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Smallholder access to purchased seeds in the presence of pervasive market imperfections and rainfall shocks: panel data evidence from Malawi and Ethiopia

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Abstract

Seed purchasing enables farmers to respond to adverse events that may cause chronic and temporary seed insecurity by allowing them to exploit opportunities associated with accessing new seeds. However, as with other inputs, seed purchasing is complicated by pervasive market imperfections and climate risk common in Sub-Sahara Africa. This study uses balanced household panel data for Malawi (2010–2018) and Ethiopia (2012–2016) and applies dynamic random effects Probit and Tobit models to assess how seed purchase decisions are affected by earlier participation in the market, lagged rainfall shocks, and historical climate variables. Our findings show that there are nonlinear effects of lagged seed purchase decisions on subsequent decisions with strong initial effects (weakening over time). For instance, initial maize seed purchase decisions are associated with about 11 and 22% higher probability of purchase and 1 and 2% higher shares of seed volumes purchased in later rounds in Malawi and Ethiopia, respectively. Seed purchase decisions also respond to climate variability and shocks. For instance, lagged drought shocks enhance subsequent maize purchase decisions in both countries. Historical average rainfall and temperature enhance maize seed purchase decisions in both countries. Overall, results point to state dependency on the demand side of the seed market, leading to selective access to purchased seeds. Also, seed purchase in smallholder farming is a liquidity and risk-dependent input choice. Policy efforts need to continue targeting reducing transaction costs and other barriers to entry into seed markets to enhance access to off-farm seed and support adaptation to rainfall shocks.

Keywords: Nonlinear transaction costs, Household seed security, Dynamic random effect models, Smallholder farmers, Rainfall shocks, Malawi and Ethiopia

Introduction

Access to a diversity of good-quality seeds is crucial for smallholder farmers' food production, nutrition, and resilience in the face of climate change and natural disasters. Smallholder farmers in developing countries access seeds through formal and informal seed systems (FAO 1998; Sperling et al. 2008). On the one hand, i*nformal* seed systems are based on farmers saving their own seeds and involved farmers' seed selection, production, storage, dissemination, and use (Almekinders et al. 1994; Almekinders and Louwaars 2002; Coomes et al. 2015; Westengen et al. 2023). *On the other hand, formal* seed systems include public and private sector institutions and a series of activities along the seed value chain, including conservation of germplasm in gene banks, development of new varieties, crop variety release, registration, seed production, and dissemination to farmers. Historically, most smallholder farmers save seeds from their previous harvests, a strategy that reduces the costs associated with purchasing seeds and provides seeds of guaranteed quality and well adapted to their local agroecology (Tripp 2006; Nordhagen and Pascual 2013). However, to meet diverse needs and challenges, smallholder farmers also source seeds outside the farm (Bellon et al. 2006; Coomes et al. 2015). Access to seed off-farm is important in complementing farmer-saved seed and enhancing household seed security. Seed security exists when both men and women within farming households have ready access to sufficient quantities of quality seeds and planting materials of preferred crop varieties adapted to their local agroecological conditions and socioeconomic needs at planting times in both good and bad seasons (FAO 1998; FAO & ECHA 2015). Access to seeds off-farm becomes even more critical when farmers want to access new seeds and want to grow new crops, when farmers' stock of farmer-saved seed has depleted (e.g., through destruction from pests and disasters or family consumption in periods of food scarcity), or when the quality of seed stored has degenerated (Almekinders et al. 1994, 2007; Nordhagen and Pascual 2013; Makate et al. 2023b). While farmers may access new seeds free of charge through emergency aid and or social networks, the bulk of new seeds is paid for in cash, either at local markets or from agro-dealers (McGuire and Sperling 2016; Sperling 2020).

As with other farming inputs, access to new seeds through the market is complicated by the pervasive imperfections that characterize many markets in the developing world, particularly Sub-Sahara Africa (SSA). Missing information on commodity prices and technologies, credit constraints, high transaction costs, and poor infrastructure make it difficult for smallholder farmers to fully engage in input and output markets (Fafchamps 2004; Dorward et al. 2005; Shiferaw et al. 2008; Markelova et al. 2009). For instance, smallholder farmers' access to new seeds through local and regional/national markets is complicated by transaction costs associated with participating in those markets. With imperfect factor markets that are poorly integrated, developed, and spatially dispersed, smallholder farmers face variable transaction costs (Binswanger and Rosenzweig 1986; Key et al. 2000; Renkow et al. 2004; Barrett 2008; Holden et al. 2010; Ricker-Gilbert and Chamberlin 2018). Following Coase (1937) and North (1987), transaction costs are the costs incurred in making a market transaction, excluding the actual price paid for the commodity. These include costs associated with: (i) searching and attracting potential trading partners, including presale inspection, (ii) negotiation, contracting, and fulfillment costs, and (iii) monitoring and implementation costs (Coase 1937; North 1987). Such costs can significantly influence decisions by households on whether to participate or not participate in the market. This is because transaction costs raise the price effectively paid by buyers and lower the price effectively received by sellers of a good, creating a price range within which some households may find it unprofitable to sell or buy (De Janvry et al. 1991;

Key et al. 2000). In seed markets and on the demand side, such transaction costs may include the costs of searching and obtaining information on production and consumption traits of the seed of different crops and or varieties desired by the farmer, costs of searching and locating them, including transport costs, and negotiation costs.

To overcome challenges posed by imperfect factor markets and maintain their position in the market, smallholder farmers invest their time in establishing localized information networks (Fafchamps 2004) and engaging in collective action (Markelova et al. 2009). Over time, such efforts help farmers reduce transaction costs and enhance their linkage to factor markets. This study focuses on smallholder farmers' seed purchase decisions in Malawi and Ethiopia and investigates how access to purchased seeds is constrained (or facilitated) by state dependency and other factors. State dependency in markets implies that market participants capitalize on their experience and established networks gained through repeated engagements in the markets to identify trading partners, which is not the case with new entrants without such experience and networks in factor markets (Fafchamps 2004; Gebru et al. 2019; Holden and Tilahun 2021; Tione and Holden 2021; Makate et al. 2023a).

Given the prevalence of pervasive and nonlinear transaction costs in input markets in SSA (Key et al. 2000; Renkow et al. 2004; Barrett 2008; Holden et al. 2010; Ricker-Gilbert and Chamberlin 2018; Tione and Holden 2021) and subsequent low access to seed through formal markets (Tripp 2006; McGuire and Sperling 2013; Nordhagen and Pascual 2013), investigating the extent of state dependency in seed markets is important. Therefore, this paper investigates the extent to which smallholder farming households' access to purchased seeds is constrained (or facilitated) by state dependency (past market access), farmer characteristics, community characteristics, lagged rainfall shocks, and long-term average climate (rainfall and temperature). Empirical evidence from such a study will help inform policies that aim to reduce barriers to entry in seed markets (through purchase) to enhance access to new seeds to complement farmers' saved seed (and seed from other sources) and enhance overall seed security under shocks for better livelihoods in smallholder farming.

We compare Malawi and Ethiopia: two countries with contrasting features regarding the policy framework governing the development of seed systems that farmers use. Key differences in policies and institutions governing formal seed systems in Malawi and Ethiopia lie in the roles played by the government and the private sector seed value chains (Langyintuo et al. 2010; Kassie et al. 2013; Erenstein and Kassie 2018; Westengen et al. 2019). In Malawi, the seed industry is characterized by the dominance of the government as buyer and distributor of seed and the high market share and power of a few private seed companies (Kassie et al. 2013). On the contrary, the government dominates Ethiopia's formal seed system in all functions and for most crops, with the private sector having a minimal role. In both countries, seed policies and regulations have evolved, with efforts directed toward developing formal seed systems. However, in Malawi, policy efforts have mainly targeted the facilitation and growth of the formal sector. At the same time, Ethiopia currently adopts a pluralistic approach that aims to target the growth of formal, intermediate, and informal sectors (Westengen et al. 2019; Mulesa et al. 2021). The differences in policy frameworks governing seed systems in the two countries could offer different constraints and opportunities to reduce transaction costs in accessing seeds through purchasing.

The rest of this article is organized as follows: The next section describes the theoretical framework and specifies the study hypotheses. In "Context, data, and estimation strategy" section outlines the empirical estimation approach and data, while "Results" section presents the results. Finally, "Discussion" section discusses the results, while "Conclusions" section concludes the article.

Theoretical framework

Theory and evidence point to poorly developed factor markets in some parts of SSA. The implication is that market access by farming households is not uniform, as they may face different transaction costs for participation (Binswanger and Rosenzweig 1986; Key et al. 2000; Renkow et al. 2004; Barrett 2008). In addition, geographic markets are spatially dispersed and not well integrated into the global economy because of differences in costs of commerce and the disparities in competition among marketing intermediaries (Fackler and Goodwin 2001; Barrett 2008). With such imperfections, market participants may face different participation transaction costs, which may change over time (Holden et al. 2007, 2010; Tione and Holden 2021). In SSA, such costs are high, and they emerge from policies, institutions, and other socioeconomic factors that contribute to high information asymmetries and differential access and use of productive resources by households (Key et al. 2000; Renkow et al. 2004; Barrett 2008; Holden et al. 2010; Ricker-Gilbert and Chamberlin 2018; Tione and Holden 2021).

Transaction costs related to market engagement affect both the demand side (e.g., acquiring inputs from the market) and the supply side (e.g., delivering farm produce to the market). Transaction costs on the demand side include expenditures incurred when conducting market transactions for inputs other than the price, including costs associated with search, negotiation, supervision, and bargaining. In contrast, farm-to-market transaction costs include the costs associated with the trading output produced from the farm. This paper focuses on transaction costs associated with access to seeds through purchase from the market. In terms of seed access through purchase, transaction costs incurred may include the costs of searching and getting information on production and consumption traits of farmers' preferred seed for their different crops and or varieties, costs of searching and locating them, and costs of negotiating and making the transactions, excluding the price paid for the seeds. Some of the specific factors that contribute to high transaction costs in developing areas, including in studied country contexts, include larger distances traveled to input markets, high costs of transportation, the poor state of roads (and poor road networks), low bargaining power by smallholder farmers, and general lack of information which increase seed search costs and overall seed access costs (Kassie et al. 2013; Husmann 2015). Farmers require new seeds every year to fulfill their production activities, and they can access them through their seed savings, relief, subsidies (e.g., coupons), or purchases. Saving their own seed is a common practice by smallholder farmers in SSA with low transaction costs (Tripp 2006), but they sometimes face storage and seed quality-related challenges. Access to relief or subsidized inputs is another important seed source in SSA, particularly following the recent revitalization of government subsidy programs (Jayne and Rashid 2013). However, such programs target specific farmers based on underlying objectives and rarely meet the farmer's demand for inputs. Besides, farmers also incur transaction costs when accessing subsidized inputs. Seed purchases allow the farmers to access new seeds and supplement other seed sources. Given the poorly developed markets common in some parts of SSA, access to purchased seeds may be restricted by high transaction costs associated with participation by farmers as buyers in seed markets. Overall, information asymmetries, limited knowledge by farmers, resource constraints, and uncertainties related to future weather add to imperfect information and transaction costs that influence access to seed by farmers (Binswanger and Rosenzweig 1986; Crawford et al. 2003; Barrett 2008).

