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**Quality-Seed Supply and Resilient Sourcing of Off-Farm Seeds under
Conflicts and Weather Shocks**

Insights from Rice Farmers in Myanmar

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Abstract

The acquisition of rice seeds from off-farm sources (off-farm seeds) can be beneficial for maintaining and raising productivity in Myanmar, where the use of off-farm rice seeds is relatively common. Identifying factors that can raise farmers' resilience in acquiring off-farm seeds is potentially important in Myanmar and similar country contexts, where persistent and recurring shocks such as conflicts and weather events can disrupt such acquisition. This study addresses an important knowledge gap by examining the potential role of Myanmar's rice seed sector in maintaining resilient access to off-farm seeds. We use unique three-year panel data on monsoon-season rice producers in Myanmar, combined with detailed spatial data on violent events, various measures of weather shocks, information on spatial variation in local and regional seed production capacity compiled from secondary sources, and an innovative methodology based on instrumental variables and machine-learning approaches. Our findings suggest that using off-farm seeds generally leads to higher rice yields in the monsoon season, particularly if farmers used recycled seeds during the previous monsoon season. This result holds at the national level, as well as within the major rice-producing agroecological zones (AEZs), namely, the Delta and Dry Zone. During the study period (2021–2023), the use of off-farm seeds declined overall and was negatively associated with rainfall and temperature shocks during the previous monsoon season, floods during the late dry season, and fatal violent events during the dry season. However, these negative effects were largely mitigated in townships hosting seed farms or research farms that specialize in early-generation seeds (EGS) of rice, and in states with higher state-level production of certified rice seeds, relative to estimated in-state seed use. While the dominant types of shocks varied across AEZs and years, the mitigating effects of government seed or research farms and state-level production of certified seeds remained robust throughout. Overall, the results indicate that continued efforts to expand local and regional EGS production, alongside stronger certified seed systems, can strengthen smallholders' resilience in off-farm seed use during conflicts and weather shocks.

Keywords: Off-farm seed use, rice, conflicts, weather shocks, machine learning, Myanmar.

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1 Introduction

Recurring conflicts and intensifying weather shocks associated with climate change pose challenges to improving welfare in low- and middle-income countries, including for smallholder agricultural households. Identifying how agrifood systems are affected by these shocks—and more importantly, which factors can enhance resilience—remains critical for low-income, agricultural-based societies. The existing literature provides evidence on the roles of various support interventions for the agriculture sector in developing countries in Asia. These interventions include research and development for varietal development (Wang et al. 2022), agricultural insurance (Biglari et al. 2019; Moritz et al. 2025), improved functioning of downstream value chains (Goeb et al. 2022; Minten et al. 2023), crop commercialization (Do and Nguyen 2024), trade liberalization (Adenäuer et al. 2025), climate-smart agricultural practices (Takeshima et al. 2026a), crop diversification (Tesfaye and Tirivayi 2020; Takeshima et al. 2026b), and training and production autonomy (such as Takeshima et al. 2025c), among others.

Access to off-farm seeds,¹ which enable farmers to acquire fresh, high-quality seeds, may also be affected by conflicts and weather-related shocks (see, for example, McGuire 2008; Sperling et al. 2008; Ayalew et al. 2026).² Nonetheless, a knowledge gap remains regarding the production effects of off-farm seeds and, consequently, the extent to which conflicts and weather shocks affect agricultural production through disruptions to seed access. Because of the dynamic nature of seed recycling (for example, Heisey and Brennan 1991; Jaffe and van Wijk 1995), the relative productivity effects of off-farm seeds, as compared to recycled seeds, can depend on shocks across a diverse set of periods, including the previous year’s production season, which can affect the quality and quantity of recycled seeds for the current season; the off season, which can affect the storage of recycled seeds; and the preplanting season, in which most off-farm seeds are typically acquired. Similarly, resilience in accessing off-farm seeds, despite conflicts or weather shocks, can be driven by complex mechanisms, especially given the relationship between off-farm and recycled seeds, and the compounding effect that seeds are highly divisible inputs with potential for significant multiplication, particularly for crops such as rice with generally high seed multiplication rates (van den Broek et al., 2015). The persistent use of saved seeds, particularly for self-pollinating crops, in many countries heightens the need for concrete evidence to understand the role of off-farm seeds and resilience in accessing them.³

We narrow these knowledge gaps using multi-round panel data from rice farmers in Myanmar. By applying the panel fixed-effects linear-probability model (FE-LPM) and using instrumental variables (IV) to account for the potential endogeneity of using off-farm seeds in the current and previous years, we assess the associations between rice yields and the use of off-farm seeds. We then identify how conflicts and weather-related shocks are associated with the use of off-farm rice seeds and how various factors, including proximity to public-sector seed and

¹In this paper, we define “off-farm seeds” as rice seeds farmers acquire from any source other than their own saved seeds from previous years. Past seed literature uses similar terms (such as McGuire 2008; Sperling et al. 2008).

²In our study, we focus on off-farm seeds as opposed to seeds that were recycled by farmers from a previous harvest, instead of distinguishing across other source types, such as the formal and informal sectors. This choice was made because farmers in under-developed regions may be more certain about whether they recycled their seeds or obtained them from elsewhere, compared to whether their seeds were sourced from the formal or informal sector.

³For example, in many low- and middle-income countries, the use of saved, recycled seeds has remained prevalent until recently (Pray & Ramaswami 1999; Singh & Morris 1997; Rohrbach et al. 1997). Even in Europe in the 2010s, for some self-pollinating crops such as wheat, about 40 percent of seeds were sourced from farmers’ own saved seeds (Ragonnaud 2011).

research farms (SF/RF), can potentially enhance farmers' resilience to shocks. In doing so, we apply a machine-learning (ML) method (least absolute shrinkage and selection operator [LASSO]) within a panel-data framework to address multicollinearity issues that arise in empirical settings such as ours, which involve potentially many interaction terms.

Myanmar provides a particularly important case study for examining the linkages between conflicts, weather shocks, and seed-sourcing behaviors, as well as resilience. As described in later sections, Myanmar exhibits a moderate level of off-farm rice seed acquisition. It produces significant amounts of high-quality rice seeds (certified seeds), compared with other selected Asian countries at similar development levels (such as Nepal and Laos).⁴ And yet, off-farm rice seed acquisition and the use of certified rice seeds remain less prevalent than in other higher-income Asian countries (such as Malaysia and Japan). In Myanmar, access to off-farm rice seeds may be more critical than in other Asian countries. At the same time, ensuring the resilience of seed systems is especially urgent due to vulnerabilities resulting from the country's lower economic development levels and incomplete seed-exchange infrastructures.

Our findings suggest that using off-farm seeds generally leads to higher rice yields in the monsoon season, particularly if the farmer used recycled seeds in the previous monsoon season. In general, the use of off-farm seeds was negatively associated with violent events and various types of weather shocks. However, these negative associations are largely mitigated if the township has public SF/RF that specialize in early generation seeds (EGS) of rice, and the state produces more registered/certified rice seeds than it uses, theoretically.

Our research contributes to the growing literature assessing resilience in agricultural production systems amid conflict and weather shocks (for example, Biglari et al. 2019; Tesfaye and Tirivayi 2020; Wang et al. 2022; Do and Nguyen 2024; Moritz et al. 2025; Adenäuer et al. 2025; Takeshima et al. 2025c) by providing additional evidence regarding off-farm seed access. Our research also contributes to the seed-system literature, particularly studies assessing the determinants and roles of off-farm seeds (McGuire 2008; Sperling et al. 2008; Tyack et al. 2025; Ayalew et al. 2026) by providing direct evidence of factors that enhance farmers' resilience in accessing off-farm rice seeds. Our study also builds on growing literature on Myanmar's agri-food system and how it is affected by conflicts or weather shocks (Boughton et al. 2021; Goeb et al. 2022; Minten et al. 2023; Takeshima et al. 2025, 2026a, 2026b). Methodologically, our study contributes to recent literature that applies ML methods such as the LASSO to the agrifood system analysis (for example, Narayanan et al. 2019; Dzanku et al. 2021; Takeshima and Kishore 2026).

The remainder of this paper is structured as follows. Section 2 briefly describes the relevant analytical context. Section 3 explains the empirical approach. Section 4 summarizes data and descriptive statistics. Section 5 presents results. Section 6 discusses policy implications. Last, section 7 concludes.

⁴The reasons remain generally unclear regarding the relatively high prevalence of off-farm rice seed use in Myanmar compared to the prevalence in other countries with similar economic development levels. One possible reason is that, due to the Irrawaddy River Basin, Myanmar has one of the largest areas with high rice production suitability (based on the Global Agroecological Zone [Fischer et al. 2012]) among countries with similar income levels globally, including Nepal and Laos, and these inherent advantages in productivity have led to remarkably high levels of seed exchange activities, relative to their overall economic development levels.

2 Context of rice seed systems in Myanmar

Detailed reviews of rice seed systems in Myanmar are provided by various past literature (such as Subedi et al. 2017; Myint et al. 2019; World Bank 2019b; Boughton et al. 2024; Phyo et al. 2025). Here we briefly discuss aspects that are relevant to our analytical contexts.

2.1 Sources of rice seeds (recycled own seeds vs. off-farm seeds)

Globally and historically, rice farmers remain heavily dependent on recycled seeds because rice is self-pollinating and can preserve desired traits when recycled from one season to the next. Yet as rice production systems and the overall economy modernize and as rice producers integrate into seed markets, sourcing off-farm seeds from local markets, other farmers, or private seed companies is increasingly common. In recent years, a moderately high share of rice producers in Myanmar have sourced seeds off their farms rather than from their own saved seeds (Figure 1). For example, according to data from the Myanmar Agricultural Performance Survey (MAPS), 56 percent of rice producers obtained off-farm seeds in the 2020 monsoon season. While this share was lower than in countries such as Japan and Bangladesh, it was comparable to Viet Nam and often higher than other South and Southeast Asian countries, including Cambodia, Laos, Nepal, and Timor-Leste. Therefore, rice seed systems in Myanmar, compared to countries with more autarchic rice seed systems, are moderately functional in terms of the level of market integration. At the same time, dependence on off-farm seed sources exposes farmers to seed market disruptions caused by conflict, weather shocks, and other disturbances. Consequently, Myanmar's rice seed systems may be less resilient than highly developed seed systems, such as those in Japan, or in countries with more off-farm seed use and less conflict, such as Bangladesh.

2.2 Supply of quality rice seeds, including certified rice seeds

As with rice seed sourcing, the use of higher-quality seeds, such as certified seeds, remains limited when the rice sector and overall economy are less developed and gradually becomes more common as they modernize.⁵ Using the intensity of certified rice seed production as a proxy for high-quality seed use, Myanmar has been characterized as medium-level among comparable South and Southeast Asian countries (Figure 2).⁶ To ease the comparison across countries, which can often be affected by the ambiguous assumption of seeding rates, Figure 2 simply divides the certified rice seeds produced by the total rice area cultivated annually, aggregating cultivated areas across all seasons. Based on this approach, the production of certified rice seeds in Myanmar in 2024 was about 16kg/ha of rice area, an increase from the estimated 13kg/ha in 2011. A seeding rate of 16kg/ha, for example, can cover either one-sixth of the total rice area at 96kg/ha ($=16 \times 6$) or one-third of the total rice area at 48kg/ha ($=16 \times 3$), respectively.⁷ This production rate is similar to Pakistan and Sri Lanka in the 2000s, and to India in the 2010s; higher than less developed countries like Laos and Nepal, where certified rice seed production

⁵Recent studies also indicate that other intermediate-quality seeds, such as “truthfully labeled” seeds (common in several other Asian countries), are not recognized in Myanmar (see Win et al. 2025).

⁶Figure 2 should be interpreted with caution. While we did our best to focus on certified seeds explicitly, some ambiguity remains, depending on countries or years, as to whether the figures also include other seed classes that have high quality but have not gone through the certification process (such as truthfully labeled seeds).

⁷While the production figures of certified rice seed for Myanmar are from the Rice Division, DOA (2024) for 2022, the figures should be interpreted with caution, because it is possible that not all seed production activities, particularly those engaged in by seed companies and other private-sector producers, were fully captured in recent years due to ongoing conflict.

has been minimal in the past few decades; but lower than more advanced countries like Malaysia, which could theoretically cover the entire rice area with seeding rates of 100kg/ha.

The SF/RF operated under the management of the Department of Agriculture and the Department of Agricultural Research—both of which are housed under the Ministry of Agriculture, Livestock and Irrigation—are the primary public-sector institutions that produce breeder seeds, foundation seeds, and certified seeds. Figure 3 illustrates the townships in which at least one SF/RF is located (in 2014).⁸ It should be noted that substantial changes have occurred in Myanmar’s certified rice seed sector over the last decade, as reflected in the growing number of certified seed varieties approved for release and the increasing role of the private sector (Figure 4). These private companies have increasingly introduced varieties developed abroad, or varieties whose original germplasm was sourced from other countries, particularly China, India, the Philippines, Japan, and Thailand.

These overall trends suggest two important aspects of Myanmar’s rice seed systems. Myanmar has a moderate level of seed production capacity, including registered seeds and certified seeds, and expanding it at a reasonable scale can have potentially meaningful effects on the rice seed sector. At the same time, such capacity may be more unequally distributed across locations, unlike in countries like Malaysia where the capacity may be more universally high. In fact, taking registered or certified seed production as an example, seed production sizes relative to the local rice-planted areas exhibited noticeable variations across states (Table 1). For example, after applying certain assumptions to seed yield and seeding rates,⁹ the production of registered or certified rice seed in the Mandalay region was sufficient to cover 76 percent of the theoretical seed use in that region, followed by Nay Pyi Taw (61 percent), Magway (42 percent), and Bago (34 percent). However, seed use was often around 10 percent or lower in most other regions, including major rice-producing regions, such as Ayeyarwady (7 percent), Yangon (9 percent), and Shan State (5 percent). While some registered or certified rice seeds are likely transferred across states, a significant share may be used within the state, given local preference for those varieties and their suitability to local agroecological conditions.

