credit services (1 if yes)                        |
| Advisory        | Does the holder get advisory services (1 if yes)                      |
| Extension       | Does the holder participate in the extension program? (1 if yes)      |
| Solar           | Access to off-grid solar energy                                       |
| PSNP            | Did HH receive any PSNP in the past 12 months?                        |
| Dist_Market     | Household Distance to the nearest market (in KMs)                     |
| Dist_Road       | Household Distance to nearest major Road (in KMs)                     |
| Dist_pop center | Household Distance in (KMs) to Nearest Population Center with +20,000 |
| Dist_border     | Household Distance in (KMs) to Nearest Border Crossing                |
| Temperature     | Annual Mean Temperature                                               |
| Precipitation   | Annual Precipitation (in mm)                                          |
| Elevation       | Elevation (m)                                                         |
| Agroecology     | Major Agroecological Zone (1 if Tropical cool)                        |
| Sex             | Sex of the holder (1 if Male)                                         |
| Age             | Age of the household head                                             |
| Married         | Marital status of the household head (1 if married)                   |
| Schooling       | School attendance of the household head (1 if yes)                    |

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