Survival and progression of societies in the presence of pervasively imperfect factor markets require production relations[1] that allow farming households to effectively carry out their current and intertemporal decisions (Binswanger and Rosenzweig 1986). For households to achieve (i) high incomes and consumption and (ii) even out consumption over time by avoiding risk and disasters and making provisions for dealing with the consequences of unavoidable and unforeseen risks and disasters, production relations should adapt to current and intertemporal problems by the people (Binswanger and Rosenzweig 1986). In the context of seed markets, farmers will need to adapt to the high transaction costs and other factors that limit their access to seed through the market. For example, farming households may engage in collective action and build their social networks over time to overcome or reduce transaction costs in buying seed from the market. Upon entering the seed market for the first time, farming households may invest in establishing networks of information and social capital that may help them face lower transaction costs in subsequent years (Binswanger and Rosenzweig 1986; Key et al. 2000; Fafchamps 2004; Barrett 2008). Therefore, past trade experience in the seed market may affect current seed market access and intensity of participation. We, hence, expect to find state dependency when analyzing farm household panel data capturing seed purchasing decisions over time.

In line with previous studies that have applied dynamic transaction cost models in studying mainly household land rental market decisions (Holden et al. 2007, 2010; Gebru et al. 2019; Holden and Tilahun 2021; Tione and Holden 2021), we study dynamic seed purchase decisions in smallholder farming in Malawi and Ethiopia. Following dynamic transaction costs models, household intertemporal decisions to purchase seed may be expressed as in Eq. 1:

$$\overline{P}_t^H = \sum_S \overline{P}_t^{HS}\left(c_t^{HS}\left[c_0 + c_t^{HS}\left\{\overline{E}_t^H, \overline{P}_{t-n}^{HS}, R_v, \mathcal{R}_{t-1}, \mathbb{C}_v, M_{vt}, \int_{t-e}^{t} G dt; v_t^w, v_t^f\right\}\right]\right) \quad (1)$$

The dynamic model specified in Eq. 1 states that a household's access to purchased seeds (P) at a time (t) is the sum of access to seeds from seed suppliers in the seed market (S), represented as $\left(\sum_S \overline{P}_t^{HS}\right)$. This access is itself a function of transaction costs (c) that consist of two components: an initial fixed cost component (c_0), and a

[1] Production relations according to Binswanger, H. P., & Rosenzweig, M. R. (1986). Behavioral and material determinants of production relations in agriculture. *The Journal of Development Studies*, *22*(3), 503–539. refer to the relations of people to factors of production, and corresponding relations of people among each other as factor owner and renters (e.g., as tenants, landlords, employers, workers, debtors, creditors).

non-linear variable transaction cost (c_t^{HS}). The variable nonlinear transaction cost components (c_t^{HS}) depend on both observable and unobservable factors, which include the household's resource endowments (land, labor, and household assets) ($\overline{E}_t^{H}$), previous participation in the seed market ($\overline{P}_{t-n}^{HS}$) that help accumulate knowledge and experience over time. These nonlinear transaction costs are not directly observable but can be identified by investigating the influence of households' previous participation in the seed market on later participation decisions using panel data on seed purchase decisions. We capture previous participation in the seed market ($\overline{P}_{t-n}^{HS}$) using lagged market participation variables that capture both participation and intensity of participation, including initial survey year participation variables and participation variables for the previous survey round (t−1).

In addition, R_v, $\mathcal{R}_{t-1}, \mathbb{C}_v$, respectively, captures long-term average rainfall, lagged rainfall shocks (1-year lag drought and flood shock), and long-term average temperature (38-year average)) for the main crop growing season. Recurrent erratic rains and weather shocks that lead to crop failure may disrupt farmer stocks of their own saved seed or make it hard to set aside seed from harvest due to urgent consumption needs, forcing farmers to source seed from elsewhere through trade (Bellon et al. 2011; Nordhagen and Pascual 2013). However, for rural smallholder farming households operating under uncertain production environments with imperfect credit and insurance markets, recurrent rainfall variability may also impose liquidity constraints, limiting technology adoption, and input use decisions such as seed purchase. Therefore, response to rainfall shocks is complex, as households may switch from selling food (relaxed liquidity constraints) in years with good rainfall and becoming net buyers in years with poor rainfall (tighter liquidity constraints). Seed purchase is a liquidity-dependent risky input (determined both by the level of liquidity constraints and the degree of uncertainty in the production environment), which implies that it may directly respond to measures of rainfall variability and shocks.

The component (M_{vt}) captures community market access. Households in communities with better access to market and market infrastructure will likely face lower transaction costs in accessing seed and may have higher chances of participating in the seed market through purchase. The component ($\int_{t-e}^{t} G\mathrm{d}t$) captures the dynamic effects of policy changes that may influence transaction costs in the seed market over time. More so, the spatial nature of the seed market implies that access to purchased seed is location-specific and conditional on household characteristics (v_t^{w}) and community characteristics (v_t^{f}), including agroecological conditions, population pressure, and market access. Based on this theoretical model, we seek to test a few hypotheses:

H1 There is persistent state dependency on the smallholder farmers' seed purchase decisions, causing selective access to purchased seeds over time. We hence expect to find lagged seed purchase variables (purchase and extent of purchase) to explain latter participation and extent of participation strongly and positively in the seed market.

H2 Long-term average rainfall in the crop growing season positively affects seed purchase decisions.

H3 Lagged rainfall shocks positively influence seed purchase decisions.

H4 The likelihood and intensity of seed purchasing (participation and extent) increase with market access within the community and household wealth endowments. Households well-endowed with resources such as labor, land, and other durable household assets are well known to face lower constraints to general technology adoption (Crawford et al. 2003; Croppenstedt et al. 2003; Barrett 2008; Winters et al. 2009; Jagwe et al. 2010), which is also true for seeds especially those sourced off-farm through purchase (Nordhagen and Pascual 2013; Makate et al. 2023b). Hence, farmers who are better endowed with land and non-land assets are expected to invest more in seed purchases.

Context, data, and estimation strategy

Context

Agriculture is central to the livelihoods of most rural households and the overall economy in Malawi and Ethiopia. Most of the population in both countries lives in rural areas and engages in agricultural activities. The year 2021 estimates by the World Bank[2] put the share of people living in rural areas at 78 and 82% in Ethiopia and Malawi, respectively. The agricultural sector's share of GDP based on World Bank[3] (2021) estimates is around 37.6%, and 22.7% for Ethiopia and Malawi, which is higher than the Sub-Saharan average (17.2%). Smallholders dominate food production in both countries, cultivating a substantial share of the area devoted to food production. For instance, in Ethiopia, approximately 96% of the total area devoted to food production is cultivated by smallholders (Taffesse et al. 2012). In Malawi, approximately 90% of agriculture is also dominated by smallholders (Tchale 2009). There are two main rainy seasons (Meher and Belg), and hence two crop growing seasons in Ethiopia, with Meher being the most important season for crop production, with more than 90% of cereal production. In Malawi, one main rainy season (November to April) dominates crop production. Five major cereal crops are at the core of Ethiopia's food production economy, including teff, maize, sorghum, wheat, and barley. In Malawi, Maize is the most important staple cereal, with more than 60% of land area devoted to it. Other important cereal crops in Malawi include sorghum, millet(s), wheat, and rice.

In both countries, the agricultural sector is characterized by poor access to inputs (e.g., fertilizers and access to quality seeds) and low agricultural productivity. Hence, efforts toward improving agricultural productivity are a priority, and improving access to quality seeds is one of the key targets for policy. Current policy interventions in seed systems in Ethiopia promote an integrated seed sector development that recognizes the complementarity of formal, informal, and intermediate seed systems(Westengen et al. 2019; Mulesa et al. 2021). In Malawi, regulatory policy efforts have focused solely on the formal sector. Informal seed systems provide the bulk of the seeds used, and they are most popular because they have short supply lines and are associated with low transaction costs for access (Nordhagen and Pascual 2013; McGuire and Sperling 2016). The formal seed system produces and supplies certified seeds of improved varieties through

[2] https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=MW-ET

[3] https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=ET-MW-ZG

a structural system that involves a series of actors along the value chain from varietal development to marketing through a network of agro-dealers. However, the formal system provides a smaller share of seeds used and is associated with narrow crop choice, high transaction costs, and affordability challenges (Nordhagen and Pascual 2013; Kansiime and Mastenbroek 2016; McGuire and Sperling 2016), limiting access to seed by poorer farmers.

The Malawi seed system is also associated with a targeted input subsidy program that provides packages of cheap seeds (Jayne and Rashid 2013; Nordhagen and Pascual 2013). Likewise, in Ethiopia, Safety net programs such as the Productive Safety Net Program (PSNP) introduced in 2005 also support farmer seed systems, in particular in areas with chronic seed and food insecurity (Gilligan et al. 2009; Dejene and Cochrane 2021; Makate et al. 2022). Access to subsidized seeds could, therefore, potentially lead to the adoption of a specific seed type, but the quantity used may be determined by the package size of cheap seeds rather than the total need for seeds on the farm. Cash constraints may limit the demand beyond the free/cheap seed package size. Limited adoption of new seeds, such as drought-tolerant maize, may also be done for testing purposes for farmers with limited experience with these new seeds. Studying constraints to access to off-farm seed sourcing decisions among smallholders hence bears important policy implications in both country contexts.