Overall, production of registered or certified seed covers only about 16 percent of the entire country’s seed use (19 percent at a seeding rate of 100kg/ha), which may be lower than several other Asian countries.¹⁰ Nonetheless, if 50 percent of rice farmers use off-farm seeds, they could account for roughly 32 percent of such seeds in any given year. While off-farm seeds remain a minority compared to noncertified seeds traded or exchanged in the market, the

⁸Given that some SF/RF are situated in contested areas, it is difficult to ascertain their operational status since 2021. Interpretation of results for these areas should therefore be treated with caution.

⁹In Table 1, only the seed and paddy production areas for each state/region were originally provided by the Rice Division (as shown in Phyoe et al. 2025). We first assumed that rice seed yields in a particular state are higher than paddy yields at similar proportions across states, and we computed the rough amount of rice seed produced in each state (more details are provided in the Table 1 note). Second, by applying the typical rice seeding rate of about 114kg/ha for Myanmar (derived from the FAOSTAT Food Balance Sheet in 2022), we derived the theoretical annual rice seed use in the state. The seeding rate of 114kg/ha is slightly higher than the 100kg/ha assumed in a separate government document (Government of Myanmar 2023) and thus yields more conservative estimates of seed production relative to theoretical seed use.

¹⁰While not perfectly comparable, the rice area covered by certified seeds reached 60 percent by 2003 in Indonesia (Suwarno et al. 2003) and 45 percent by 2012 in the Philippines (Sombilla and Quilloy 2014), while 42 percent of rice producers in India had been using certified seeds by 2016 (Government of India 2020). In addition, the adoption rate of hybrid rice which tends to be more commonly certified, was still only around 2 percent in Myanmar in 2014 (Myint et al. 2019) and is not likely to have grown substantially since then.

production scale of registered or certified rice seeds may still be large enough to affect farmers' access to off-farm seeds.

3 Empirical methods

3.1 Data

Our primary data on farm respondents comes from MAPS. Specifically, we focus on 4 rounds of monsoon harvesting season data administered from January 2022 through January 2024, which capture key variables including rice yield and the primary source of seeds used on the largest rice plot that they cultivated during the 2021, 2022, and 2023 monsoon seasons, with production seasons occurring from May through October 2021, 2022, and 2023. Each round of MAPS data is nationally representative, collected through multi-stage stratified sampling. Some samples are panel samples that provide information on rice production and seed use across multiple rounds. Each round also includes information on the previous year's seed sources; some panels have a maximum of 4 consecutive rounds of seed use data. Our analyses require at least 3 consecutive rounds of data—including the first round, from which lagged seed-use data is used—to estimate panel-data regressions using lagged seed-use data. Therefore, our final sample consists of 2,064 panels of monsoon-season rice farmers and a total of 6,957 observations, of which 2,064 from the first round are used only to extract lagged seed-source data, and the remaining 4,893 observations are used as dependent variables in the regressions.

Information on state-level areas used for the production of Registered Seeds and Certified Seeds was obtained from the Rice Division, Department of Agriculture (2024), as cited in Phyo and colleagues (2025). Data on the townships and farm areas of licensed seed companies in Myanmar were extracted from the Myanmar Seed Information Portal (Government of Myanmar 2026).

Data on the intensity of violent events within the village-tracts of the respondents are obtained from ACLED (Raleigh et al. 2010) and have been used in recent studies assessing the role of conflicts on various development outcomes across the world, including Myanmar (Minten et al. 2023; Boughton et al. 2024; Takeshima et al. 2024, 2025, 2026a). ACLED data compile information on violent events, including their dates and approximate geographic coordinates, from numerous sources which allow us to identify how many events occurred in each village-tract within a particular time period. These violent events include battles, explosions/remote violence, and violence against civilians. The ACLED data also reports whether each event directly involved any fatality.¹¹

Weather data are extracted from various sources. Historical daily rainfall, temperature, and wind speed data are from the AgERA5 dataset (Dee et al. 2011). Daily satellite-based data used to extract flood occurrence (described in a later section) are from De Groeve et al. (2015). Nighttime light data are from Elvidge et al. (2021), whose methodologies have also been applied to 2022 and 2023. Lastly, gridded International Wealth Indexes for 2020 (at 10km×10km grids)

¹¹More detailed definitions of violent events are provided in https://acleddata.com/acleddatanew/wp-content/uploads/2021/11/ACLED_Codebook_v1_January-2021.pdf. Battles can include armed clashes, the government regaining territories, and nonstate actors overtaking territories. Explosions or remote violence include chemical weapons; air or drone strikes; suicide bombs; shelling, artillery, or missile attacks; remote explosives, landmines, or improvised explosive devices (IEDs); and grenades. Violence against civilians includes sexual violence, attacks, and abduction or forced disappearances.

are extracted from Li et al. (2024).¹² All these data, except flood data, are extracted at the village-tract level. Flood data are extracted at the township level, using the GIS shapefiles of townships and village tracts in Myanmar from GeoNode (<https://geonode.themimu.info/>).

3.2 Empirical model

We first estimate the effects of the off-farm seed use on rice yield through IV FE-LPM. We then analyze the linkage between conflicts or weather shocks and off-farm seed use, and identify various factors associated with heterogeneity in these linkages using the LASSO approach.

3.2.1 Simple correlations between off-farm seed use at years t (S_{ijt}) and $t - 1$ ($S_{ij,t-1}$)

We first estimate a very simple illustrative regression on the dynamic relations between off-farm seeds use decisions

$$S_{ijt} = \alpha + \alpha_{S1}S_{ij,t-1} + \alpha_{S2}S_{ij,t-2} + c_{ij} + \varepsilon_{ijt} \quad (1)$$

in which α represents estimated correlation coefficients after controlling for unobserved farmer-specific fixed effects c_{ij} , and idiosyncratic error ε_{ijt} . Equation (1) is not a structural equation; rather it is used to simply assess the correlations between S_{ijt} and $S_{ij,t-1}$ while controlling for farm fixed-effects and $S_{ij,t-2}$.

3.2.2 Effects of off-farm seed use on rice yield

We estimate the following IV FE-LPM

$$\ln Y_{ijt} = \beta + \beta_{S0}S_{ijt} + \beta_{S1}S_{ij,t-1} + \beta_{SS}S_{ijt}S_{ij,t-1} + \beta_X X_{ijt} + c_{ij} + \varepsilon_{ijt} \quad (2)$$

in which the dependent variable ($\ln Y_{ijt}$) is the natural log of the monsoon-season rice yield for farmer i , in township j , in year t . S_{ijt} is a binary variable and takes the value of 1 if farmer i used off-farm seeds in year t , and 0 otherwise. X_{ijt} is a vector of other time-variant exogenous variables (described in a later section). Notations β s are estimated parameters. Equation (2) posits that $\beta_{S0} > 0$ and $\beta_{SS} < 0$; the use of off-farm rice seeds in year t has yield-enhancing effects, but use of off-farm seeds in year $t - 1$ implies relatively high quality of seeds recycled from year $t - 1$ and potentially suppress the effect of using off-farm seeds again in year t .

In Equation (2), both S_{ijt} and $S_{ij,t-1}$, and thus $S_{ijt}S_{ij,t-1}$, are all potentially endogenous because S_{ijt} can be endogenous with Y_{ijt} , and $S_{ij,t-1}$ can be endogenous with S_{ijt} due to their dynamic relations. We therefore estimate an IV-regression version of (2). Specifically, we use cluster averages, excluding self-observation, of endogenous variables, namely, sample-averages of S_{ijt} and $S_{ij,t-1}$ at township-level j as well as their products $\bar{S}_{jt}$, $\bar{S}_{j,t-1}$, and $\bar{S}_{jt}\bar{S}_{j,t-1}$, respectively, to

¹²International Wealth Indexes estimated subnationally by Li et al. (2024) builds on original work by Rutstein and Staveteig (2014) and Smits and Steendijk (2015), taking a standardized range of 0 to 100, with 0 representing the lowest level of wealth (no assets).

instruments S_{ijt} , $S_{ij,t-1}$ and $S_{ijt}S_{ij,t-1}$, respectively.¹³ We further expand the set of IVs by applying Lewbel’s (2012) approach and test its validity using the Baum and Lewbel (2019) method.¹⁴

3.2.3 Roles of local or regional seed production capacity on off-farm seed use and resilience to conflicts and weather shocks

We then estimate a more fully parameterized model

$$S_{ijt} = \gamma + \gamma_f \cdot f(V_{jt}, W_{ijt}) \cdot R_j + \gamma_g \cdot g(V_{jt}, W_{ijt}) \cdot H_{ij} + \gamma_k \cdot k(V_{jt}, W_{ijt}) \cdot X_{ijt} + \gamma_s \bar{S}_{j,t-1} + \gamma_V V_{jt} + \gamma_W W_{ijt} + \gamma_X X_{ijt} + c_{ij} + \varepsilon_{ijt} \quad (3)$$

in which V_{jt} is a set of indicators of violent events at township j and W_{iji} is a set of indicators of weather-shocks at village-tracts of farmer i . R_j is a vector of local or regional seed production related indicators—that is, a dummy variable indicating the within-township presence of SF/RF and the state-level certified seed (CS) production relative to the theoretical seed use. H_{ij} is a set of other time-invariant variables, which will be explained further below, that control for any other potential factors at j such that the actual effects of R_j can be separately identified from other potential confounders. Functions $f(\cdot)$, $g(\cdot)$, and $k(\cdot)$ denote the set of key variables among V_{jt} , W_{ijt} , H_{ij} , and X_{ijt} that are selected by ML approaches described in subsection 3.2.3.1 below. Notations γ ’s are estimated parameters.

In Equation (3), we insert $\bar{S}_{j,t-1}$ instead of $S_{ij,t-1}$ because $\bar{S}_{j,t-1}$ is less likely to be endogenous to S_{ijt} than $S_{ij,t-1}$. The focus of (3) is not to estimate the dynamics in S_{ijt} but rather identify the effects of R_j (that is, coefficients γ_f), which can be more precisely achieved by excluding explicit modeling of the relationship between S_{ijt} and $S_{ij,t-1}$. Inserting $\bar{S}_{j,t-1}$ as an additional variable can control for the effect of the prevalence of off-farm seed use in year $t - 1$, which is partly correlated with $S_{ij,t-1}$.

3.2.3.1 Robust identification of the roles of local or regional seed production indicators

An empirical challenge in estimating Equation (3) is that the off-farm seed use decisions can be affected by conflicts and different types of weather-shocks from several different periods, due to a relatively long life cycle of rice seeds. Specifically, S_{ijt} can be affected by shocks during the production in monsoon season of year $t - 1$ from which some seeds can be recycled, the subsequent dry season during which recycled seeds are processed or stored, and the beginning of the monsoon season in year t when off-farm seeds are typically acquired and if farmers decide to do so (for example, Takeshima and Nagarajan 2015). These challenges may be relatively more evident for seed acquisition decisions than for some other inputs, such as fertilizer and mechanization services, which typically do not involve the use of recycled products as an option. However, including shock variables from many different periods can potentially lead to significant multicollinearity and reduced precision in Equation (3).

We address this challenge by applying LASSO methods. Essentially, the method proceeds in two steps: (a) we first identify a subset of $V_{jt}R_j$ and $W_{iji}R_j$ that have high predicting

¹³Past studies used a similar approach of constructing instrumental variables from “leave-one-out” cluster averages of endogenous variables (Takeshima et al. 2025a, 2026a).

¹⁴Similarly, past studies used such approaches to expand the set of IVs to minimize under-identification problems (see, for example, Karymshakov et al. 2023; Paudel et al. 2025; Takeshima et al. 2025a).

power of S_{ijt} (that is, conflicts or certain types of weather-shocks from specific subperiods m) using LASSO; and (b) we then estimate Equation (3) using a structural-model version of LASSO (post-double-selection LASSO [PDS-LASSO hereafter] as described in Chernozhukov et al. 2015 and Belloni et al. 2016, for example).¹⁵ Step (a) is not a structural model and simply identifies whether $V_{jt}R_j$ and $W_{ijt}R_j$ are highly correlated with S_{ijt} . PDS-LASSO in step (b) allows us to obtain structural parameters for those subsets of $V_{jt}R_j$ and $W_{ijt}R_j$ of our interest, that is, term $\gamma_f \cdot f(V_{jt}, W_{ijt}) \cdot R_j$, while controlling for a large number of other factors that may also affect off-farm seed use but are not our primary focus, namely, term $\gamma_g \cdot g(\cdot)$ in (3).¹⁶ Appendix A provides a technical description of LASSO and PDS-LASSO.

3.3 Variables

3.3.1 Violent events (V_{jt})

Variables V_{jt} are township-level counts of violent events (regardless of fatality), and fatal violent events,¹⁷ for the following 4 sub-periods (m): (i) May through October in year $t - 1$ (the monsoon season in the previous year from which some harvests might have been saved as seeds for use in t); (ii) November in $t - 1$ through April in t (dry season during which saved seeds are processed and stored up to the beginning of the monsoon season in t); (iii) February through April in t (subperiod of (ii) and used for capturing shocks in periods closer to the beginning of the monsoon season in t); (iv) April in t (in which most seed sourcing decision may be made). Arguably, these four reference periods are selected to capture the relevant timing for the life cycle of seeds. We also tried slightly different subperiods and found that, in general, these four periods have high predictive power.