Data

We rely on household survey data from Malawi and Ethiopia, available through the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA), to study dynamic seed purchase decisions. The LSMS-ISA data, commonly known as the Ethiopia Socioeconomic Survey (ESS) and Integrated Household Survey (IHS) in Ethiopia and Malawi, respectively, collect comprehensive information on agricultural activities and household living conditions in respective countries. This study uses data from rural households engaged in agricultural activity with complete and usable information on seed purchasing.

We constructed a three-year, balanced household panel for Ethiopia of 2 398 rural households interviewed successively in three panel rounds (2011/12, 2013/14, and 2015/16). The 3-year household panel for Ethiopia started with 3 969 households, of which 3 466 (87%) were rural in 2011/12. We trace rural households successively interviewed in all three rounds, with consistent household identification information, those who engage in some agricultural activity, and usable information on seed use, particularly seed purchasing, to construct a balanced panel. Similarly, for Malawi, we rely on four rounds of Malawi LSMS-ISA data conducted in 2010, 2013, 2016, and 2019. The Malawi panel survey started with 1 619 households, with about 71% (1 144) rural households traced in four successive rounds. We constructed a 4-year balanced panel data of 971 households in Malawi, which we analyze in this paper. The loss in households from the baseline to subsequent rounds could lead to attrition bias in estimation. Hence, we use probit models (one for each studied country) to assess and control for possible attrition bias in all our results. The probit models (Table D in supplementary material) use dummy variables (1 = yes) to indicate households dropping out in the follow-up surveys from the baseline surveys (i.e., missing in the complete panel). We did not observe a significant attrition bias effect in our results. We, hence, present the results where we include the inverse mills ratio for testing and controlling for attrition bias in our analysis as part of the supplementary material (Tables F and G). We provide more details on the steps to test and control for potential attrition bias in later sections (estimation strategy).

The LSMS-ISA household survey data for Malawi and Ethiopia are supplemented with community-level information gathered through focus group interviews. The community-level information captures various information that defines the communities' access to basic services, infrastructure, and market access. We use such data to define the market access index (elaborated in the next section—estimation strategy). Besides the household and community information, we also gather historical climate (rainfall and temperature) data for clusters (villages) from where households were interviewed and use it to define long-term average climate (rainfall and temperature) and lagged rainfall shock (1-year lag) variables. We specifically use historical monthly weather data from WorldClim[4] (Masarie and Tans 1995; Fick and Hijmans 2017) to define (i) long-term average rainfall, (ii) 1-year lag rainfall shocks(1-year lag drought and flood shock), and (iii) long-term average temperature. We define a 1-year lag rainfall shock as a normalized deviation of rainfall received in the previous season (1-year lag) from the expected seasonal rainfall, as defined by its historical average. Accordingly, we define the 1-year lag of rainfall shock($\mathcal{R}_{t-1}$) as follows: $\mathcal{R}_{t-1}=\left[\frac{\text{rain}_{vt-1}-\overline{\text{rain}}_{\text{v}}}{\sigma_{\text{rain}_{\text{v}}}}\right]$, where $\mathcal{R}_{t-1}$ is a rainfall shock measure for a cluster (village) (v) in the year (t−1), and rain_{vt-1} is the observed amount of rainfall in the previous season, $\overline{\text{rain}}_{v}$ is the historical average seasonal rainfall for the village (v) for the period (1980–2018), and, $\sigma_{\text{rain}_{\text{v}}}$ is the standard deviation of rainfall during the same period. The resultant rainfall shock is a Z-score with negative (below average) and positive (above average) deviations. We split the variable into a drought shock (the absolute values of below-average deviations) and a flood shock (above-average deviations), which measures the extent of below and above-average rainfall deviations from the expected mean (historical average). In addition to the 1-year lag, rainfall shock ($\mathcal{R}_{t-1}$), and long-term average rainfall (R_v) we also include long-term average maximum temperature ($\mathbb{C}_v$). We incorporate long-term average maximum temperature in our analysis mainly to avoid potential omitted variable bias, given that crop production decisions respond both to rainfall and temperature. We present the distribution of the three climate variables and we incorporate in our analysis in Fig. 1.

For our dynamic random effects Probit and Tobit models for seed purchasing in Malawi and Ethiopia, we use the initial survey rounds in 2010 and 2012 as baseline survey rounds. Therefore, seed purchase variables (seed purchase and quantities purchased) in the baseline surveys are used as initial year participation variables and have the same values in all the successive survey rounds. Also, we used seed purchase variables for the previous survey round to define lagged seed purchase variables (seed purchase and quantity purchased). Therefore, for Malawi, we use seed purchase variables for the 2016, 2013, and 2010 survey rounds as lagged seed purchase variables for 2019, 2016, and 2013, respectively. Similarly, seed purchase variables in the 2014 and 2012 survey rounds are used for Ethiopia as lagged seed purchase variables for the 2016 and 2014 survey

[4] https://www.worldclim.org/data/monthlywth.html

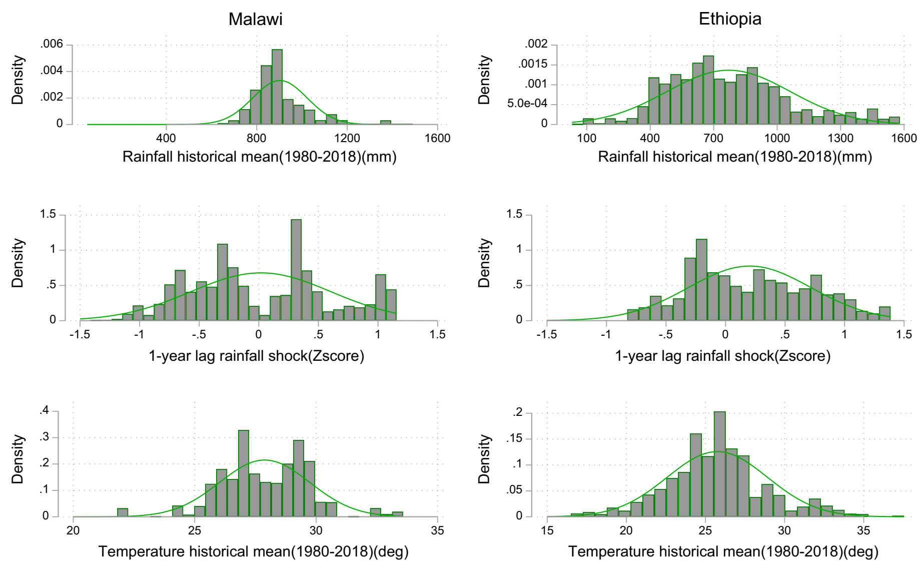

Fig. 1 Histograms showing the distribution of climate variables used in the analysis based on WorldClim data

rounds, respectively. The final datasets that we use for our dynamic random effect models for Malawi and Ethiopia comprise three and two-panel rounds, respectively, as the initial round (baseline) is lost because we do not have lagged seed purchase variables. We use these lagged seed purchase variables to test for dynamic state-dependent effects in the seed market in the studied countries. If we find initial and lagged seed purchase variables significantly enhancing later seed purchases, this will confirm the importance of nonlinear transaction costs in the seed market, which highly influence access to seed through purchase.

Estimation strategy

We study dynamic seed purchase decisions using dynamic Probit and Tobit models (Wooldridge 2005) (Wooldridge 2005; Rabe-Hesketh and Skrondal 2013; Falco et al. 2014). We adopt Wooldridge's auxiliary model (which includes values of observed time-varying explanatory variables at each panel period (excluding the initial period)) to avoid biased estimates that could arise from the initial conditions problem common in dynamic nonlinear unobserved effects panel models (Wooldridge 2005; Rabe-Hesketh and Skrondal 2013). The dynamic Probit and Tobit models incorporate our key variables of interest (lagged market participation, long-term climate (rainfall and temperature), lagged rainfall shocks (1-year lag drought and flood shocks), and market access), from which we will test our hypotheses. Following Wooldridge (2005), we specify the dynamic Probit model for seed purchase as follows:

$$D\left(\pi_{jt}^{\mathrm{HS}} = 1|\pi_{j0}^{\mathrm{HS}}, \pi_{j,t-n}^{\mathrm{HS}}, R_v, \mathcal{R}_{t-1}, \mathbb{C}_v, X_{jt}, b_j\right) = \Phi\left(\rho_1\pi_{j0}^{\mathrm{HS}} + \rho_2\pi_{j,t-n}^{\mathrm{HS}} + \mathrm{R}_v\vartheta + \mathcal{R}_{t-1}\varphi + \mathbb{C}_v\omega + X_{jt'}\theta + b_j\right) \tag{2}$$

The dependent variable for this model (π_{jt}^{HS}) is a dummy variable measuring whether the household (j) purchased seed from the seed market (S) at a time (t). The subscript ($t-n$)

communicates participation in the previous survey round (n). The equation is conditioned on several explanatory variables, including: (i) a dummy variable for initial survey round seed market participation (π_{j0}^{HS}) which remains the same for subsequent survey rounds, (ii) a dummy variable for participation in the seed markets in the previous survey round ($\pi_{j,t-n}^{\mathrm{HS}}$), (iii) long-term average rainfall (R_{v}), (iv) lagged rainfall shocks (1-year lag drought and flood shock), ($\mathcal{R}_{t-1}$), (v) long-term average maximum temperature ($\mathbb{C}_v$), and other control variables (X_{jt}'). The statistical significance of ρ in Eq. 2 assesses whether there is state dependency in the seed market. The initial hypothesis is that there is no state dependency in the seed market (i.e., $\rho = 0$). Unobservable household heterogeneity is identified by (b_j) and is assumed to be additive in the standard normal cumulative distribution function (Φ) and is modeled on the initial conditions of the dependent variable (π_{j0}^{HS}) and the list of covariates(X_j) (Wooldridge 2005) as follows:

$$b_j = \delta_0 + \delta_1 \pi_{j0}^{\mathrm{HS}} + \delta_2 X_j + \delta_j \tag{3}$$

where $\delta_j \sim \mathrm{Normal}\left(0, \sigma_\delta^2\right)$ and is independent of $\left(\pi_{j0}^{\mathrm{HS}} + X_j\right)$. δ_0 is a constant. The vector of control variables (X_{jt}') include the household wealth endowments (farm size(ha), household labor units (elaborated below), and asset wealth index (elaborated below)), household age dependency ratio, farm population pressure (consumer units/farm size), characteristics of the household head (age (years), education (at least secondary education(1 = yes)), sex (1 = female; 0 otherwise), marital status (1 = single; 0 otherwise), and community characteristics (elaborated below). We define male household adult equivalent labor units where we assign 1, 0.8, and 0.5 to an adult male, adult female, and children between 5 and 15 years of age, respectively (Salecker et al. 2020; Tione and Holden 2021). Household members available within the household for at least a month within the panel year are counted as members in the LSMS-ISA data and are hence considered in computing labor units. We combine information on household ownership of durable non-land assets (e.g., agricultural equipment and machinery) and household dwelling characteristics common in each country to create the household asset wealth index using principal components analysis (PCA) (Filmer and Pritchett 2001). Community characteristics include market access index and community population pressure (elaborated below). We proxy market access within the community using a market access index generated using principal components analysis (PCA) (Filmer and Pritchett 2001). We construct this index using captured proxies for market access within the two studied countries. In Malawi, the component variables used in constructing the index include: (a) the community has a daily or weekly market, (b) the community is near an urban center, (c) the community has a permanent ADMARC center, (d) community has a farmer cooperative, (e) and community has a warehouse for storing produce before selling. In Ethiopia, the component variables used include: (a) the community has a weekly agricultural market, (b) the community is near an urban center, (c) the community has private input dealers as sources of seed and other inputs (in addition to the government sources), and (d) community has farmer cooperatives working in the seed sector. The slight discrepancy in the component variables used in making the market access index is due to data availability. Community population pressure is measured by a ratio of the total number of people within the community (Pn) to the number of households within the community (Ch)(Pn/Ch). In addition, we also include regional and survey year dummies to control for the variation in access to purchased seeds across space and time. In addition to the dynamic probit model for seed purchase decisions, we also specify dynamic Tobit models to study the intensity of participation. The dynamic Tobit model controls for unobserved heterogeneity as with the dynamic probit model specified earlier, except that it uses the intensity of participation as a dependent variable and accounts for censoring in the intensity of participation decisions. Following Wooldridge (2005) and Wooldridge (2010), we specify the dynamic Tobit model for the intensity of seed purchase as in Eq. 4:

$$\overline{P}_{jt}^{\mathrm{HS}} = \max\left[0.X_{jt}'\theta, R_v\vartheta, \mathcal{R}_{t-1}\varphi, \mathbb{C}_v\omega, k\left(\overline{P}_{j,t-n}^{\mathrm{HS}}, \pi_{j,t-n}^{\mathrm{HS}}, \pi_{j0}^{\mathrm{HS}}, \overline{P}_{j0}^{\mathrm{HS}}\right)\rho + b_j + \varepsilon_{jt}\right] \quad (4)$$

For all ($t = 1, \ldots T$, and $j = 1, 2, 3, \ldots, N$ households). The specification communicates that in the dynamic Tobit model, the intensity of seed purchase in kilograms/ha ($\overline{P}_{jt}^{\mathrm{HS}}$) is regressed on the previous survey round seed purchase intensity ($\overline{P}_{j,t-n}^{\mathrm{HS}}$), a dummy variable for the previous survey round seed purchase ($\pi_{j,t-n}^{\mathrm{HS}}$), initial survey round seed purchase dummy(π_{j0}^{HS}), and intensity ($\overline{P}_{j0}^{\mathrm{HS}}$), and other covariates($R_{\mathrm{v}}, \mathcal{R}_{t-1}, \mathbb{C}_{\mathrm{v}}, X_{jt}'$) as described prior. Where the idiosyncratic error term $\varepsilon_{jt} \sim \left(0, \sigma_{\varepsilon}^2\right)$, and is independent of $(R_v, \mathcal{R}_{t-1}, \mathbb{C}_v, X_{jt}', \overline{P}_{j,t-n}^{\mathrm{HS}}, \pi_{j,t-n}^{\mathrm{HS}}, \pi_{j0}^{\mathrm{HS}}, \overline{P}_{j0}^{\mathrm{HS}})$. The functional expression $k(.)$ allows the influence of the lagged seed purchase variables to be different depending on whether the previous response was a corner solution or not and the intensity of seed purchased in the previous survey round. In the dynamic Tobit model, the unobservable household effect is modeled on initial participation in the seed market, including the intensity of seed purchased and other covariates. We model these dynamic seed purchase decisions using balanced panel data described previously.

As a robustness check to our main results, we present results in the supplementary material (Tables F and G), where we test and control for potential attrition bias due to dropping out households in subsequent rounds. To handle the possible attribution bias effect, we follow the following steps: First, we estimate probit attrition models for respective countries with dummy variable (1 = yes) for households not observed in the complete panel for the respective countries, and zero otherwise, using household characteristics at baseline as explanatory variables. We present results from the attrition probit models as part of the supplementary material (Table E). From the attrition probit results, we see that some household characteristics were significant in explaining the probability of dropping out, indicating that attrition was not random, which could lead to bias. Second, we construct an inverse mills ratio (IMR) from the attrition probit models. The IMR that we construct becomes a time-invariant variable in our balanced panel dataset as households retain the same value of IMR across panel rounds. Third, we use the constructed IMR to test and control for the potential attrition bias effect by including it as an additional explanatory variable in our dynamic random effect probit and Tobit models. The IMR was not significant in any of the models, which suggests that attrition does not significantly alter our results and conclusions. We present results from this exercise (where we test and control for potential attrition bias) in Tables E and F in the supplementary material.

In addition, we also test for the robustness of results on the intensity of participation in the seed markets using an alternative outcome variable for intensity and an alternative model choice. We derive an outcome variable that measures the contribution of volumes of purchased seeds to the total volumes of seeds used by the farmer (an average share per household derived by averaging the individual crop shares for all crops grown and specifically for Maize). In addition to modeling this outcome variable, which is bounded between 0 (no seeds purchased) to 1 (all seeds used were purchased) using a Tobit estimator, we also specify a fractional probit regression estimator as a robustness check. A fractional regression estimator is also appropriate in capturing nonlinear relationships when the outcome variable is bounded and takes values between 0 and 1. Fractional regression models ((e.g., fractional probit)) implement quasi-maximum likelihood estimators to constrain the predicted value between zero and one (Papke and Wooldridge 1996; Wooldridge 2011). Results from the supplementary analysis are presented together with the main results in Tables 2 and 3. All the analysis was carried out in STATA version 17.0.

Results

Descriptive statistics

The means and standard deviations for variables used in the analysis are presented in Table 1. We only interpret our main outcome variables for brevity, which we also present graphically in Table 1. First, we describe seed purchasing trends in general (All crops), followed by trends for maize seed purchase. Seed purchasing in Malawi has increased from 43% in 2010 to 53% in 2019. On the contrary, seed purchasing slightly decreased by about 5% in Ethiopia, from 54% in 2012 to 49% in 2016 (Table 1) and Fig. 2.

Likewise, the average quantities of seed purchased in Malawi have increased from about 5.8 kg in 2010 to 8.2 kg in 2019. In the Ethiopian sample, on average, households purchased about 13 kg of seeds in 2012, which rose by about 4 kg in 2014 before slightly reducing by 2 kg in 2016. We also see that in Malawi (Ethiopia), the average contribution of purchased seeds to the total volume of seeds used (in general) slightly increased (decreased) by about 5% from the first to the last survey round.

If we specifically focus on maize seed purchase decisions, we see that in Malawi, the proportion of farmers purchasing maize seeds lingers around 30% across survey rounds, with the lowest proportion being 29% in 2013 and the highest being 38% in 2016. In Ethiopia, the proportion of farmers purchasing maize seeds is slightly lower than those in Malawi, and they linger at around 20%, with the highest proportion recorded in 2012 (24%) and the lowest in 2016 (21%). Likewise, the average quantities of maize seed purchased in Malawi range between 3 and 5 kg across survey rounds (Table 1). In Ethiopia, the average quantity of maize seed purchased across rounds is about 3 kg per household. In addition, purchased seeds for Maize contributed to about 25% of maize seeds used in 2010, slightly increasing to 34% in 2019 in Malawi. In Ethiopia, maize seed purchases contributed to about 29% of the total maize seed used, slightly decreasing to about 26% in 2016.

The rest of the variables that we use in the analysis, including lagged participation and intensity of participation variables, climate variables, household socioeconomics characteristics, characteristics of the household head, and community characteristics, are

Table 1 Descriptive statistics of variables used in the analysis

Variables	Malawi								Ethiopia					
	2010		2013		2016		2019		2012		2014		2016	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outcome variables (seed purchasing)														
Purchased seed in given survey year (1 = yes)	0.43	0.50	0.45	0.50	0.54	0.50	0.53	0.50	0.54	0.50	0.55	0.50	0.49	0.50
Amount of seed purchased (kg)	5.83	12.29	5.75	10.88	8.03	13.03	8.23	14.64	12.82	31.89	16.32	45.92	14.35	48.19
Share of seeds purchased (quantity purchased/total seeds used-averaged for all crops grown)	0.23	0.36	0.21	0.33	0.34	0.39	0.28	0.36	0.26	0.36	0.24	0.34	0.21	0.34
Purchased maize seed (1 = yes)	0.31	0.46	0.29	0.45	0.38	0.48	0.35	0.48	0.24	0.43	0.22	0.41	0.21	0.41
Amount of maize seed purchased (kg)	3.73	8.12	3.24	6.82	4.68	8.47	4.20	8.56	3.18	7.80	3.21	7.29	2.67	6.65
Share of maize seeds purchased (quantity purchased/total seeds used)	0.25	0.41	0.26	0.41	0.35	0.45	0.34	0.45	0.29	0.43	0.26	0.41	0.26	0.42
Lagged participation variables (all crops in general)														
Household purchased seed in the first panel round (1 = yes)	0.43	0.50	0.43	0.50	0.43	0.50	0.43	0.50	0.54	0.50	0.54	0.50	0.54	0.50
Household purchased seed in the previous panel round (1 = yes)			0.43	0.50	0.45	0.50	0.54	0.50			0.54	0.50	0.55	0.50
Amount of seed purchased seed in the first panel round (kg)	5.83	12.29	5.83	12.29	5.83	12.29	5.83	12.29	12.82	31.89	12.82	31.89	12.82	31.89
Amount of seed purchased seed in the previous panel round (kg)			5.83	12.29	5.75	10.88	8.03	13.03			12.82	31.89	16.32	45.92
Lagged participation variables (Maize)														
Household purchased maize seed in the first panel round (1 = yes)	0.31	0.46	0.31	0.46	0.31	0.46	0.31	0.46	0.24	0.43	0.24	0.43	0.24	0.43
Household purchased maize seed in the previous panel round (1 = yes)			0.31	0.46	0.29	0.45	0.38	0.48			0.24	0.43	0.22	0.41
Amount of maize seed purchased seed in the first panel round (kg)	3.73	8.12	3.73	8.12	3.73	8.12	3.73	8.12	3.18	7.80	3.18	7.80	3.18	7.80
Amount of maize seed purchased seed in the previous panel round (kg)			3.73	8.12	3.24	6.82	4.92	8.58			3.18	7.80	3.21	6.98
Climate variables														
Rainfall historical mean (1980–2018) in mm	902.55	117.33	902.55	117.33	902.55	117.33	902.55	117.33	770.82	291.63	770.82	291.63	770.82	291.63
1-year lag rainfall shock (Z-score)	0.75	0.32	−0.33	0.52	−0.32	0.21	−0.03	0.43	−0.08	0.42	0.35	0.56	0.35	0.50
Temperature historical mean (1980–2018) in degrees celsius	27.88	1.86	27.88	1.86	27.88	1.86	27.88	1.86	25.75	3.17	25.75	3.17	25.75	3.17