3.3.2 Weather shocks (W_{ijt})

We measure weather shocks of four types: temperature, rainfall, windstorms, and floods. Temperature shocks and rainfall shocks are measured based on the average daily maximum temperatures and total rainfall at the village-tract levels of respondents for the same four sub-periods described above, as well as deviations from the historical norms, that is, the absolute value of the z-score based on historical averages and distributions between 1990 and 2020. Similar measures have been used in recent studies assessing weather shocks (see, for example, Takeshima et al. 2025b, 2026). Windstorms for the same four sub-periods are measured as the number of days for which the daily maximum wind speed exceeded two standard deviations above historical averages, based on the historical patterns in the same village tracts, following approaches used in recent studies (Zhang et al. 2021; de Brito Neto et al. 2022). Flood shocks for the same four sub-periods are measured using the number of days of flooding at the township-level, following the approach by De Groeve et al. (2007, 2015) that uses the Advanced Microwave Scanning

¹⁵Simply estimating a standard panel fixed-effects regression in step (b) can yield incorrect results without accounting for the fact that key variables are selected from step (a). PDS-LASSO corrects for this issue.

¹⁶PDS-LASSO merely controls for $\gamma_g \cdot g(\cdot)$ to derive consistent structural estimates for $\gamma_f \cdot f(\cdot) \cdot R_j$ and does not derive structural estimates for $\gamma_g \cdot g(\cdot)$.

¹⁷These violent events are provided by ACLED (2025) (originally Raleigh et al. 2010) and consist of any of the following: battles (armed clashes, the government's regaining territories, and non-state actors' overtaking territories), explosions/remote violence (for example, chemical weapons, air/drone strikes, suicide bombs, shelling/artillery/misile attacks, remote explosives/landmines/IEDs, and grenades), and violence against civilians (for example, sexual violence, attacks, and abduction or forced disappearances).

Radiometer - Earth Observing System (AMSR-E) passive microwave measurement applied to satellite imagery.

3.3.3 Variables X_{ijt} and H_{ij}

Variable X_{ijt} consists of other exogenous characteristics of respondents which include key household demographics, such as the age and education of the farm management decision-maker and household size, which might vary over time due to migration of household members. X_{ijt} also proxies related assets—size of farmland owned, the number of machines owned (measured in aggregate horsepower),¹⁸ and the type of livestock owned (principal component), as well as access to markets proxied by distances to the nearest input-retailers and township center (time of travel in hours) and access to the labor market proxied by local wages of male agricultural workers. X_{ijt} also includes the average annual nighttime light in township j at year t , as well as the village tract-level sample share of respondents who use irrigation at year t to proxy general access to irrigation given the local hydrological conditions and infrastructure. X_{ijt} further includes the township-level sample shares of rice producers growing one of 3 major modern varieties—Sinthukha, Manawthukha, and Ayarmin. Finally, X_{ijt} includes year dummy variables to control for any year-specific factors.

The variable H_{ij} is the total farm area under all licensed rice seed companies in township j . This variable is time-invariant since we do not have information about its variation across years t . Nonetheless, the variable H_{ij} captures the growing importance of the private-sector seed companies in filling the supply gap for high-quality rice seeds by supplementing public-sector rice seed production in Myanmar. Furthermore, the variable H_{ij} also includes a proxy of township-level variations in basic wealth levels as measured through the International Wealth Indexes. We treat this variable as time-invariant because the most recent data are from 2020, prior to the study period. Including this wealth proxy alongside other development indicators, such as nighttime lights and market access, helps separate the extent to which resilience of off-farm seed access is attributable to greater wealth and clarifies the effects of SF/RF and certified seed supply on resilience.

4 Descriptive statistics

4.1 Seed sources

Figure 5 shows the share of monsoon-season rice growers using off-farm seeds by year, using all nationally representative MAPS samples. Our analyses use the subsample of the data as described in Section 3. From Figure 5 we see that use of off-farm seeds declined sharply from 56 percent to 38 percent at the national level between 2020 and 2023. Declines have been common across agroecological zones (AEZs), with the major rice-producing Dry and Delta Zones experiencing sharper drops from 66 percent to 48 percent and from 53 percent to 31 percent, respectively. These downward trends also hold consistently for two major off-farm seed sources, namely, markets and other farmers, with declines from 31 percent to 21 percent and from 25 percent to 17 percent, respectively, at the national level.

¹⁸Following the past study in Myanmar (Takeshima et al. 2025), we apply the following: 40 horsepower (hp) for four-wheel tractors, 15 hp for two-wheel tractors and Trawlarjee, and 5 hp for irrigation pump. We also assign 5 hp for other minor machines. We apply slightly different hp and find that our main results are largely robust.

4.2 Sample descriptive statistics

Table 2 provides descriptive statistics of respondents’ characteristics. The use of off-farm seeds among our sample respondents is on a similar scale as the nationally representative figures in Figure 5, suggesting that our sample—subsamples based on panel data availability—offers a good representation of Myanmar. Table 2 also suggests that sampled farmer respondents are around 45–50 years old; have completed eight years of education; have four to five household members; and own about 3.5 ha of farmland, poultry and a few other livestock animals, and agricultural equipment totaling an equivalent of roughly 13 to 16 horsepower. They are typically located 30 minutes to an hour away from agri-input retailers and the nearest township center. About 13 percent, 10 percent, and 7 percent of the sample respondents in the township grow Sinthukha, Ayarmin, and Manawthukha varieties, respectively. On average, respondents are in townships with licensed rice seed companies that hold about 40 ha of farmland, though significant variation is indicated by the standard deviations.

4.3 Violent events and weather shocks

Table 3 summarizes the respondent-level statistics of violent events and weather shocks. A typical respondent experienced 15 violent events, 11 of which were fatal, during the monsoon season in the previous year; 19 violent events, including 13 fatal events, during the dry season; and 11 and 3 violent events in February–April and April, specifically. These figures increased substantially in the 12 months leading up to both the 2021 and 2022 monsoon seasons, reflecting the widespread violence that occurred after the military coup of early 2021. Prevalence was also high: respondents experienced at least one violent event and one fatal violent event 70–80 percent and 60–70 percent of the time, respectively.

Weather shock patterns varied considerably. In the previous year’s monsoon season, a typical respondent experienced rainfall and temperatures that were 1.2 and 0.85 standard deviations (STD) away from historical averages, and about 7.6 and 4.5 days of extreme winds and floods, respectively. Similarly, in the periods between November–April and February–April, as well as in the month of April alone, respondents experienced temperatures that were 0.8 STD, 0.9 STD, and 1.0 STD away from historical averages; 6.4, 3.1, and 0.6 days of extreme winds; and 3.7, 1.7, and 0.6 days of floods.

5 Results

5.1 Simple dynamic associations of off-farm seed use

In Table 4, we first show simple correlations between off-farm seed use decision in the current monsoon season (S_{ijt}) and those of the past monsoon seasons ($S_{ij,t-1}$, $S_{ij,t-2}$), estimated from Equation (1). At both the national level and within each AEZ (Hill, Delta, Dry, Coastal), we observe clear negative correlations between S_{ijt} and $S_{ij,t-1}$, typically between -0.2 and -0.3 , suggesting that farmers are less likely to use off-farm seed if they used them in the preceding monsoon season. Negative correlations are more pronounced when $S_{ij,t-2}$ is included. This is intuitive: off-farm seed use in year t is considerably less common if off-farm seed was used in both $t - 1$ and $t - 2$. While Table 4 merely shows simple correlations, these patterns are consistent with seed use of self-pollinated crops like rice, and highlight the importance of controlling for potential dynamics, which motivated the use of IV-method in Equation (2).

5.2 Rice yield effects of using off-farm seeds

Table 5 shows the estimated associations between rice yield and off-farm seed use in year t based on Equation (2). Results from the IV-FE regression generally indicate significantly positive associations, after controlling for respondent characteristics and unobservable fixed effects. Associations are significantly positive, particularly if recycled seed, as opposed to off-farm seed, was used in year $t - 1$. This is indicated by significantly negative coefficients for the interaction term “Off-farm seed in $t \times$ Off-farm seed in $t - 1$ ”. Specifications tests confirm that our IVs are suitable, that is, no overidentification nor under-identification, indicating the Lewbel IV approach is appropriate.

These results are intuitive and consistent with the hypothesis that the relative gains from newly obtaining off-farm seeds in year t are more positive compared to using recycled seeds they lose more of their original quality after being recycled twice, that is, in year t as well as year $t - 1$, as opposed to being recycled only once in year t . Specifically, use of off-farm seeds in year t is associated with a rice yield that is about 13.7 percent higher compared to use of recycled seed in $t - 1$. This result is statistically significant at the 10-percent level. This associated gain falls to about 11.6 percent if off-farm seed was also used in $t - 1$, and this result is statistically insignificant. Results also generally hold consistently when focusing on specific AEZs. Specifically, in the Delta and Dry Zones, corresponding associations are 15.4 percent (statistically significant) and -1.2 percent (statistically insignificant), and 12.3 percent (statistically significant) and 8.4 percent (statistically insignificant), respectively.

It is worth noting that the estimated associations are combinations of various cases that can occur whenever farmers obtain seeds from off-farm sources, whether this involves a change in varieties; a switch to higher-quality seeds, such as certified seeds; or continued use of lower-quality seeds, for example, noncertified or informally marketed seeds. Due to limited information, disentangling overall associations into their component types is not possible in our study. Nonetheless, our estimates of the overall associations reflect the potential importance of frequent access to off-farm seeds under prevailing seed-sector conditions in Myanmar and the consequences of a reduction in access. Thus, we further identify factors leading to higher resilience in access to off-farm seeds below.

5.3 Potential roles of seed farms/research farms and registered/certified seed production on off-farm rice seed use under shocks

5.3.1 Key violence and weather shock predictors of off-farm rice seed use in the 2021, 2022, and 2023 monsoon seasons

Table 6 summarizes the dominant predictors of off-farm seed use decisions incrementally selected by the ML LASSO process. The model weighs more flexible parameterization over model parsimony by lowering the penalty term λ . The most parsimonious model selects only fatal violent events during the previous monsoon season. These events are then interacted with household size and the age of the farm decision-maker. At lower values of the penalty term λ , more variables are added as predictors of off-farm seed use, among which are two variables of interest: within-township presence of SF/RF and state-level CS production relative to theoretical in-state seed use. Namely, these include the following: the incidence of at least one fatal violent event in the previous monsoon season, floods during the late dry season, and floods at the end of the dry season. Each of these are interacted with the dummy variable of within-township presence of SF/RF. Rainfall and temperature shocks during the previous monsoon season are

interacted with state-level CS production relative to theoretical in-state seed use.

Figure 5 in Appendix B illustrates the process by which the LASSO method narrows the set of dominant variables as the penalty term λ is increased, including variables that contain within-township presence of SF/RF and state-level CS production relative to theoretical in-state seed use.

5.3.2 Roles of seed farms/research farms and certified seed production on resilience in off-farm rice seed use

Table 7 summarizes the PDS-LASSO results of Equation (3), namely, the roles of key combinations of violent events and weather shock variables, and their interactive effects with two key proxies of local/regional seed-supply capacity: the in-township presence of public SF/RF and the size of state-level certified rice seed production relative to the theoretical state-level seed use selected from the LASSO process. As described in the methodology, Equation (3) also jointly controls for all the other exogenous variables that are also selected by the LASSO process. Table 7 shows both the primary results, as well as robustness check results (last 2 columns).

Table 7 generally shows the significantly adverse effects of several shock variables, particularly for respondents in townships without SF/RF and in states with relatively small production of certified rice seeds (coefficients excluding interaction terms). For example, abnormally high or low rainfall during the previous monsoon season, that is, one STD more or less rainfall than the historical average, is associated with a 7.4 percentage point (pp) lower likelihood of using off-farm rice seeds. Similarly, doubling the number of floods during the late dry season (February–April) and experiencing at least one incident of fatal violent events during the dry season (November–April) are associated with 6.1pp and 7.1pp lower likelihood of using off-farm rice seeds, respectively. Results are qualitatively similar in robustness checks models wherein temperature shocks may have suppressing effects on off-farm seed use.

Direct impact pathways are generally more difficult to establish, but some explanations hold. The adverse effects of rainfall shocks in the previous monsoon season may reduce the availability of seeds to save for next season due to reduced yields and therefore lower access to recycled seeds both from own-farm and local off-farm sources. However, respondents may adapt by relying more on recycling own seeds by spending more time on better selection, processing, and storage methods, for example, since sourcing off-farm seeds of preferred varieties may be more costly. Off-farm seed prices may be generally higher due to shortage and because additional transaction costs may be needed to identify the new sellers of preferred varieties. Increased flood incidence in the township and violent events during the dry season may work through similar mechanisms: unless floods or violent events directly impact the respondents, such as by destroying stored seeds, the relative costs for obtaining desired seeds off-farm may be higher.

5.3.2.1 Mitigating roles by local/regional certified seed production efforts

The lower part of Table 7 then shows significantly mitigating effects of having in-township SF/RF, higher in-state certified seed production relative to seed use, or a combination thereof. For example, higher state-level certified seed production significantly mitigates the adverse effects of rainfall shocks, while in-township presence of SF/RF significantly mitigates the effects of flooding at the end of the dry season, as well as the effects of fatal violent events during the dry season.