Table 1 (continued)

Variables	Malawi								Ethiopia					
	2010		2013		2016		2019		2012		2014		2016	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Other explanatory variables														
Farm size(ha)	0.73	0.50	0.74	0.52	0.78	0.55	0.77	0.54	1.20	2.04	1.38	3.83	1.36	2.14
Household labor units (adult equivalent)	2.88	1.32	3.24	1.36	3.18	2.58	3.30	1.41	3.88	1.51	3.60	1.51	3.91	1.74
Share of male labor (male labor units/total household labor units)	0.39	0.21	0.38	0.20	0.42	0.32	0.38	0.22	0.43	0.20	0.41	0.18	0.41	0.19
Household asset wealth index(normalized)	0.13	0.17	0.13	0.18	0.12	0.19	0.14	0.20	0.23	0.16	0.21	0.20	0.20	0.20
Farm population pressure ratio (Household size/farm size)	11.77	12.89	12.80	13.23	12.72	14.28	12.50	14.38	10.88	11.62	11.41	12.37	11.90	13.23
Community population pressure ratio (No. of people in community/No. of households in community)	5.48	3.62	5.48	3.62	8.03	9.72	7.34	5.61	5.43	1.77	5.36	1.81	5.49	2.35
Community market access index(normalized)	0.26	0.28	0.26	0.28	0.25	0.30	0.26	0.28	0.66	0.20	0.65	0.22	0.66	0.19
Female decision maker (1 = yes)	0.23	0.42	0.26	0.44	0.29	0.45	0.29	0.45	0.18	0.38	0.19	0.39	0.20	0.40
Household head is single(1 = yes)	0.23	0.42	0.23	0.42	0.33	0.47	0.31	0.46	0.15	0.35	0.18	0.38	0.20	0.40
Household dependency ratio ((number of dependents/ economically active members*100)	114.99	87.85	112.58	81.02	101.31	78.95	94.18	80.05	70.26	50.14	108.56	84.13	107.20	81.17
Age of household head(years)	43.55	15.83	46.06	15.57	48.05	14.01	50.35	14.39	44.54	14.85	46.17	14.50	48.12	14.62
Education level attained at least 12th grade (Ethiopia), at least JCE(Malawi)	0.34	0.47	0.34	0.47	0.27	0.45	0.31	0.46	0.69	0.46	0.68	0.47	0.66	0.47
Observations	971		971		971		971		2398		2398		2398	

Descriptive statistics are not weighted; For all "normalized" variables we use the unit-based normalization method as follows: Normalized $V = (V\text{-minimum}(V))/(\text{maximum}(V)\text{-minimum}(V))$; where ($V$) is the original variable (the index), and (Normalized V) is the normalized version of variable which is bounded between 0 (minimum), and 1 (maximum). First panel round for Malawi (Ethiopia) is 2010 (2012)

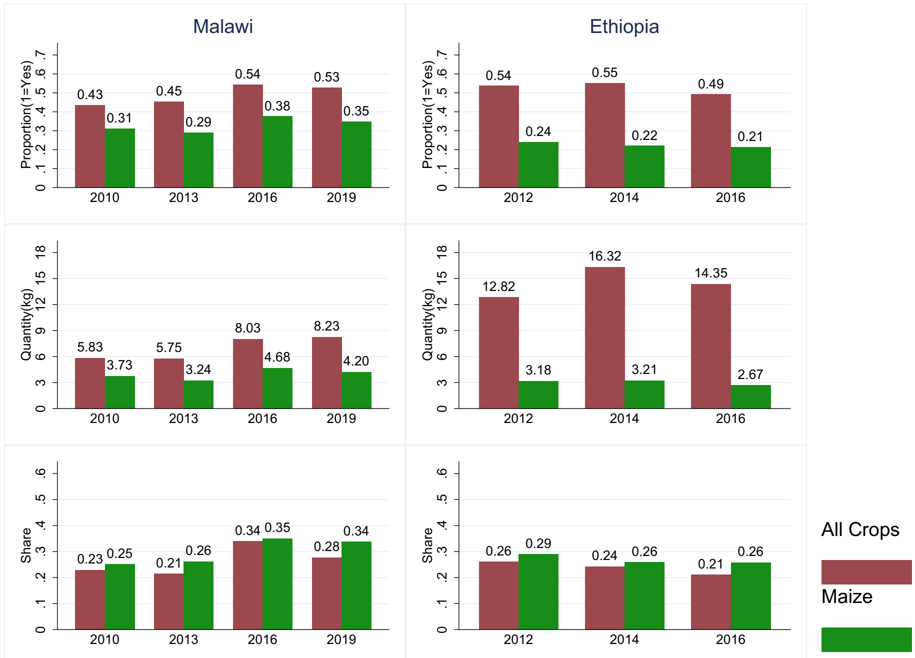

Fig. 2 Seed purchasing trends in the studied countries: The top panel figures show participation in the seed market (seed purchase) in general (for all crops grown) and specifically for Maize. The middle and bottom panels show the intensity (in kilograms and shares) of participation in kg/household purchased for the full sample of participants + potential participants

shown in Table 1. In addition to the descriptive statistics for control variables as shown in Table 1, we also show how seed purchasers compare with non-purchasers in terms of their socioeconomic characteristics in the supplementary material (Table A-B).

Main results

Findings from the dynamic random effects Probit, Tobit, and fractional probit models for seed purchasing decisions in general and maize seed are presented in Tables 2 and 3, respectively. We report average partial effects (APE) to help interpret the economic and not just the statistical significance of variables. We report results from (i) a dynamic random effect probit regression of participation (1 = yes), (ii) dynamic random effects Tobit regression of volumes of seeds purchased (in kg), and (iii) both dynamic Tobit and fractional probit regression models of shares of purchased seed (volume of seed purchased/total volume of seeds used). The full spectrum of control variables used in the analysis is shown in the tables of results (Tables 2 and 3). In addition, we provide results reporting corresponding coefficients for presented APEs in the supplementary material (Tables C and D). We present and interpret the results from our key variables, as clarified earlier.

Impact of lagged seed purchase variables on current seed purchase decisions

We start with results from the model of general input purchasing (All crops model) for both Malawi and Ethiopia, as presented in Table 2, and then move to the model for Maize seed purchase decisions. In Malawi, we learned that dummy variables for purchasing seeds in the first and previous rounds significantly enhance the probability and

Table 2 Dynamic random effects Probit and Tobit models for seed purchase decisions in Malawi and Ethiopia. Reported are average partial effects