Using the results of Table 7, Table 8 quantifies the mitigating effects of the within-

township SF/RF, higher in-state certified seed production, or both for their corresponding value ranges in our sample. Specifically, rainfall shocks would lower off-farm seed use by 8.0pp in the absence of state-level certified seed production, as was the case in Kayin state in Table 1. However, this effect changes to -5.3pp at the average level of relative registered-seed/certified seed (RS/CS) production size and becomes statistically insignificant ($+2.8\text{pp}$) when state-level RS/CS production is as high as 76 percent of theoretical in-state seed use, such as in Mandalay state in Table 1. These patterns are consistent with the hypothesis that, in states with relatively high CS production intensity, access to off-farm seeds is more resilient to adverse rainfall shocks during the previous monsoon season, which might generally have affected local seed availability. Similarly, while frequent floods typically reduce the likelihood of off-farm seed use by 6.1pp in townships without SF/RF, this effect is no longer statistically significant in townships with SF/RF. In addition, the significantly negative effects (-7.1pp) of having at least one fatal violent event during the dry season in townships without SF/RF become statistically insignificant (-4.8pp) at the sample average. For townships with SF/RF are even more statistically insignificant ($+1.5\text{pp}$).

Moreover, consistent with the hypothesis, enhanced high-quality seed production at local/regional levels can increase resilience in local seed markets and access to off-farm seeds by rice producers. Although CS generally accounts for a relatively small share, it may still account for roughly 30 percent of total seeds sourced off-farm. Even if some CS may be supplied to other states, a sizeable portion of CS may still be supplied within the state because they may be more agronomically suited to the area, thereby affecting local seed availability. Additionally, a large enough share of CS could indirectly affect the local availability of off-farm seeds through reduced prices.

While our results are consistent and informative, it is important to note that they may be specific to the shocks that prevailed in Myanmar during our study period and may not be generalized to other contexts. Specifically, the LASSO and PDS-LASSO methods in our analyses are partly designed to detect the effects of shocks and mitigating roles of local/regional seed production that are particularly pronounced in our study contexts, namely, rainfall shocks in the previous monsoon season, fatal violent events in the dry season, and floods in the late dry season.

5.3.3 Robustness checks across potential spatiotemporal variations

We further assess the robustness of the key findings from the previous section, that is, the roles of within-township public SF/RF and state-level certified rice seed production in enhancing the resilience of off-farm seed use to violent events and weather shocks.

5.3.3.1 Spatial robustness across agroecological zones

We first redo the analyses separately for subsamples from each major AEZ to see if these resilience-enhancing roles generally hold across AEZs. Table 9 and Table 10 summarize the results corresponding to Table 7 and Table 8. The dominant types of shocks influencing off-farm seed use decisions identified by LASSO differ across AEZs, suggesting some heterogeneity during the period between 2021 and 2023: in the Hill Zone, these were flooding at the end of dry season (April); in the Dry Zone, flooding at the end of dry season and violent events in the late dry season; and in the Delta Zone, flooding in the late dry season and violent events in the previous monsoon season.

Note that the key types of shocks identified in Table 9 can differ from those in Table 7 because the former may exhibit more variation within specific AEZs, while the latter may be

relatively homogeneous within AEZs and instead exhibit relatively larger variation at the national level. Identifying varying types of dominant shocks is still valid in our analyses because we focus on the effects of local/regional seed production capacity for corresponding samples, rather than the effects of specific types of shocks, on off-farm seed use decisions.

Importantly, results in the lower panel of Table 9 suggest that greater local/regional seed production capacity broadly enhances resilience in off-farm seed use against each of these shocks in the corresponding AEZ. Such patterns are indicated by generally, though not always statistically significant, positive coefficients for the interaction terms between local/regional seed production capacity and the shock variables. Consequently, as shown in Table 10, the statistically significant negative effects of floods at the end of the dry season and violent events in the late dry season in states with low CS production across the Hill and Dry Zones, respectively, become statistically insignificant in states with higher CS production. Similarly, in the Dry and Delta Zones, flooding at the end of the dry season or the late dry season and violent events during the previous monsoon season is significantly negatively associated with off-farm seed use in townships without public SF/RF. These effects become insignificant in townships with public SF/RF.

Overall, the results in Table 9 and Table 10 suggest that our primary results in Table 7 and Table 8 are broadly applicable across many AEZs.

5.3.3.2 Temporal robustness across years

We then rerun analyses separately for subsamples of panel periods, that is, 2021/22 and 2022/23, to see if the results remain generally consistent. The results shown in Table 11 and Table 12 suggest that violent events and rainfall shocks in the previous monsoon season were either the dominant types of shocks or particularly affected off-farm seed use decisions in the 2021/22 and 2022/23 seasons. Importantly, as in Table 9, the lower panel of Table 11 shows that greater local/regional seed production capacity significantly enhances resilience in off-farm seed use against each of these shocks in the corresponding periods. Table 12 illustrates similar results across scenarios, as in Table 8 and Table 10. In states with low CS production, such as Kayah State, having double the incidents of violent events and rainfall that is one STD away from the historical average in the previous monsoon reduced the likelihood of off-farm seed use by 8.1 pp and 7.8 pp in the 2021/22 and 2022/23 seasons, respectively. Yet these negative effects largely disappear in states with higher RS/CS production like Mandalay State.

Overall, the results in Table 11 and Table 12 suggest that our primary results in Table 7 and Table 8 are not driven by specific subperiods but hold more consistently across these subperiods.

6 Policy implications

Our findings suggest that enhancing the capacity of local production of quality seeds is critical, not only for ensuring long-term agricultural productivity growth, which was the conventional objective, but also for maintaining resilience in farmers' choices of rice seed sources amid conflicts and weather shocks. This is particularly relevant in Myanmar, where farmers acquire more of their seeds from off-farm sources than in other economically similar Asian countries. Enhancing production capacity for domestic rice seed is also important in Myanmar,¹⁹ as suitable

¹⁹According to UN Comtrade Data, the annual average rice seed import during the period between 2011 and 2024 was only about 250 tons, including from China (101 tons), South Korea (36 tons), Thailand (27 tons) and Malaysia

hybrid seeds may be scarce, due to the preferences of rice consumers in the country or incompatibility with local agronomic conditions.

Support is needed to increase the production of EGS, including breeder seeds, foundation seeds, and certified seeds. First, both the public and private sectors should consider expanding SF/RF through adequate seed production infrastructure to townships without these facilities.²⁰ Doing so can expand the production of both breeder and foundation seeds, which can be used for further multiplication to CS by surrounding seed-producing farmers and private companies. Although the public sector engages in CS production, this activity should be limited to the private sector to avoid crowding out private-sector activities, a concern previously reported in the context of seed aid interventions in conflict zones by McGuire (2008) and Sperling and colleagues (2008). Additionally, modernizing or setting up new seed testing labs with sufficient seed testing equipment, particularly in areas far from existing seed testing labs, can allow more timely testing of samples from seed producers and verification of their quality.²¹ Similarly, transaction costs for CS production can be reduced by increasing the number of seed inspectors, either in public sector organizations or through a licensing strategy for private sector inspectors (for example, Tripp and Louwaars 1997).

As an indirect approach to increasing seed production capacity, it may be useful to legalize an intermediate-quality class of seeds, such as truthfully labeled seeds (TLS), which is currently prohibited in Myanmar (Win et al. 2025). Typically, TLS undergoes less rigorous inspections, often limited to staff inspections at seed testing labs, whereas CS also requires inspections of seed production fields by seed inspectors or certification officers. As a result, TLS production is less costly, can be more decentralized, and is more easily undertaken by local seed producers' groups, among other benefits (for example, Tripp and Louwaars 1997). TLS is commonly used in several other Asian countries, sometimes at a larger scale than CS.²² Greater availability of foundation seeds produced in RF can facilitate the production of both TLS and CS.

7 Conclusion

Enhancing the resilience of smallholders to conflicts and weather shocks, as well as boosting overall agricultural productivity, is increasingly important in low- and middle-income countries such as Myanmar, which are characterized by persistent fragility. Among many factors, resilient access to off-farm rice seeds can be crucial for maintaining or raising productivity in Myanmar, where the use of off-farm rice seeds is relatively common despite the low level of economic development. A knowledge gap remains regarding how access to off-farm rice seeds can be affected by conflicts and weather shocks, and how efforts to enhance local seed production can strengthen resilience against these shocks. Addressing this gap is difficult due to

(22 tons). These imports accounted for less than 0.1 percent of estimated seed use during these years (United Nations Statistics Division 2026).

²⁰Number of Seed Farms had increased from 12 in 1995 to 44 in the mid-2010s (World Bank 1995; Min 2014), which can further be expanded.

²¹While the numbers and types vary, some South Asian countries have numerous seed testing labs, including at least 28 in Bangladesh (Jaim and Akter 2012), 120 in India (Janaiah and Debdudd 2017) and 31 in Pakistan (Huda et al. 2011).

²²For example, in Nepal, close to 15,000 tons of improved but noncertified rice seeds (many of them TLS) were used around the late 2010s and early 2020s, as opposed to the approximately 200–1,700 tons of certified rice seeds during that period (Government of Nepal 2024). Similarly, in Thailand in 2012, production quantity of informally certified rice seeds (similar to TLS) was 450,000 tons, in contrast to 90,000 tons for certified rice seeds (Chaowagul 2014).

empirical challenges in identifying relevant types of shocks from among many possible combinations, as well as accounting for the dynamic nature of seed-sourcing decisions for self-pollinating crops such as rice.

We aimed to narrow this knowledge gap by using unique three-year panel data on monsoon-season rice producers in Myanmar, detailed spatial data on violent events, various measures of weather shocks, and information on spatial variation in local or regional seed production capacity compiled from secondary sources. We overcame the empirical challenges through IV methods and ML approaches. Our findings suggest that using off-farm seeds generally leads to higher rice yields in the monsoon season, particularly if the farmer used recycled seeds in the previous monsoon season. This result was demonstrated at the national level and in the major rice-producing Dry Zone and Delta Zone. During the study period of 2021–2023, the use of off-farm seeds was negatively associated with rainfall and temperature shocks experienced during the previous monsoon season, floods during the late dry season, and fatal violent events during the dry season. Out of all the shocks considered in the study, these were found to be the dominant types. However, these negative effects were largely mitigated if the township had public SF/RF specializing in EGS of rice and the state produced more registered/certified rice seeds than it used, in theory. While the dominant shocks varied across specific AEZ and years, the mitigating effects of SF/RF state-level production of certified seeds remained robust in each AEZ and year.

Overall, our results indicate that continued efforts to expand local or regional EGS production can strengthen smallholders' resilience in off-farm seed use during conflicts and weather shocks. Boosting formal-sector rice seed production, including certified rice seeds, can be a viable direction for Myanmar, based on comparisons with other Asian countries on the frequency of off-farm rice seed use and the level of certified rice seed production. Steps to enhance the supply capacity of quality rice seeds include investing in the physical infrastructure of SF/RF and seed testing laboratories, and in the institutional infrastructure for seed inspection services in ways that encourage private sector seed production without excluding the informal seed sector. While these measures are often pursued to raise rice productivity more broadly, additional benefits for resilience, as demonstrated in our study, are also substantial in shock-prone countries such as Myanmar.

References

- Abeygunasekara J, S Senevirathna & W Malaviarachchi. 2004. *Contract Seed Production Program of the Dept. of Agriculture (DOA) Sri Lanka*. Available at https://www.ip-cinfo.org/fileadmin/user_upload/contract_farming/presentations/Contract_farming_of_seed_in_Sri_Lanka.pdf.
- ACLED (Armed Conflict Location & Event Data). 2025. *Armed Conflict Location & Event Data*. Available at <https://acleddata.com>. Accessed March 1, 2026.
- Adenäuer M, C Frezal & T Chatzopoulos. 2025. Weathering the Storm: Trade Openness and the Resilience of Agricultural Markets Under Increasing Weather Extremes. *Journal of Agricultural Economics* 76(2), 241-250.
- Ayalew H, G Berhane, M Wondale & C Breisinger. 2026. Armed Conflict and Climate-Induced Weather Disruptions in Agricultural Input Use: Evidence from Ethiopia. *Agricultural Economics*, 57(1), e70083.
- Baum CF & A Lewbel. 2019. Advice on using heteroskedasticity-based identification. *Stata Journal*: 19(4):757-767.
- Belloni A, V Chernozhukov, C Hansen & D Kozbur. 2016. Inference in high-dimensional panel models with an application to gun control. *Journal of Business & Economic Statistics* 34:590-605.
- Biglari T, H Maleksaeidi, F Eskandari & M Jalali. 2019. Livestock insurance as a mechanism for household resilience of livestock herders to climate change: Evidence from Iran. *Land Use Policy* 87, 104043.
- Bordey FH, PF Moya, JC Beltran & DC Dawe. 2016. *Competitiveness of Philippine Rice in Asia*. Science City of Muñoz (Philippines): Philippine Rice Research Institute and Manila (Philippines): International Rice Research Institute. 172 p.
- Boughton D, J Goeb, I Lambrecht, D Headey, H Takeshima, K Mahrt, I Masias, S Goudet, C Ragasa, MK Maredia, B Minten & X Diao. 2021. Impacts of COVID-19 on agricultural production and food systems in late transforming Southeast Asia: The case of Myanmar. *Agricultural Systems* 188:103026.
- Boughton D, B Belton, I Lambrecht, I Masias & B Minten. 2024. *Myanmar's Agrifood Systems: Historical Development, Recent Shocks, Future Opportunities*. IFPRI, Washington DC.
- Chaowagul M. 2014. *The Rice Seed Industry of Thailand*. ReSAKSS Asia Policy Note 5.
- Chernozhukov V, C Hansen & M Spindler. 2015. Post-selection and post-regularization inference in linear models with many controls and instruments. *American Economic Review: Papers & Proceedings* 105(5):486-490.
- de Brito Neto FA, D Mendes & MHC Spyrides. 2022. Analysis of extreme wind events in the Weddell Sea region (Antarctica) at Belgrano II Station. *Journal of South American Earth Sciences*, 116, 103804.
- De Groeve T, Z Kugler, GR Brakenridge, 2007. Near Real Time Flood Alerting for the Global Disaster Alert and Coordination System. Proceedings of the 4th International ISCRAM Conference (B. Van de Walle, P. Burghardt and C. Nieuwenhuis, eds.) Delft, the Netherlands, May 2007, pp.33-40.
- De Groeve T, RG Brakenridge & S Paris. 2015. *Global Flood Detection System: Data Product Specifications*. Joint Research Center Technical Report. European Commission.
- Dee DP. et al. 2011. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Society*, 137(656), 553–597.