Variables	Malawi ("All crops model")				Ethiopia ("All crops model")			
	Participation (1 = yes)	Intensity (kg)	Intensity (average share)		Participation (1 = yes)	Intensity (kg)	Intensity (average share)	
	Probit	Tobit	Tobit	Fractional probit	Probit	Tobit	Tobit	Fractional probit
Household purchased seed in the first panel round (1 = yes)	0.0683*** (0.02246)	0.8625** (0.40623)	0.0239** (0.01188)	0.0194 (0.01689)	0.1583*** (0.02345)	4.4721*** (1.13255)	0.0330*** (0.00814)	0.0247** (0.01122)
Household purchased seed in the previous panel round (1 = yes)	0.0652** (0.02970)	0.9436** (0.39950)	0.0200* (0.01097)	0.0299** (0.01482)	0.0517* (0.03091)	3.1879*** (1.16985)	0.0104 (0.00820)	0.0100 (0.00970)
Volume(share) of seed purchased in the first panel round in kg(proportion)		0.0133 (0.01589)	0.0167 (0.02139)	0.0461 (0.02957)		0.1157*** (0.01685)	0.0929*** (0.01650)	0.1499*** (0.02030)
Volume(share) of seed purchased in the previous panel round in kg(proportion)		0.0032 (0.01701)	0.0106 (0.02070)	0.0151 (0.02666)		0.0251 (0.01718)	0.0428** (0.01818)	0.0384* (0.01974)
Farm size(ha)	0.0746*** (0.02355)	2.9130*** (0.38528)	0.0635*** (0.00969)	0.1027*** (0.01348)	0.0038 (0.00274)	0.2792*** (0.10626)	0.0024*** (0.00073)	0.0038*** (0.00126)
Household labor units	0.0086 (0.00559)	0.1005 (0.08977)	0.0045** (0.00226)	0.0062** (0.00302)	0.0083* (0.00482)	0.7808*** (0.26607)	0.0039** (0.00182)	0.0064** (0.00260)
Rainfall historical mean (1980–2018) in mm(log)	0.0483 (0.11653)	1.6214 (1.94112)	0.0656 (0.04893)	0.1095 (0.07178)	0.1560*** (0.01949)	4.1005*** (1.11607)	0.0415*** (0.00773)	0.0262** (0.01131)
1-year lag negative rainfall deviation	0.1027*** (0.03981)	1.9189*** (0.63497)	0.0480*** (0.01599)	0.0695*** (0.02185)	−0.1317*** (0.04468)	−4.1784* (2.50199)	−0.0374** (0.01688)	−0.0316 (0.02507)
1-year lag positive rainfall deviation	0.0112 (0.06133)	1.6918* (0.98564)	0.0330 (0.02477)	0.0531 (0.03735)	−0.0598*** (0.01502)	−1.2390 (0.85623)	−0.0218*** (0.00586)	−0.0209** (0.00940)
Temperature historical mean (1980–2018) in degrees celsius	0.0312*** (0.00688)	0.4244*** (0.11550)	0.0130*** (0.00292)	0.0159*** (0.00413)	−0.0200*** (0.00269)	−1.0539*** (0.15388)	−0.0084*** (0.00106)	−0.0121*** (0.00152)
Community market access index(normalized)	0.0019 (0.00651)	0.0604 (0.10697)	0.0010 (0.00269)	0.0014 (0.00393)	0.0090* (0.00503)	0.4454 (0.28321)	0.0029 (0.00192)	0.0037 (0.00272)
Community population pressure ratio	0.0018 (0.00136)	0.0063 (0.02126)	0.0003 (0.00053)	0.0001 (0.00071)	0.0080** (0.00323)	0.5226*** (0.18166)	0.0124*** (0.00188)	0.0126*** (0.00276)
Farm population pressure	0.0005 (0.00086)	0.0251* (0.01426)	0.0003 (0.00036)	0.0004 (0.00053)	−0.0001 (0.00004)	−0.0203** (0.00877)	0.0024* (0.00123)	0.0015 (0.00190)
Household asset wealth index(normalized)	0.2272*** (0.04982)	4.1379*** (0.78431)	0.1133*** (0.02102)	0.1558*** (0.02807)	0.0466*** (0.00724)	2.7491*** (0.42122)	−0.0002*** (0.00006)	−0.0003 (0.00022)
Female decision maker (1 = yes)	−0.0602** (0.02568)	−0.6632 (0.43264)	−0.0232** (0.01090)	−0.0272* (0.01571)	−0.0118 (0.02582)	−2.4132* (1.43071)	0.0195*** (0.00285)	0.0275*** (0.00450)
Household head is single(1 = yes)	0.0129 (0.02604)	−0.2879 (0.42914)	−0.0008 (0.01079)	−0.0041 (0.01489)	0.0382 (0.02645)	3.7722*** (1.46205)	−0.0166* (0.00980)	−0.0212 (0.01432)
Age of household head(years)	−0.0030*** (0.00070)	−0.0472*** (0.01197)	−0.0014*** (0.00030)	−0.0019*** (0.00043)	−0.0013** (0.00054)	−0.1051*** (0.03028)	0.0167* (0.00999)	0.0154 (0.01473)
Education level attained at least 12th grade (Ethiopia), at least JCE(Malawi)	0.0066 (0.02032)	0.1820 (0.33709)	0.0046 (0.00848)	0.0079 (0.01244)	−0.0028 (0.01571)	0.1751 (0.85712)	−0.0005** (0.00021)	−0.0006* (0.00031)
Household dependency ratio	0.0001 (0.00012)	0.0022 (0.00204)	0.0001 (0.00005)	0.0001 (0.00007)	0.0002** (0.00009)	0.0058 (0.00467)	−0.0006 (0.00586)	−0.0018 (0.00850)
Regional & year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2 (continued)

Variables	Malawi ("All crops model")				Ethiopia ("All crops model")			
	Participation (1 = yes)	Intensity (kg)	Intensity (average share)		Participation (1 = yes)	Intensity (kg)	Intensity (average share)	
	Probit	Tobit	Tobit	Fractional probit	Probit	Tobit	Tobit	Fractional probit
Number of panel households	971	971	971	971	2398	2398	2398	2398
Observations	2913	2913	2913	2913	4796	4796	4796	4796

***, **, and * communicates significance at 1, 5, and 10% respectively; robust standard errors in parentheses. Participation equations are modeled using dynamic random effects probit models. Intensity equations use volumes of seeds purchased(kg) and average shares of seeds purchased (volume of seeds purchased as a fraction of total seeds used-averaged for all crops grown) as dependent variables. Volumes of seeds in kg are modeled using dynamic random effects Tobit models, while shares are modeled using both dynamic random effects Tobit and fractional probit models

intensity of purchasing seeds in all our model specifications (Table 2). Precisely, households who purchased seed in the first round and previous round, respectively, had a 7 and 6% higher probability of purchasing seed in the analyzed sample. More so, purchasing seed in the first and previous rounds in Malawi is associated with a marginal increase in quantities (shares) of seed purchased by 0.9 kg (2.4%) and about 0.94 kg (2.0%), respectively (Table 2). Similarly, in Ethiopia, we find that dummy variables for purchasing seeds in the first round and previous survey rounds enhanced both the probability and intensity of seed purchasing in the studied sample. However, we find previous seed purchasing decisions to have a somewhat greater impact on driving seed purchasing in Ethiopia than in Malawi. For instance, the seed purchase dummy in the first survey round increased the probability of purchasing seed by about 16% in Ethiopia, which is more than double that we found in Malawi (7%). In addition, dummies for participation in the seed market (as buyers) in the first survey round and previous survey round are associated with marginal increases in the quantity (share) of seeds purchased by between 4.5 (3%) and 3.2 kg, respectively, in Ethiopia (Table 2). In Ethiopia, we also find that the initial year quantity (share) of seed purchased is associated with a marginal increase in the average quantity (shares) purchased by 0.12 kg (between 9 and 15%) (Table 2).

Table 3 reports APEs from dynamic Probit, Tobit, and fractional probit random effects models for Maize seed purchase decisions in Malawi and Ethiopia. From the results, we learn that, like what we found with general seed purchase decisions, lagged maize seed purchase variables significantly enhance current maize seed purchasing in both Malawi and Ethiopia. In Malawi and Ethiopia, the dummy for maize seed purchase in the first survey round is associated with an 11% and 22% higher probability of purchasing maize seed in later rounds (Table 3). In addition, the dummy for purchasing maize seed in the first survey round is associated with a 1 kg (1%) and a 2 kg (1.5 to 2%) increase in quantities (shares) of Maize seed purchased in later rounds in Malawi and Ethiopia, respectively (Table 3). Also, a marginal increase in the quantity (shares) of maize seed purchased in the first survey round is associated with 0.08 (3–8%) kg (shares) of maize seed purchased in the following survey rounds in Ethiopia (Table 3).

Overall, we gather evidence that there is persistent state dependency on the demand side of the seed market in general and particularly in the maize seed market, causing selective access to purchased seed in Malawi and Ethiopia. Also, it is mainly initial participation and extent of participation that explain participation in subsequent

Table 3 Dynamic random effects Probit and Tobit models for Maize seed purchase decisions in Malawi and Ethiopia. Reported are average partial effects

Variables	Malawi ("Maize model")				Ethiopia ("Maize model")			
	Participation (1 = yes)	Intensity (kg)	Intensity (share)		Participation (1 = yes)	Intensity (kg)	Intensity (share)	
	Probit	Tobit	Tobit	Fractional probit	Probit	Tobit	Tobit	Fractional probit
Household purchased maize seed in the first panel round (1 = yes)	0.1065*** (0.02264)	0.9798*** (0.36961)	0.0121*** (0.00464)	0.0130** (0.00535)	0.2199*** (0.02240)	1.9841*** (0.26226)	0.0198*** (0.00262)	0.0149*** (0.00230)
Household purchased maize seed in the previous panel round (1 = yes)	0.0216 (0.02778)	0.0915 (0.36346)	0.0017 (0.00456)	0.0039 (0.00510)	0.0439 (0.02685)	0.3936 (0.25062)	0.0039 (0.00251)	0.0063*** (0.00188)
Volume(share) of maize seed purchased in the first panel round in kg (proportion)		0.0297 (0.02006)	0.0319 (0.02018)	0.0297 (0.02137)		0.0752*** (0.01427)	0.0752*** (0.01427)	0.0315* (0.01775)
Volume(share) of maize seed purchased in the previous panel round in kg(proportion)		0.0237 (0.02025)	0.0175 (0.02065)	0.0264 (0.02657)		0.0118 (0.01389)	0.0118 (0.01389)	0.0350* (0.01818)
Farm size(ha)	0.0410* (0.02245)	1.3223*** (0.28537)	0.0166*** (0.00357)	0.0285*** (0.00485)	0.0013 (0.00170)	0.0237 (0.01561)	0.0002 (0.00016)	0.0003*** (0.00008)
Household labor units	0.0042 (0.00526)	0.0331 (0.06670)	0.0004 (0.00083)	0.0005 (0.00097)	0.0044 (0.00389)	0.0537 (0.04751)	0.0005 (0.00048)	0.0007 (0.00050)
Rainfall historical mean (1980–2018) in mm(log)	0.2470** (0.11399)	3.1735** (1.46413)	0.0396** (0.01835)	0.0377* (0.02187)	0.1446*** (0.01695)	1.6674*** (0.21608)	0.0167*** (0.00216)	0.0121*** (0.00288)
1-year lag negative rainfall deviation	0.0396** (0.01877)	0.3100 (0.23861)	0.0038 (0.00298)	0.0019 (0.00361)	0.0790** (0.03460)	0.5713 (0.42178)	0.0057 (0.00422)	0.0052 (0.00525)
1-year lag positive rainfall deviation	0.0557 (0.05208)	0.7484 (0.66894)	0.0092 (0.00835)	0.0102 (0.00933)	− 0.0571*** (0.01350)	− 0.7137*** (0.16266)	− 0.0071*** (0.00163)	− 0.0059*** (0.00154)
Temperature historical mean (1980–2018) in degrees celsius	0.0171** (0.00678)	0.1941** (0.08711)	0.0024** (0.00109)	0.0020 (0.00125)	0.0023 (0.00230)	0.0596** (0.02953)	0.0006** (0.00030)	0.0010*** (0.00031)
Community market access index(normalized)	− 0.0022 (0.00625)	− 0.0296 (0.07983)	− 0.0004 (0.00100)	− 0.0003 (0.00133)	0.0059 (0.00401)	0.0270 (0.04906)	0.0003 (0.00049)	0.0000 (0.00055)
Community population pressure ratio	− 0.0011 (0.00128)	− 0.0086 (0.01604)	− 0.0001 (0.00020)	− 0.0000 (0.00023)	0.0050* (0.00272)	0.0494 (0.03443)	0.0021*** (0.00048)	0.0019** (0.00075)
farm population pressure	0.0014* (0.00081)	0.0232** (0.01039)	0.0003** (0.00013)	0.0003* (0.00020)	− 0.0002 (0.00013)	− 0.0039** (0.00183)	0.0005 (0.00034)	0.0006 (0.00048)
Household asset wealth index(normalized)	0.1793*** (0.04651)	2.9343*** (0.58260)	0.0391*** (0.00772)	0.0484*** (0.00931)	0.0276*** (0.00607)	0.3903*** (0.07746)	− 0.0000** (0.00002)	− 0.0001 (0.00008)
Female decision maker (1 = yes)	− 0.0112 (0.02520)	− 0.1456 (0.32301)	− 0.0018 (0.00404)	− 0.0014 (0.00498)	− 0.0121 (0.02146)	− 0.1654 (0.26545)	0.0039*** (0.00077)	0.0048*** (0.00085)
Household head is single(1 = yes)	− 0.0105 (0.02495)	− 0.2808 (0.31963)	− 0.0035 (0.00400)	− 0.0064 (0.00475)	0.0407* (0.02157)	0.3704 (0.26408)	− 0.0017 (0.00265)	− 0.0001 (0.00202)
Age of household head(years)	− 0.0027*** (0.00070)	− 0.0292*** (0.00918)	− 0.0004*** (0.00012)	− 0.0003* (0.00015)	− 0.0001 (0.00045)	− 0.0003 (0.00552)	0.0037 (0.00264)	0.0010 (0.00200)
Education level attained at least 12th grade (Ethiopia), at least JCE(Malawi)	0.0071 (0.01974)	0.2233 (0.25182)	0.0028 (0.00315)	0.0053 (0.00424)	0.0072 (0.01243)	− 0.0524 (0.15232)	− 0.0000 (0.00006)	0.0000 (0.00006)
Household dependency ratio	0.0002 (0.00012)	0.0019 (0.00152)	0.0000 (0.00002)	0.0000 (0.00002)	0.0001 (0.00007)	0.0011 (0.00082)	− 0.0005 (0.00152)	− 0.0008 (0.00177)

Table 3 (continued)

Variables	Malawi ("Maize model")				Ethiopia ("Maize model")			
	Participation (1 = yes)	Intensity (kg)	Intensity (share)		Participation (1 = yes)	Intensity (kg)	Intensity (share)	
	Probit	Tobit	Tobit	Fractional probit	Probit	Tobit	Tobit	Fractional probit
Regional and year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of panel households	971	971	971	971	2398	2398	2398	2398
Observations	2913	2913	2913	2913	4796	4796	4796	4796

***, **, and * communicates significance at 1, 5, and 10% respectively; robust standard errors in parentheses; Participation equations are modeled using dynamic random effects probit models. Intensity equations use volumes of seeds purchased (kg) and average shares of seeds purchased (volume of seeds purchased as a fraction of total seeds used for Maize) as dependent variables. Volumes of seeds in kg are modeled using dynamic random effects Tobit models, while shares are modeled using both dynamic random effects Tobit and fractional probit models

years compared to participation in previous surveys. The state dependency is more pronounced in Ethiopia than in Malawi. Seed purchase from available markets gives smallholder farmers with experience and established networks an advantage over new entrants. We, hence, could not reject our first hypothesis. We discuss this main result in the following sections.

Climate variability and seed purchase decisions

Here, we report results on the link between historical climate (rainfall and temperature) and lagged rainfall shocks (1-year lag drought and flood shock) on seed purchase decisions in studied countries. We found long-term climate (rainfall and temperature) and the lagged rainfall shock (1-year lag) to explain seed purchase decisions in studied countries. In Ethiopia, we found a 1% increase in historical average rainfall associated with about a 0.002 unit increase in the probability of purchasing seed and a 4 kg (3–4%) increase in the volume (share) of purchase (Table 2). In Malawi, the link between historical rainfall and seed purchasing (in general) is also positive (Table 2). For maize seed purchase decisions, a marginal (1%) increase in historical mean rainfall is associated with a 0.002 probability increase in maize seed purchase and about a 3 kg increase in the intensity of purchase in Malawi (Table 3). Similarly, in Ethiopia, a marginal (1%) increase in historical average rainfall is associated with increased probability and intensity of maize seed purchases(Table 3).

Results linking lagged rainfall shocks to seed purchase decisions reveal that in Malawi, a marginal increase in the drought shock (absolute value of below-average rainfall deviations) enhances the probability and intensity of seed purchases (in general) by about 10% and 2 kg (5–6% shares), respectively (Table 2). On the contrary, in Ethiopia, a marginal increase in the drought shock variable is associated with a 13% reduction in the probability of seed purchases (Table 2). However, for maize seed purchase decisions, we found that a marginal increase in the 1-year lag drought shock variable in Ethiopia and Malawi marginally enhances maize seed purchases (Table 3). In Malawi, the drought shock enhances the chances of maize seed purchases by 4%, while in Ethiopia, it enhances the probability of maize seed purchases by 8%. The flood shock variable is associated with reduced seed purchase decisions in Ethiopia (Tables 2 and 3).

Our results also show that in Malawi, a marginal (1 degree) increase in historical average temperature is associated with a 3% and 0.4 kg (1%) increase in the probability and intensity (share) of seed purchases in Malawi (Table 2). In Ethiopia, general seed purchase decisions decline with increasing historical average temperature (Table 2). For Maize, we find the probability and intensity of maize seed purchases to increase with the historical average temperature in both countries. For instance, in Malawi (Ethiopia), the probability and intensity of maize seed purchases were found to increase by 2% (0.2%) and 0.2 kg (0.06 kg), respectively (Table 3).

In addition to the results presented in the tables, we plot average partial effects showing the relationships between rainfall shock variables (positive and negative rainfall deviations and historical mean rainfall), and maize seed purchase decisions in general (in pooled samples), and in sub-groups of farmers: (a) between initial market participants (with knowledge and experience from past engagements) versus non-initial participants (without experience), (b) farmers with relatively small versus larger farm sizes based on total farm size, (c) Rich versus poor farmers based on their non-land asset wealth endowments. The results are summarized in the supplementary material (Figures A–D). Insights from the plots (i.e., on the effects of negative rainfall deviations on Maize seed purchase decisions) reveal that smallholder farmers with knowledge and experience of the maize seed markets (gained from previous market engagements) and those with high land and non-land asset wealth endowments in both Malawi and Ethiopia have an elevated advantage in purchasing maize seeds post-drought shock exposure as adaptation compared to their poorer counterparts (see supplementary material Figures A–D).

Overall, (i) historical mean rainfall enhances seed purchase decisions in both Malawi and Ethiopia, (ii) rainfall variability (drought or flood shocks) generally enhances (discourages) general seed purchase decisions in Malawi (Ethiopia), (iii) lagged drought shocks enhances maize seed purchases in both countries, and (iv) historical mean temperature enhances maize seed purchase decisions in both Malawi and Ethiopia. Also, wealthier farmers and those with experience gained from past market engagements are more likely to purchase maize seeds post-negative rainfall deviation exposure than their counterparts. Therefore, the hypothesis that lagged rainfall shocks does not encourage seed purchasing was rejected for Maize seed purchase decisions in Malawi and Ethiopia. Also, we could not reject our hypothesis that historical mean rainfall enhances seed purchase in subsequent seasons in Malawi and Ethiopia. Also, maize seed purchase decisions increase with increasing historical mean temperature. We discuss some of these key results in the next sections (discussion).

Other correlates of seed purchase decisions

In addition to our results on key variables of interest, we also found market access and household endowments to significantly explain household general and maize seed purchase decisions in Malawi and Ethiopia (Tables 2 and 3). In Malawi and Ethiopia, households with better market access are more likely to purchase seeds (Table 2). Likewise, a marginal increase in the market access index is associated with higher chances of purchasing seed and intensity of seed purchase in Ethiopia (Table 2). Overall, we establish evidence that better market access correlates to higher access to seeds through purchase in Malawi and Ethiopia. Hence, we could not reject our hypothesis, which states that seed purchasing increases with improved market access.

We also attempt to report associations between household resource endowments and seed purchase decisions. We found that a 1 ha increase in farm size is associated with a 7% increase in the probability of purchasing seed and about a 3 kg increase in purchase intensity in Malawi (Table 2). Similarly, in Ethiopia, a 1 ha increase in farm size is associated with a 0.6% increase in the probability of purchasing seed and a 0.3 kg increase in purchase intensity. Household labor units are also positively associated with seed purchasing decisions. A unit increase in labor units is associated with a 1% increase in the probability of purchasing seeds in both Malawi and Ethiopia. Also, a unit increase in household labor units is associated with a 0.2 and about 1 kg increase in the intensity of seed purchase in Malawi and Ethiopia, respectively (Table 2). For maize seed purchase decisions, we also found farm size to positively explain the probability and intensity of maize purchase in both Malawi and Ethiopia and that household labor units enhance both the probability and intensity of maize seed purchase in Ethiopia (Table 3). The household asset wealth index also positively correlates with seed purchase decisions in general (Table 2) and maize seed purchase decisions (Table 3) in Malawi and Ethiopia. Overall, and as expected, households better endowed with land, labor, and household assets are more likely to purchase seed from available markets than their poorer counterparts.

Discussion

Our findings show that there is state dependency on the demand side of the seed market in general and for maize seed, causing selective access in both Malawi and Ethiopia. The implication of the result is that *ceteris paribus*, smallholder farmers with experience and established networks, have an advantage in the seed market compared to new entrants. This finding is in line with previous studies and the theory of non-convex transaction costs in factors markets that alludes to the fact that where markets are imperfect, participants are likely to face pervasive and dynamically variable nonlinear transactions, which lead to selective access (Holden et al. 2007, 2010; Gebru et al. 2019; Tione and Holden 2021). Hence, entry into the seed market and establishing information networks is a sunk cost that potential market participants must overcome and later use to make future transactions (Fafchamps 2004; Barrett 2008).