- Do MH & TT Nguyen. 2024. Impact of crop commercialization on smallholder farmers' resilience to shocks: Evidence from panel data for rural Southeast Asia. *Food Policy* 128, 102709.
- Dzanku FM, R Osei & I Osei-Akoto. 2021. The impact of mobile phone voice message reminders on agricultural outcomes in Mali. *Agricultural Economics* 52(5):789-806.
- Elvidge CD, M Zhizhin, T Ghosh, FC Hsu & J Taneja. 2021. Annual time series of global VIIRS nighttime lights derived from monthly averages:2012 to 2019. *Remote Sensing* 13(5), p.922.
- Fischer G, et al., 2012. *Global agro-ecological Zones (GAEZ v3.0)*, Laxenburg, Austria: International Institute for Applied Systems Analysis.
- Goeb J, M Maredia, KZ Win, I Masias, I Lambrecht, D Boughton & B Minten. 2022. Urban food prices under lockdown: Evidence from Myanmar's traditional food retail sector during COVID-19. *Applied Economics* 54(47):5412-5441.
- Government of India. 2020. *All India Report on Agriculture Census 2015-16*. Government of India.
- Government of Japan. 2020. *National Rice Statistics*. Ministry of Agriculture, Forestry and Fisheries. <https://www.maff.go.jp/e/data/stat/index.html>.
- Government of Myanmar. 2023a. *Myanmar Agricultural Statistics (2014-2015 to 2022-2023)*. Nay Pyi Taw, Myanmar. Available at <https://www.csostat.gov.mm/PublicationAndRelease/MyanAgriculture>. Accessed May 20, 2026.
- Government of Myanmar. 2023b. *Myanmar Agriculture Sector in Brief*. Nay Pyi Taw, Myanmar. Available at <https://www.moalidop.gov.mm/wp-content/uploads/2026/05/Brief-2023-Book.pdf>. Accessed June 15, 2026.
- Government of Myanmar. 2026. *Myanmar Seed information Portal*. Seed Division, Department of Agriculture, Ministry of Agriculture, Livestock and Irrigation.
- Government of Nepal. 2024. *Statistical information on Nepalese agriculture*. Ministry of Agriculture and Livestock Development, Planning and Development Cooperation Coordination Division, Statistics and Analysis Section, Singhadurbar, Kathmandu.
- Government of Sri Lanka. 2019. *Agricultural Performance Report 2019*. Department of agriculture, Peradeniya, Sri Lanka.
- Government of Sri Lanka. 2023. *Agricultural Performance Report 2023*. Department of agriculture, Peradeniya, Sri Lanka.
- Harun R, EEE Ariff, S Suhainee & AA Sobri. 2025. Rice seed industry in Malaysia: Issues and challenges along the supply chain. *Economic and Technology Management Review* 24, 37-53.
- Heisey PW & JP Brennan. 1991. An Analytical Model of Farmers' Demand for Replacement Seed. *Amer. J. Agr. Econ* 73(4), 1045-1052.
- Hisano S. 1999. The Japanese rice seed market under the 1986 Main Crop Seed Law and agribusiness strategies. *The Review of Agricultural Economics (Japanese)* 55, 73-85.
- Hossain M, A Janaiah, M Husain & F Naher. 2001. "The Seed Delivery System in Bangladesh: Institutional and Policy Issues. *Bangladesh Development Studies XXVII, no. 4*: 1-40.
- Huda MN & IM Saiyed. 2011. Quality seed in SAARC countries: Production, processing, legal and quality control and marketing system. SAARC Agriculture Center.
- Jaim WMH & S Akter. 2012. *Seed, Fertilizer and Innovation in Bangladesh: Industry and Policy Issues for the Future*. Washington, DC: International Food Policy Research Institute.
- Jaffe W & J van Wijk. 1995 *The Impact of Plant Breeders' Rights in Developing Countries*:

- Debate and Experience in Argentina, Chile, Colombia, Mexico, and Uruguay*. Directorate General International Cooperation (DGIS) Ministry of Foreign Affairs, The Hague.
- Jafri SK, M Imran & MH Asif. 2022. *Investigating Pakistan's seed industry dynamics*. State Bank of Pakistan Staff Notes 02/22. Karachi, Pakistan.
- Janaiah A & B Debdutt. 2017. *The Rice Seed System in India: Structure, Performance, and Challenges*. In *The future Rice strategy for India* (pp. 359-382). Academic Press.
- JICA & Sanyu Consultants Inc. 2018. *Preparatory Survey on Agriculture Income Improvement Project in the Republic of the Union of Myanmar*. Available at <https://openjicare-port.jica.go.jp/pdf/12306882.pdf>. Accessed May 20, 2026.
- JICA & Sanyu Consultants Inc. 2023. *Lao People's Democratic Republic Advisor for Rice Seed Management: Final Report*. Available at <https://openjicare-port.jica.go.jp/pdf/12371951.pdf>. Accessed May 20, 2026.
- Karymshakov K, B Sulaimanova & M Bergolo. 2023. Employment Vulnerability and Earnings in Kyrgyzstan. *Journal of Development Studies* 59(7):1076-1091.
- Lewbel A. 2012. Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. *Journal of Business & Economic Statistics* 30(1):67-80.
- Li Y, B Wu, C Wang, Z Chen, S Liu & B Yu. 2024. Measuring human settlement wealth index at 10-km resolution in low-and middle-income countries from 2005 to 2020 using multi-source remote sensing data. *International Journal of Digital Earth* 17(1):2353160.
- McGuire SJ. 2008. Securing access to seed: Social relations and sorghum seed exchange in Eastern Ethiopia. *Human Ecology* 36, 217-229.
- Moritz L, L Kuhn & I Bobojonov. 2025. The Impact of Agricultural Index Insurance on Farmers' Welfare and Climate Resilience: Findings from Uzbekistan. *Australian Journal of Agricultural and Resource Economics* 69(3), 598-610.
- Min MT. 2014. *Situation of Breeding and Production of Rice in Myanmar*. Ministry of Agriculture and Irrigation, Department of Agriculture.
- Minten B, J Goeb, KZ Win & PP Zone. 2023. Agricultural value chains in a fragile state: The case of rice in Myanmar. *World Development* 167:106244.
- Mugnisjah WQ. 2004. *Situasi Perbenihan di Indonesia (The Seed Sector Situation in Indonesia)*. Teknologi Benih. <https://repository.ut.ac.id/4535/1/LUHT4431-M1.pdf>.
- Myint PL, O Napasintuwong & NK Win. 2019. Impact assessment of extension program on hybrid rice adoption in Myanmar. *International Journal of Food Science and Agriculture* 3(3):159-172.
- Narayanan S, E Lentz, M Fontana, A De & B Kulkarni. 2019. Developing the women's empowerment in nutrition index in two states of India. *Food Policy* 89, 101780.
- Paudel GP, J Chamberlin, U Grote & TT Nguyen. 2025. Sustainable intensification of wheat through early sowing: insights from the Eastern Indo-Gangetic plains. *Environment, Development and Sustainability*, 1-27.
- Philippines Rice Research Institute. 2016. *2016 National Rice R&D Highlights*. Socioeconomic Division, Philippines Rice Research Institute.
- Phyoe NN, T Myint, HL Lynn & NN Htwe. 2025. *The Cost and Return Analysis of Contract and Non-Contract Rice Seed Production Farmers in the Mandalay Region*. Food and Fertilizer Technology Center for the Asian and Pacific Region. Available at <https://ap.fttc.org.tw/article/3834>.
- Pray CE & B Ramaswami. 1999. Liberalization's impact on the Indian seed industry: Competition, research, and impact on farmers. *International Food and Agribusiness Management*

- Review* 2(3-4), 407-420.
- Rai D & W Dukpa. 2019. *Chapter 4: Seeds Without Borders Initiative in Bhutan: Current Status, Implementation Modalities and Future Directions*. In *Seeds Without Borders Initiative in South Asia Current Status and Future Directions*, by PR Pandey, H Bhandari & SM Bokhtiar.
- Raleigh C, A Linke, H Hegre & J Karlsen. 2010. Introducing ACLED: An armed conflict location and event dataset: Special data feature. *Journal of Peace Research* 47(5):651-660. <https://doi.org/10.1177/0022343310378914>
- Rana MA. 2014. *The seed industry in Pakistan: Regulations, politics and entrepreneurship*. IFPRI PSSP Working Paper.
- Ragonnaud G. 2011. *Seed use by farmers in the European Union*. Briefing for the Library of the European Parliament.
- Rice Division, Department of Agriculture (DOA). (2024). *Seed Producing Area, Yield and Production of Rice Certified Seeds by States and Regions*. Nay Pyi Taw. Myanmar.
- Rice for Africa. 2012. *Current situation of seed multiplication and distribution in Vietnam*. CARD seminar. September 19, 2012.
- Rohrbach D. 1997. *Alternative strategies for smallholder seed supply: proceedings of an International Conference on Options for Strengthening National and Regional Seed Systems in Africa and West Asia*. Harare, Zimbabwe.
- Rutstein SO and S Staveteig. 2014. *Making the Demographic and Health Surveys Wealth Index Comparable*. Vol. 9. Rockville, MD: ICF International.
- Singh RP & ML Morris. 1997. *Adoption, Management, and Impact of Hybrid Maize Seed in India*. CIMMYT Economics Working Paper No.97-06. Mexico, D.F.: CIMMYT.
- Sombilla MA & K Quilloy. 2014. *Strengthening the Philippine Rice Seed System*. ReSAKSS Asia Policy Note 10.
- Sperling L, HD Cooper & T Remington. 2008. Moving towards more effective seed aid. *J. Devel. Stud.* 44(4): 586-612.
- Spielman DJ & A Kennedy. 2016. Towards better metrics and policymaking for seed system development: Insights from Asia's seed industry. *Agricultural systems*, 147, 111-122.
- Subedi A, MH Thijssen, G Audet-Bélanger, T Maung Shwe & N Lin Oo. 2017. *The Rice Seed Supply and Demand System in the Delta, Myanmar*. Study report. Wageningen Centre for Development.
- Smits J & R Steendijk. 2015. The International Wealth Index (IWI). *Social Indicators Research* 122 (1): 65–85.
- Susilowati SH. 2014. *Situation on breeding and production of rice in Indonesia*. Powerpoint presentation. Local disk. Washington DC. Available at http://eapvp.org/files/report/docs/Indonesia_Rice%20Presentation.pdf. Accessed on June 13, 2026.
- Suwarno NW, YP Nuswantoro & MD Munarso. 2003. *Hybrid rice research and development in Indonesia*. In *Hybrid rice for food security, poverty alleviation, and environmental protection*, SS Virmani, CX Mao, B. Hardy (eds). IRRI.
- Swe KL & AK Swe. 2015. *Promotion of climate resilience in rice and maize*. Myanmar National Study.
- Takeshima H & L Nagarajan. 2015. Farmer preferences on seed purchase timing: some evidence from Nigeria. *Journal of Crop Improvement* 29(1):131-158.
- Takeshima H, B Minten, J van Asselt, I Lambrecht, I Masias, J Goeb, ZW Aung & MT Htar. 2025a. Fertilizer and conflict: Evidence from Myanmar. *Food Policy* 133:102786.

- Takeshima H, A Kishore & A Kumar. 2025b. Weather shocks and rice (*Oryza sativa*) yield response to fertilizer: Representative field-level evidence from Bangladesh. *Agronomy Journal* 117(2): e70047.
- Takeshima H, N Djanibekov, N Abduvalieva, B Mirkasimov & K Akramov. 2025c. Resilience in technical efficiency and enabling factors: Insights from panel farm enterprise surveys in Kazakhstan and Uzbekistan. *Applied Economics* 57(53), 8961–8983.
- Takeshima H, B Minten, J van Asselt, ZW Aung & J Goeb. 2026a. Climate shocks, conflict, and agricultural change. *Global Food Security*, in press.
- Takeshima H, I Masias, B Minten, J van Asselt, PT Naing & HE Win. 2026b. *Crop diversification and nutritional resilience amid conflicts: Evidence from farmers in Myanmar*. IFPRI DP 02405.
- Tesfaye W & N Tirivayi. 2020. Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda. *World Development*, 125, 104686.
- Tripp R & N Louwaars. 1997. Seed regulation: Choices on the road to reform. *Food Policy* 22(5), 433-446.
- United Nations Statistics Division. 2026 *UN Comtrade Database*. United Nations. <https://comtradeplus.un.org/>. Accessed May 1, 2026.
- van den Broek J, A Subedi, F Jongeleen & N Oo. 2015. Pathways for Developing the Seed Sector of Myanmar: A Scoping Study. Wageningen: Wageningen University: Centre for Development Innovation.
- Wai TT. 2012. *The Role of Institutions in Agriculture Sector Development of Myanmar*. (Doctoral dissertation, MERAL Portal).
- Wang R, RM Rejesus, JB Tack, JV Balagtas & AD Nelson. 2022. Quantifying the yield sensitivity of modern rice varieties to warming temperatures: Evidence from the Philippines. *American Journal of Agricultural Economics* 104(1), 318-339.
- Win MT, MK Maredia, D Ortega & KZ Win. 2025. Effects of quality signaling on farmers' valuation of legume seeds: Evidence from Myanmar. *Journal of the Agricultural and Applied Economics Association* 4(4), 507-522.
- World Bank. 1995. *Myanmar Second Seed Development Project: Project Completion Report*. Washington DC.
- World Bank. 2011. *Cambodia: Overview of a Cambodian seed sector*. World Bank.
- Zhang Y, X Sun & C Chen. 2021. Characteristics of concurrent precipitation and wind speed extremes in China. *Weather and Climate Extremes* 32, 100322.

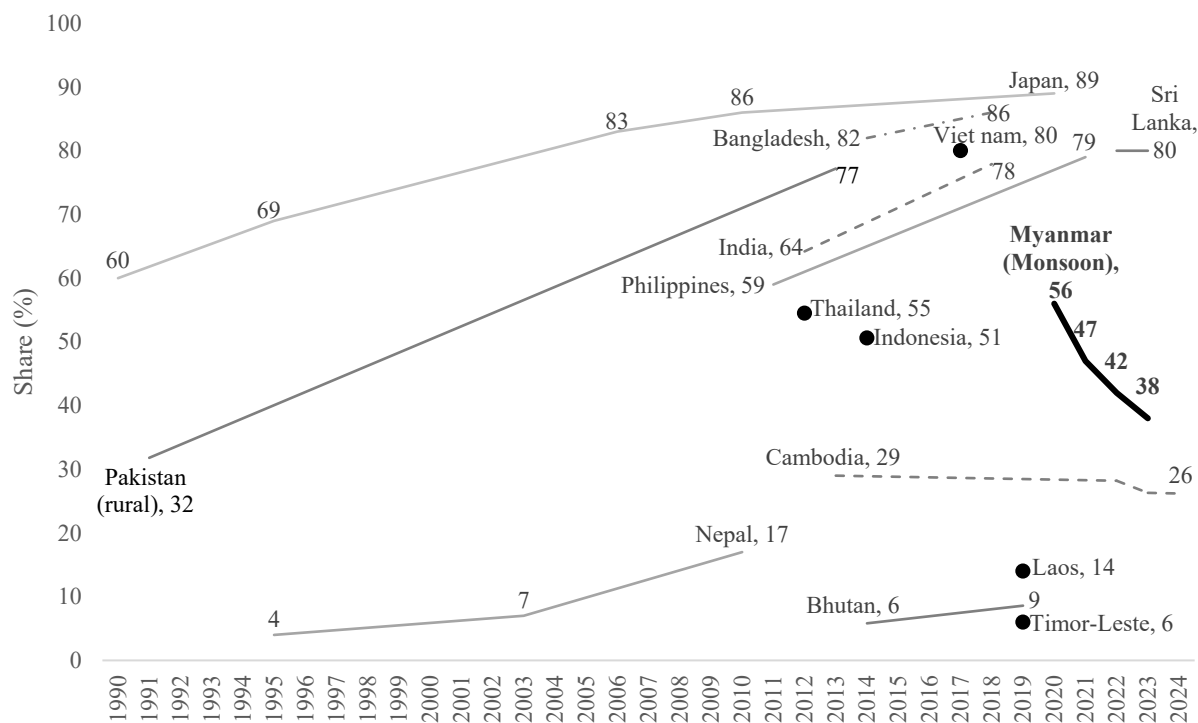


Figure 1. Shares (%) of rice farmers obtaining off-farm seeds in Myanmar and other selected Asian countries^{a, b, c}

Source: Authors' compilations from various datasets: Bangladesh - Bangladesh Integrated Household Survey; Bhutan - National Seed Centre's figure cited in Rai & Dukpa (2019); Cambodia, Laos, Timor-Leste, Viet Nam - Agricultural Census in corresponding years; Japan - Hisano (1999, Table 5); Government of Japan (2020); Laos - Ag Census 2019/20; Myanmar - MAPS Survey 2020-2023; Nepal - Nepal Living Standard Surveys waves 1-3; India - Situation Assessment Survey of Agricultural Households 2013, 2019; Pakistan - Pakistan Integrated Household Survey 1991; Pakistan Rural Household Panel Survey (PRHPS) 2012, 2013; Philippines - Philippines Rice Research Institute (2016), Bordey et al. (2016); Sri Lanka - Paddy Farmer Survey (2022, 2023); Thailand - Department of Rice (2012) cited in Chaowagul (2014).

Viet Nam - authors' compilation based on Thailand Viet Nam Socio Economic Panel (TVSEP) and Viet Nam Living Standard Survey data;

Note: ^aFigures for Japan are the share (%) of rice seeds rather than rice farmers. ^bFigures for Bhutan are based on Seed Replacement Rates reported in above sources. ^cFor Viet Nam figures, we first obtained figures from TVSEP data for their 3 study provinces (Ha Tinh = 78%, Thua Thien Hue = 76%, and Dak Lak = 65%). We then verify from VLSS data that expenditure values for seeds used in rice production in these 3 provinces are generally representative, and significantly lower than Mekong Delta region which account for a large share of more commercialized rice production. We there argue that figure for Viet Nam (80%) in 2017 is reasonable.

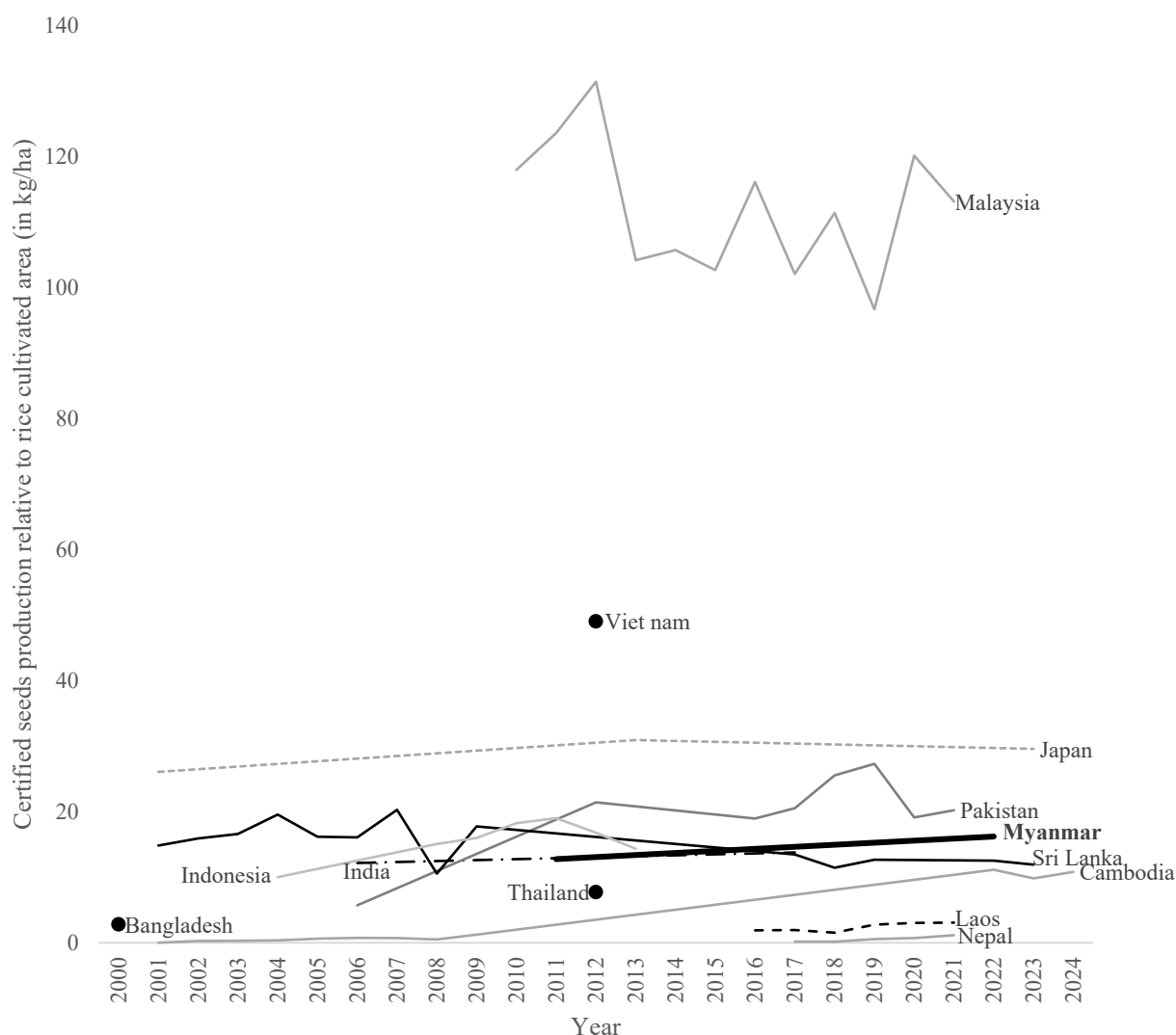


Figure 2. Annual production intensity of certified rice seeds (expressed as kg/ha of rice cultivated area) in Myanmar and select Asian countries, 2000–2024^a

Source: Compilations by authors from the following studies: Bangladesh - Hossain et al. (2001); Cambodia - World Bank (2011, p.41); For 2021–2024, Cambodia Agricultural Surveys (2021–2024); India – Huda and Saiyed (2011) for 2006, author’s computations from Janaiah & Debdutt (2017) for 2017; Indonesia - Mugnisjah (2004, Table 1.4), Susilowati (2014); Japan – Government of Japan (2026); Laos - JICA & Sanyu Consultants (2023) - Table 1.4.3 - citing DAEC; Malaysia – Harun et al. (2025); Myanmar – Swe and Swe (2015) for 2011/12, Rice Division, DOA (2024) for 2022; Nepal – Government of Nepal (2024); Sri Lanka - Abeygunasekara et al. (2004), Government of Sri Lanka (2019, 2023) for 2017–2023; Pakistan – Huda et al. (2011) for 2006, Rana (2014) for 2012, Jafri et al. (2022) for 2016–2020; Thailand - Chaowagul (2014); Viet Nam – Rice for Africa (2012).

Note: ^aFigures for Japan have lower ceiling given its relatively low seeding rate (about 35kg/ha) enabled by highly mechanized transplanting and weeding systems.



Figure 3. Township with public seed farms/research farms^a

Source: Authors' compilation based on Min (2014).

Note: ^aAs highlighted in the main text, more recent information on SF/RFs (post-2014) has not been readily available, and some of these farms might not have been functioning due to ongoing conflicts. Therefore, results should be interpreted with caution.

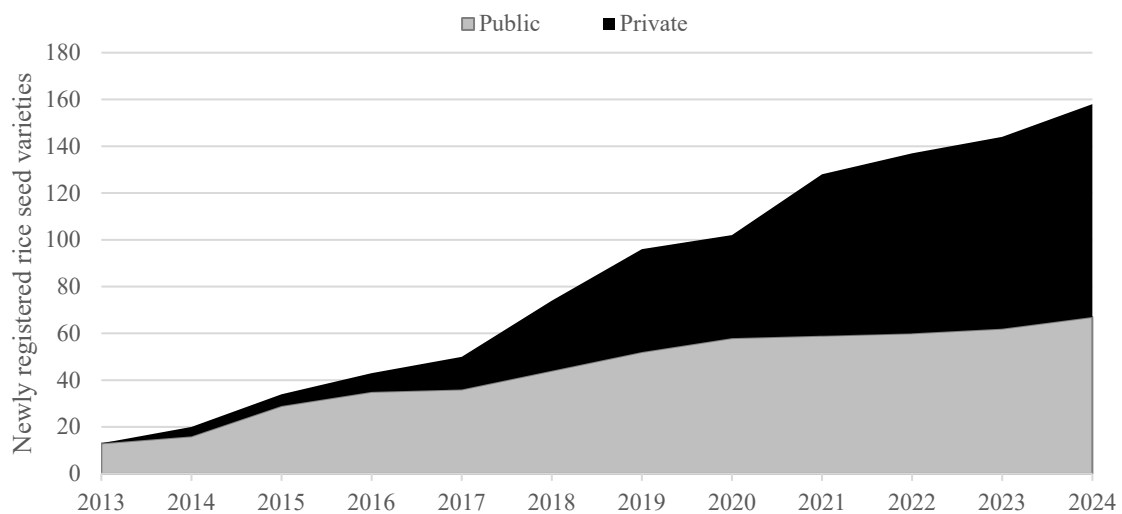


Figure 4. Cumulative percentage of newly registered rice seed varieties in the country over the period from 2013 to 2024

Source: Authors' compilation based on data from the National Seed Committee.