However, the most significant challenge for potential market participants is getting over the first hurdle of entering the market. Upon entry, participation (and extent of participation) in subsequent years is a factor of initial market investments that marginally reduce over time across space (Holden et al. 2007; Gebru et al. 2019; Tione and Holden 2021). This notion possibly explains why we found initial participation variables to explain participation in subsequent years more compared to participation in previous surveys. This notion further confirms the importance of building useful networks and gathering experience once households enter the seed market for the first time, reducing constraints in seed access through purchase in subsequent years. This notion is also in line with literature that alludes that smallholder farming households engage in collective action and invest in building their social networks to overcome or reduce widespread and pervasive transaction costs in accessing input markets in SSA (Key et al. 2000; Fafchamps 2004; Barrett 2008).

The observation of relatively more potent state dependency effects that lead to selective access to seed through purchase in Ethiopia than Malawi may be partly explained by key differences that characterize seed systems in the two countries. Such factors may include different policies governing access to seed through the formal systems and differences in the development of formal seed systems. The use of the formal seed system in Malawi, particularly for maize seed, has developed much faster in the recent past than in Ethiopia (Jayne and Rashid 2013; Kassie et al. 2013; Sheahan and Barrett 2017), which could explain the slight contrast in our findings. For example, government input support programs such as the farm input support program (FISP) in Malawi have had a greater impact on improving input market development and improved availability, awareness, and access to seed through the formal system in Malawi compared to other countries such as Ethiopia (Jayne and Rashid 2013; Sheahan and Barrett 2017) which could explain the difference. Also, the economic policy of seed in Ethiopia and Malawi differ particularly in the roles played by public and private entities in the formal system (Langyintuo et al. 2010; Erenstein and Kassie 2018; Westengen et al. 2019). For instance, in Malawi, formal seed systems are dominated by both public and private players in the seed value chain (Kassie et al. 2013), while in Ethiopia, only the public entities dominate much of the functions of the system with little room for the private sector in practice a phenomenon that has been to linked to higher transaction costs in seed value chains and low access to improved seeds (Husmann 2015; Mekonnen et al. 2021). Given that access to seed through purchase is a crucial factor behind household seed security (Sperling 2002, 2020; Nordhagen and Pascual 2013), the existence of nonlinear transaction costs which constrain access to seed in Malawi and Ethiopia contributes to household seed insecurity among other factors.

Overall, the state dependency that we found in seed purchase decisions shows the importance of accumulating market experience, established information networks, and market linkages in facilitating access to purchased seeds over time. However, some other factors, for instance, demand side ignorance and stubborn preferences for sourcing seeds, could also contribute to state dependency.

We also gather evidence that seed purchase decisions respond to rainfall variability (lagged rainfall shocks) in both countries. Rainfall variability (drought or flood shocks) generally enhances (discourages) seed purchase decisions (averaged for all crops) in Malawi (Ethiopia), but lagged drought shocks (below-average rainfall deviations) encourage maize seed purchasing decisions in both Malawi and Ethiopia. For maize seed purchase decisions, the effects of lagged rainfall shocks (e.g., negative rainfall deviation) are greater for farmers with market experience and those with relatively high-wealth endowments than their counterparts. Also, historical average rainfall and temperature enhance maize seed purchase decisions in both countries. Recurrent rainfall variability, which may lead to crop failure, may disrupt farmer stocks of their own saved seed or make it hard to set aside seed from harvest due to urgent consumption needs, driving farmers to source seed from elsewhere through trade (Bellon et al. 2011; Nordhagen and Pascual 2013; Makate et al. 2023b). Also, recurrent exposure to rainfall variability may induce learning on the benefits of different seed options, promoting farmers to choose seed options such as purchases that help them deal with future shocks (Holden and Quiggin 2017). This view possibly explains why we found the 1-year lag of drought shocks to enhance general seed purchasing decisions in Malawi and maize seed purchases in Malawi and Ethiopia. The Maize crop is highly sensitive to rainfall shocks, particularly drought shocks (Katengeza et al. 2019), possibly explaining why maize seed purchase decisions respond to drought shocks in both countries.

However, it is also possible that rainfall shocks, through their effects on household economies, lead to less resource allocation for purchasing seeds. This notion partly explains the findings in Ethiopia, where lagged rainfall variability (drought and flood shocks) reduces general seed purchase decisions (all crops model). This idea is accurate partly because exposure to shocks may increase hunger and poverty and discourage the adoption of beneficial technologies (Dercon 2005; Yesuf and Bluffstone 2009). Also, farmer perceptions of the benefits of different seed options (purchased seeds vs. farmer-saved seed) with increased rainfall uncertainty may explain the contrasting effect of rainfall variability. Also, the contrast in seed systems and the availability of subsidized seed inputs in the two countries could explain the disparity in the results. Access to the farm input subsidy program (FISP) in Malawi has improved awareness, availability, and access to improved seeds and has also enhanced input market development in Malawi (Jayne and Rashid 2013), which is not the case in Ethiopia. For example, a study in Malawi by Katengeza et al. (2019) found that exposure to lagged rainfall shocks (drought shocks) combined with the provision of subsidized seeds after shock exposure leads to higher uptake of improved (drought-tolerant) maize varieties. On the contrary, in Ethiopia, some studies (e.g., Alem et al. (2010)) have found lagged rainfall variability to discourage the use of productivity-improving risky inputs such as fertilizers. Hence, the key differences in seed systems features, farmer perceptions, differences in exposure and access to seeds off-farm, and the level of transaction costs in accessing seeds from available markets could explain the contrast in the effects of lagged rainfall variability (drought or flood shocks) on general seed purchase decisions (defined for al crops) in the studied countries.

The findings that higher historical average rainfall enhances seed purchasing in both Malawi and Ethiopia could reflect on the marginal benefits of rainfall amount received on crop harvest, which may ease liquidity constraints faced by households and hence their ability to source seeds through purchase. In rural contexts like Malawi and Ethiopia, where households have low income levels and input, and credit markets are imperfect, abundant rainfall may be associated with increased crop harvest and household disposable incomes, which relax liquidity constraints in the adoption of agricultural technologies (Alem et al. 2010; Dercon and Christiaensen 2011; Falco et al. 2014). Overall, results from this paper portray that seed purchasing practices respond to measures of rainfall variability and experience and knowledge of the seed market, and high-wealth endowments enhance their response to negative shocks (e.g., drought shocks).

We also gather evidence that other factors, including market access and household resource endowments, positively correlate with seed purchasing. Households well-endowed with resources such as labor, land, and other durable household assets and with better market access are well known to face lower constraints to technology adoption (Crawford et al. 2003; Croppenstedt et al. 2003; Barrett 2008; Winters et al. 2009;

Jagwe et al. 2010), and this also stands true for accessing purchased seeds (Nordhagen and Pascual 2013; Makate et al. 2023b). This view is in line with theory and evidence that states that the choice of technologies by smallholder farmers is a function of many factors, including resource endowments (land, labor, and assets), markets, institutions, and infrastructure that facilitate access and use of these resource endowments and markets (Crawford et al. 2003; Croppenstedt et al. 2003; Winters et al. 2009).

Conclusions

We study the evolution of the seed market in Malawi (2010 to 2019) and Ethiopia (2012 to 2016), focusing specifically on smallholder seed purchasing decisions over time. By investigating the influence of the household's previous participation decisions in the seed market (through purchase) on later participation decisions, we gather evidence that pervasive nonlinear transaction costs characterize access to off-farm seed through the market. These nonlinear transaction costs emanate from policies, institutions, and social factors that determine the degree of information asymmetries in farmers' access and use of seed and productive resources. As a result, these transaction costs constrain access to seeds through the markets, reducing household seed security over time. However, the problem will likely reduce over time for households that can break the first hurdle of entering the market because of established social networks, experience, and market linkages that may marginally reduce transaction costs and improve subsequent access to purchased seeds.

Seed purchasing also responds to historical mean rainfall, lagged rainfall shocks, market access, and household resource endowments. The decisions to purchase seeds and the intensity of purchase are positively affected by historical mean rainfall in both Malawi and Ethiopia. Also, lagged drought shocks enhance general seed purchasing decisions in Malawi and maize seed purchases in both Malawi and Ethiopia. Maize farmers in Malawi and Ethiopia with market experience (gained from previous market engagements) and high-asset wealth endowments have an elevated advantage in purchasing maize seeds post-drought shock exposure as an adaptation strategy compared to their opposite counterparts. High rainfall levels (historically) may increase harvest and household disposable income, thereby reducing liquidity constraints faced by households, allowing them to access seed off-farm through purchase. Also, lagged rainfall shocks may increase liquidity constraints and the risk and uncertainty in the production environment, influencing seed purchasing by smallholder farmers. Improved market access and high-asset endowments enhance seed purchasing in smallholder farming.

Given the importance of seed purchasing in enhancing seed diversity and improving household seed security, policy efforts may target reducing transaction costs, pervasive information asymmetries between smallholder farmers and seed suppliers, and other entry barriers into formal and informal seed markets to improve seed access. For instance, continual development and upgrading of road infrastructure and agricultural support services such as rural financing and extension are some worthwhile interventions. Also, scaling up efforts that improve the availability of quality seeds locally for farmers, such as direct seed marketing interventions in Ethiopia, enhancing access to market information through localized information networks, promoting collective action for seed access via cooperatives or community seed banks, and strengthening the connections between farmers and multiple seed sources, are all potential and beneficial options. All such efforts that reduce transaction costs and pervasive information gaps will increase the effective demand for purchased seed and enhance farmers' seed security over time. Improved road infrastructure and access to market information would also facilitate output market participation, hence providing farmers with income from selling surplus produce. In addition, Investments in rural financing and insurance will ease farmers' constraints when they try to access seeds off-farm through purchasing to enhance the adaptation of their cropping activities to recurrent rainfall shocks.

Supplementary Information

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Supplementary Material 1.

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Author contributions
Conceptualization was contributed by C.M, A.A, S.T.H, and O.T.W; data selection, management, and analysis were involved by C.M; draft paper preparation was performed by C.M; review and editing was attributed by A.A, S.T.H, O.T.W, and C.M; supervision was done by A.A, S.T.H, and O.T.W; and funding acquisition did by O.T.W. All authors have read and approved this version of manuscript.

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Availability of data and materials
Data and codes used in the analysis will be made available upon request.

Declarations

Competing interests
Authors declare no competing interests.

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