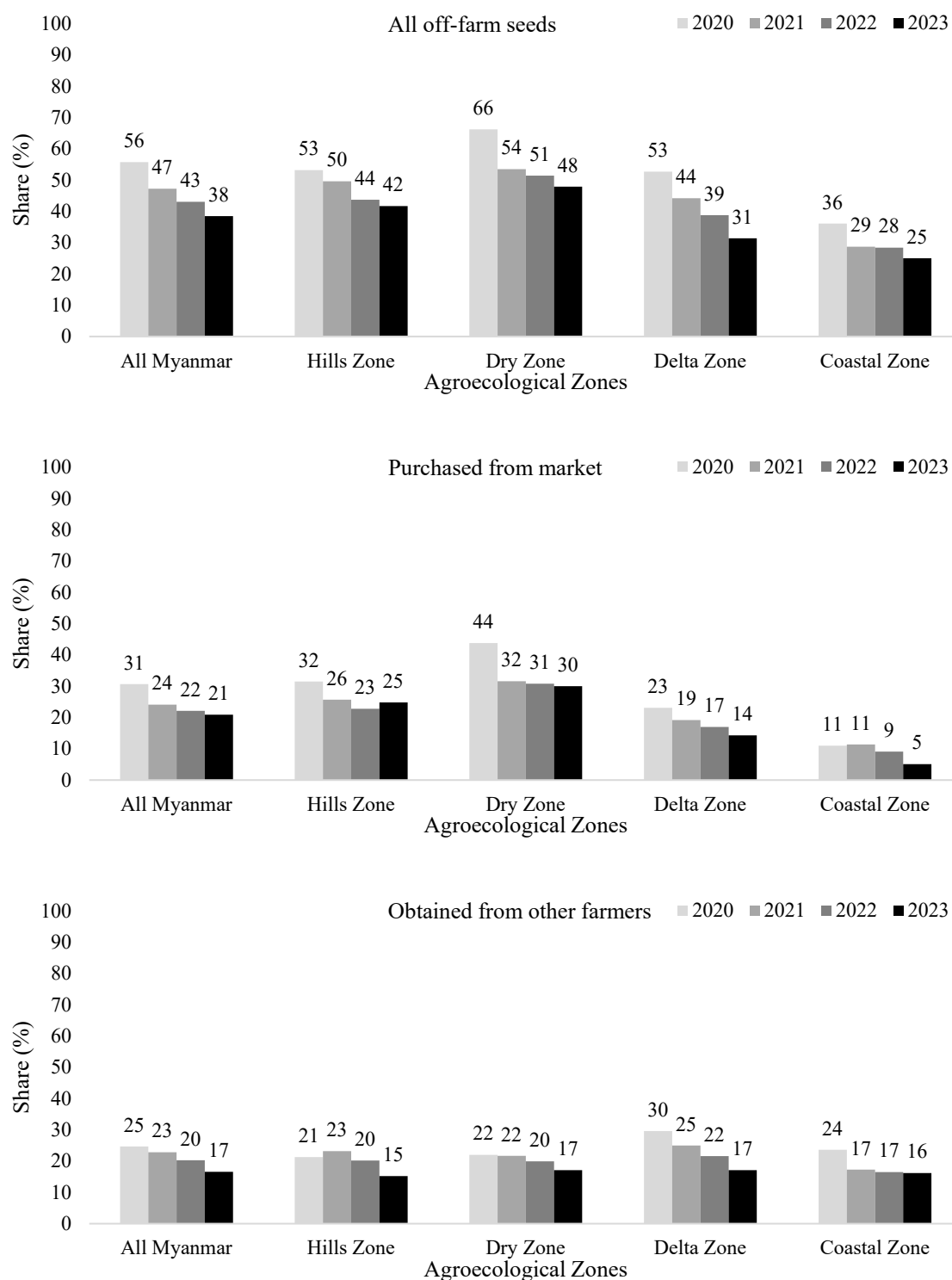


Figure 5. Shares (%) of monsoon-season rice farmers obtaining off-farm seeds in Myanmar between 2020 and 2023, by years and agroecological zones^a

Source: Authors' compilations from MAPS data.

Note: ^aA small fraction of respondents (typically less than 4%) selected "others" which are not shown here.

Table 1. Back-of-the-envelope calculation of relative size of certified rice seed production to total rice seed use in 2022 monsoon/2023 dry season^a

State/Region	(a) Area of registered/certified rice seeds production	(b) Assumed seed production by seed companies ^b		(c) Assumed seed production by other seed producers ^d		(d) Estimated production of registered / certified rice seeds (= (b1)*(b2) + (c1)*(c2))		(e) Non-seed production (paddy production) ^d		(f) Theoretical rice seed use based on seeding rate of 114kg/ha (ton/year) ^c	(g) Relative proportion (%) of registered/certified rice seeds produced to theoretical rice seed use in the state	
		(b1) Area	(b2) Yield ^c	(c1) Area	(c2) Yield	(d1) tons	(d2) Yield	(e1) Area (ha) (= total rice area – (a))	(e2) Yield		(g1) Based on seeding rate of 114kg/ha (= (d1)/(f)*100)	(g2) Based on seeding rate of 100kg/ha
Ayeyarwady	3,793	116	5.00	3,677	4.44	16,881	4.45	2,101,367	4.06	239,556	7	8
Bago	10,698	317	5.00	10,380	4.43	47,563	4.45	1,235,757	4.06	140,876	34	38
Chin	97	0	5.00	97	2.60	253	2.60	17,942	2.38	2,045	12	14
Kachin	291	0	5.00	291	3.86	1,121	3.86	204,343	3.53	23,295	5	5
Kayah	61	0	5.00	61	3.75	228	3.75	29,364	3.43	3,348	7	8
Kayin	47	0	5.00	47	3.91	182	3.91	218,194	3.58	24,874	1	1
Magway	3,063	149	5.00	2,914	4.06	12,555	4.10	261,797	3.71	29,845	42	48
Mandalay	4,476	112	5.00	4,364	4.60	20,627	4.61	239,282	4.21	27,278	76	86
Mon	453	68	5.00	385	3.57	1,707	3.77	299,526	3.27	34,146	5	6
Nay Pyi Taw	1,106	1106	5.00	0	–	5,528	5.00	79,283	4.36	9,038	61	70
Rakhine	771	0	5.00	771	3.44	2,654	3.44	403,880	3.15	46,042	6	7
Sagaing	2,849	25	5.00	2,825	4.45	12,681	4.45	813,428	4.07	92,731	14	16
Shan	670	31	5.00	638	4.24	2,860	4.27	518,829	3.88	59,147	5	6
Tanintharyi	261	0	5.00	261	3.98	1,038	3.98	93,523	3.64	10,662	10	11
Yangon	1,478	5	5.00	1,473	3.97	5,868	3.97	543,767	3.63	61,989	9	11
Myanmar	30,112	1,929	5.00	28,183	4.33	131,746	4.38	7,060,282	3.95	804,872	16	19

Source: Seed production areas (a) are from Rice Division, DOA (2024) cited in Phyoe et al. (2025); Area and yield for total rice production (combining both rice seeds and paddy) used in (e) are from Government of Myanmar (2023).

Note: ^aThis table merely shows the estimated amount of certified rice seeds produced in each state and interprets it in the context of estimated total rice seed use in that state. Since some certified seeds produced in a certain state can be used in rice production in other states, **the figures in this table cannot be interpreted as the actual share of registered/certified rice seeds to total rice seed use in each state/region**. Nonetheless, the figures are useful in interpreting the scale of certified rice seeds produced and potential variations across states/regions. ^bTo derive approximate state-level areas under seed companies, we used the national area under seed companies provided in Government of Myanmar (2023b) and land areas operated by licensed seed companies focusing on rice seed production registered under the Myanmar Seed Information Portal by the Government of Myanmar (2026). Specifically, we computed aggregated areas of all these seed companies in each state and allocated them proportionately across states so that total sum equals the national level figure of 1,929 ha which was reported by Government of Myanmar (2023b). While this assumes that all these seed companies use the same proportion of their land for seed production, it is the only reasonable way to reflect cross-state distribution of rice seed companies in a neutral way. Importantly, since Nay Pyi Taw has

disproportionately high concentration of large rice seed companies, we assumed that all seed production in Nay Pyi Taw was done by seed companies. We then apply the aforementioned proportional allocations to all the other states. ^cProvided in Government of Myanmar (2023b). ^dWe then assumed that the seed yield by other seed producers are higher than the yield by non-seed producers at the same proportions across all states. Applying such rules and using the estimated areas (c1) and areas (e1), we derived figures (c1)–(e2) so that corresponding total figures at national levels match those that are reported by the Government of Myanmar (2023a, 2023b). Based on this calculation, seed yield by nonseed companies (c2) is 9.3 percent higher than grain yields (e2) for all states other than Nay Pyi Taw. Estimated figures are not too far off from available studies in earlier years. For example, one study in Shwebo district (Sagaing state) found that seed production yield was about 4.35ton/ha in 2015 (JICA and Sanyu Consultants Inc. 2018; Table 3.3.21), similar to the figures for Sagaing province in this table as well as national level average. ^eObtained from FAOSTAT which uses approximately 114kg/ha as seeding rate. The figure is slightly higher than 100kg/ha assumed in Government of Myanmar (2023). Therefore, the figure in column (g1) provides more conservative estimates.

Table 2. Descriptive statistics of other control variables

Variables	All rounds	2021	2022	2023
	Mean (std.dev)	monsoon Mean	monsoon Mean	monsoon Mean
Used off-farm seeds (yes = 1) in t	0.424 (0.493)	0.496	0.408	0.384
Used off-farm seeds (yes = 1) in $t - 1$	0.484 (0.500)	0.579	0.473	0.418
Age of farm management decision maker (years)	47.527 (11.322)	44.075	48.606	49.038
Education completed farm management decision maker (years)	7.880 (4.356)	8.189	7.690	7.870
Household size	4.628 (1.766)	4.850	4.601	4.473
Land owned (hectares)	3.358 (4.685)	3.660	3.693	3.335
Machines owned (total horsepower)	13.661 (15.105)	14.393	13.542	13.193
Livestock ownership (yes=1)				
Chicken	0.515 (0.500)	0.563	0.521	0.466
Sheep	0.001 (0.035)	0.002	0.001	0.001
Goat	0.022 (0.148)	0.027	0.023	0.017
Pig	0.171 (0.376)	0.185	0.166	0.165
Draft animal	0.312 (0.463)	0.420	0.358	0.256
Others	0.270 (0.444)	0.229	0.217	0.277
Male farm wage (per day, paddy-100kg equivalent) ^a	0.122 (0.061)	0.179	0.112	0.085
Travel time to the most commonly used agri-input retailer (hours)	0.634 (0.632)	0.694	0.598	0.630
Travel time to the township center (hours)	0.776 (0.830)	0.804	0.745	0.794
Irrigation access (township-level sample share using irrigation)	0.446 (0.497)	0.462	0.446	0.434
Nighttime light (index)	0.630 (1.330)	0.705	0.621	0.577
International Wealth Index (0 = lowest; 100 = highest)	46.038 (11.255)	45.932	45.907	46.308
Sample share of off-farm seed users at township-level in $t - 1$	0.358 (0.181)	0.352	0.335	0.395
Sample share within township growing Manawthukha variety	0.065 (0.141)	0.066	0.064	0.067
Sample share within township growing Sinthukha variety	0.135 (0.207)	0.140	0.136	0.129
Sample share within township growing Ayarmin variety	0.096 (0.086)	0.086	0.095	0.106
Township-level total farm area under rice seed companies (ha)	38.579 (350.168)	37.408	38.435	39.785
State-level registered/certified rice seeds production/theoretical seed use	0.232 (0.222)	0.237	0.228	0.232
In township with public seed farms/research farms (as of 2014 in which the latest information was available)	0.271 (0.445)	0.263	0.272	0.277
Sample-size	4,893	1,310	2,064	1,519

Source: Authors' computations based on MAPS data and various other data.

Note: ^aBased on farmgate paddy prices during the planting season.

Table 3. Descriptive statistics of violent events and weather shocks

Variables	All rounds	Period leading up to the 2021 monsoon	Period leading up to the 2022 monsoon	Period leading up to the 2023 monsoon
	Mean (std.dev)	Mean	Mean	Mean
Number of violent events at township-level (fatal and non-fatal)				
Monsoon season in the previous year (May – October)	15.176 (28.789)	2.198	20.336	19.358
Dry season (November – April)	18.748 (35.106)	14.898	23.190	16.033
Late dry season (February – April)	10.939 (19.762)	14.276	11.237	7.655
End of dry season (April)	3.144 (7.023)	3.082	3.746	2.380
Any violent events at township-level (yes = 1, fatal and non-fatal)				
Monsoon season in the previous year (May – October)	0.728 (0.445)	0.194	0.944	0.894
Dry season (November – April)	0.806 (0.318)	0.864	0.930	0.844
Late dry season (February – April)	0.804 (0.397)	0.848	0.816	0.749
End of dry season (April)	0.554 (0.497)	0.476	0.635	0.511
Number of violent events at township-level (fatal)				
Monsoon season in the previous year (May – October)	11.055 (30.202)	1.210	19.039	8.697
Dry season (November – April)	12.864 (35.101)	4.541	22.224	7.323
Late dry season (February – April)	4.197 (8.963)	4.436	4.473	3.617
End of dry season (April)	1.487 (5.147)	1.800	1.628	1.026
Any violent events at township-level (yes/no, fatal)				
Monsoon season in the previous year (May – October)	0.582 (0.493)	0.106	0.760	0.752
Dry season (November – April)	0.697 (0.459)	0.465	0.814	0.739
Late dry season (February – April)	0.603 (0.489)	0.437	0.688	0.631
End of dry season (April)	0.371 (0.483)	0.189	0.478	0.382
Rainfall shocks - deviations from historical average (absolute value of z-score)				
Monsoon season in the previous year (May – October)	1.213 (0.735)	1.624	1.072	1.499
Dry season (November – April)	0.537 (0.413)	0.513	0.326	0.843
Late dry season (February – April)	0.702 (0.632)	0.993	0.595	0.596
End of dry season (April)	0.648 (0.535)	1.112	0.327	0.683
Temperature shocks - deviations from historical average (absolute value of z-score of daily maximum temperatures)				
Monsoon season in the previous year (May – October)	0.850 (0.623)	1.573	0.762	0.347
Dry season (November – April)	0.794 (0.460)	0.699	0.770	0.908
Late dry season (February – April)	0.928 (0.602)	1.079	1.104	0.560
End of dry season (April)	0.960 (0.816)	1.687	0.795	0.556
Windstorm shocks – total number of days exceeding 2 standard deviations above historical average of that day				
Monsoon season in the previous year (May – October)	7.557 (3.106)	8.336	6.988	7.658
Dry season (November – April)	6.352 (4.030)	4.417	8.692	4.840
Late dry season (February – April)	3.089 (2.707)	1.628	4.869	1.929
End of dry season (April)	0.639 (0.996)	0.477	0.957	0.346
Flood shocks – total number of days exceeding 1.5 standard deviations above historical average of potential flood indicator of that day				
Monsoon season in the previous year (May – October)	4.523 (11.235)	4.385	5.165	3.768
Dry season (November – April)	3.718 (10.887)	4.184	3.529	3.572
Late dry season (February – April)	1.701 (5.839)	1.940	1.833	1.316
End of dry season (April)	0.605 (2.686)	1.074	0.389	0.494

Source: Authors' computations based on corresponding data described in earlier section.

Table 4. Inter-year associations of off-farm seed use (monsoon season)

Variables	Dependent variable = Used off-farm seeds (yes = 1) in year t			
	<i>Myanmar</i>			
	Coef. (std.err)	Coef. (std.err)		
Use off-farm seeds (yes = 1) in $t - 1$	-0.242*** (0.022)	-0.415*** (0.033)		
Use off-farm seeds (yes = 1) in $t - 2$		-0.264** (0.040)		
Respondent fixed effects	Yes	Yes		
Constant	Yes	Yes		
Number of observations	4,893	1,530		
Average rounds per panel	2.4	2.0		
R-square	.241	.174		
	<i>Hills Zone</i>		<i>Delta Zone</i>	
	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)
Use off-farm seeds (yes = 1) in $t - 1$	-0.317*** (0.055)	-0.528*** (0.086)	-0.265*** (0.033)	-0.419*** (0.049)
Use off-farm seeds (yes = 1) in $t - 2$		-0.274*** (0.091)		-0.298*** (0.063)
Respondent fixed effects	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes
Number of observations	848	224	1,928	648
Average rounds per panel	2.3	2.0	2.4	2.0
R-square	.304	.227	.173	.129
	<i>Dry Zone</i>		<i>Coastal Zone</i>	
	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)
Use off-farm seeds (yes = 1) in $t - 1$	-0.184*** (0.036)	-0.373*** (0.052)	-0.175 (0.108)	-0.316* (0.184)
Use off-farm seeds (yes = 1) in $t - 2$		-0.219*** (0.066)		-0.105 (0.213)
Respondent fixed effects	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes
Number of observations	1,850	596	250	56
Average rounds per panel	2.4	2.0	2.3	2.0
R-square	.246	.159	.257	.105

Source: Authors.

Note: ***1% **5% *10%.

Table 5. Monsoon season rice yield effects of using off-farm seeds

Variables	Dependent variable = ln (yield)					
	Myanmar		Delta Zone (excluding Mon State)		Dry Zone	
	Panel-Fixed effects (OLS)	Panel-Fixed effects (IV regression)	Panel-Fixed effects (OLS)	Panel-Fixed effects (IV regression)	Panel-Fixed effects (OLS)	Panel-Fixed effects (IV regression)
Off-farm seed in t (yes = 1)	0.012 (0.036)	0.137* (0.081)	0.066* (0.039)	0.154* (0.080)	0.031 (0.049)	0.123** (0.063)
Off-farm seed in $t - 1$ (yes = 1)	0.037 (0.029)	0.196 (0.134)	0.099*** (0.036)	0.153** (0.060)		
Off-farm seed in t × Off-farm seed in $t - 1$	-0.004 (0.047)	-0.218* (0.131)	-0.130** (0.058)	-0.319*** (0.108)	-0.003 (0.058)	-0.039 (0.073)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes
No. obs	2244	2244	840	840	948	948
Average round per obs.	3.0	3.0	3.0	3.0	3.0	3.0
R-square		.008	.052	.037		.042
p-value(H_0 : no overidentification)		.326		.603		.444
p-value(H_0 : underidentification)		.000		.000		.003
p-value(H_0 : Lewbel IV is appropriate) ^a		.998		.924		.964
Associations with using off-farm seed in t (recycled seeds in $t - 1$)	0.012 (0.036)	0.137* (0.081)	0.066* (0.039)	0.154* (0.080)	0.031 (0.049)	0.121** (0.063)
Associations with using off-farm seed in t (off-farm seeds in $t - 1$)	0.045 (0.038)	0.116 (0.085)	0.036 (0.048)	-0.012 (0.070)	0.028 (0.043)	0.084 (0.055)

Source: Authors.

Note: ***1% **5% *10%. ^aBased on Pagan-Hall test suggested in Baum and Lewbel (2019).

Table 6. Key predictors of off-farm seed use selected by the LASSO process applied to (3)^a

Penalty term (λ)	Selected variables added as penalty term λ is lowered		
155.7	VF 0510 $\times$ Household size	VF 0510 $\times$ Age	
141.8	VN 0510 $\times$ Household size		
129.2	VF 0510 $\times$ Seed Company	VNY 0510 $\times$ Household size	Wind 0510 $\times$ Irrigation
117.8	VN 0510 $\times \bar{S}_{j,t-1}$	Rainfall 0510 $\times$ Farm size	Flood 0510 $\times$ Seed Company
107.3	VNY 0004		
97.8	Flood 0510 $\times$ Ayarmin	VFY 0510 $\times$ SFRF	
89.1	VF 0510 $\times$ Farm wage	VNY 0510 $\times$ Manawthukha	VNY 0510 $\times$ Age
	Wind 0510 $\times$ Manawthukha		
81.2	Rainfall 0510	VFY 0510	
	Rainfall 0510 $\times$ LV	Flood 0510 $\times$ Farm wage	
74.0	VN 0510 $\times$ Farm size	VFY 0510 $\times$ Irrigation	Wind 0510 $\times$ Seed Company
67.4	VN 0510 $\times$ Nighttime light	VF 0510 $\times$ Sinthukha	Rainfall 0510 $\times$ Farm wage
	Flood 0204 $\times$ SFRF	Rainfall 0510 $\times$ CSST	Flood 0510 $\times$ Farm size
61.4	VN 0510 $\times$ Seed Company	Wind 0510 $\times$ Education	Flood 0004 $\times$ SFRF
55.9	VF 0510 $\times$ Education	VNY 0510 $\times$ LV	Temperature 0510 $\times$ Distance to input retailers
	Flood 0510 $\times \bar{S}_{j,t-1}$		Temperature 0510 $\times$ Irrigation
	Rainfall 0510 $\times \bar{S}_{j,t-1}$		
51.0	VF 0510 $\times$ Distance to township center	VFY 510 $\times$ Manawthukha	
46.4	Temperature 0004	Temperature 0510 $\times \bar{S}_{j,t-1}$	Rainfall 0510 $\times$ Age
	Wind 0510 $\times$ LV	Flood 0510 $\times$ Ayarmin	
42.3	Wind 0004	Wind 0510 $\times$ Farm wage	Temperature 0510 $\times$ Household size
38.6	Wind 0510	VN 0204	Temperature 0510 $\times$ Capital
	Rainfall 0510 $\times$ Distance to input retailers	Wind 0510 $\times$ Manawthukha	Wind 0510 $\times$ Capital
	Flood 0510 $\times$ Household size	Flood 0510 $\times$ Education	Temperature 0510 $\times$ CSST
:		:	

Source: Authors' estimations.

Note: 0510 = Monsoon season in the previous year; 1104 = Dry season; 0204 = Late dry season; 0004 = End of dry season; VF = number of fatal violent events; VFY = had at least one fatal violent event; VN = number of violent events; VNY = had at least one violent event; Irrigation = sample irrigation share within the township; LV = Livestock holdings (principal component); Seed Company = Total farm areas of rice seed companies within the township; Manawthukha = sample share of producers growing Manawthukha variety in the township; Sinthukha = sample share of producers growing Sinthukha variety in the township; Ayarmin = sample share of producers growing Ayarmin variety in the township; CSST = State level certified seed production relative to theoretical seed use; SFRF = township has public seed farms/research farms; ^aShaded variables include the state level certified seed production relative to theoretical seed use, and in-township presence of public seed farms/research farms, our primary variables of interest.

Table 7. Effects of shocks on off-farm seed use and mitigating roles of local seed production capacity

Variables	Dependent variable = 1 if the farmer used <i>off-farm</i> seeds in year t monsoon season rice production		
	Primary model	Robustness checks 1	Robustness checks 2
	OLS with PDS-selected variables	OLS using CHS lasso-orthogonalized variables	OLS using CHS post-lasso-orthogonalized variables
	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)
Rainfall shocks (previous monsoon season) (one standard deviation away from historical average)	−0.074*** (0.027)	−0.213* (0.123)	−0.249** (0.105)
Temperature shocks (previous monsoon season) (one standard deviation away from historical average)	−0.040 (0.041)	−0.380*** (0.143)	−0.332** (0.142)
ln(Flood intensity) (end of dry season)	−0.001 (0.042)	0.224 (0.170)	−0.156 (0.217)
ln(Flood intensity) (late dry season)	−0.061* (0.037)	−0.036 (0.330)	−0.423* (0.231)
Fatal violent events (dry season) (yes = 1)	−0.071** (0.031)	−0.074*** (0.029)	−0.093*** (0.028)
Rainfall shocks (previous monsoon season) × 1pp higher relative share of state-level CS production	0.0014* (0.0008)	0.005* (0.003)	0.005** (0.002)
Temperature shocks (previous monsoon season) × 1pp higher relative share of state-level CS production	0.001 (0.001)	0.008*** (0.003)	0.007** (0.003)
ln(Flood intensity) (end of dry season) × In-township presence of public SF/RF	0.099* (0.058)	−0.241 (0.226)	0.271 (0.290)
ln(Flood intensity) (late dry season) × In-township presence of public SF/RF	−0.008 (0.075)	−0.017 (0.456)	0.520* (0.313)
Fatal violent events in township (dry season) (yes = 1) × In-township presence of public SF/RF	0.086** (0.038)	0.099*** (0.035)	0.104*** (0.034)
Other controls (approximated by LASSO)	Yes	Yes	Yes
Farmer fixed effects	Yes	Yes	Yes
Constant	Yes	Yes	Yes
Number of observations	4,893	4,893	4,893
Number of panel sample	2,064	2,064	2,064
Average rounds per panel sample	2.4	2.4	2.4
p-value (H_0 : variables jointly insignificant)	.000	.000	.000

Source: Authors.

Note: ***1% **5% *10%. Previous monsoon season = May through October in year $t - 1$; Dry season = November in year $t - 1$ through April in year t ; Late dry season = February through April in year t ; End of dry season = April in year t ; pp = percentage point; CS = certified rice seed; SF = Seed Farms; RF = Research Farms; PDS = Post-double-selection; CHS = Chernozhukov–Hansen–Spindler.

Table 8. Estimated effects of key shocks on off-farm seed use across local/regional seed production scenarios

Shocks	Dependent variable = 1 if the farmer used <i>off-farm</i> seeds in year <i>t</i> monsoon season rice production		
	State-level certified seed production (% relative to theoretical state-level seed use in Table 1)		
	Minimum (0%, Kayin-state level in Table 1)	Average (16%, national level in Ta- ble 1)	Maximum (76%, Mandalay-state level in Table 1)
Rainfall shocks (previous monsoon season) (one standard deviation away from historical average)	-0.074*** (0.027)	-0.053** (0.021)	0.028 (0.051)
	Presence of public seed farms/research farms in the township		
	No (0.000)	Average (0.272)	Yes (1.000)
ln(Flood days) (late dry season)	-0.061* (0.037)	-0.063 (0.040)	-0.069 (0.077)
Fatal violent events (dry season) (yes = 1)	-0.071*** (0.031)	-0.048 (0.030)	0.015 (0.043)

Source: Authors' computations based on Table 7.

Note:***1% **5% *10%.

Table 9. Same PDS-LASSO models for Table 7 estimated for each of 3 major agroecological zone samples (Primary model - OLS with PDS-selected variables)

Variables	Dependent variable = 1 if the farmer used <i>off-farm</i> seeds in year <i>t</i> monsoon season rice production		
	Hills Zone	Dry Zone	Delta Zone
	Coef. (std.err)	Coef. (std.err)	Coef. (std.err)
ln(Flood intensity) (end of dry season)	−0.457* (0.280)	−0.127** (0.064)	
ln(Flood intensity) (late dry season)			−0.417*** (0.162)
Violent events in township (previous monsoon season) (yes = 1)	−0.091 (0.074)		−0.180** (0.077)
Violent events in township (late dry season) (yes = 1)		−0.322** (0.136)	
ln(Flood intensity) (end of dry season) × 1pp higher relative share of state-level CS production	0.152* (0.081)		
ln(Flood intensity) (end of dry season) × ln-township presence of public SF/RF		0.173 (0.129)	
ln(Flood intensity) (late dry season) × ln-township presence of public SF/RF			0.201 (0.130)
Violent events in township (previous monsoon season) × ln-township presence of public SF/RF	0.142* (0.075)		0.035 (0.126)
Violent events in township (late dry season) × 1pp higher relative share of state-level CS production		0.004* (0.002)	
Other controls (approximated by LASSO)	Yes	Yes	Yes
Farmer fixed effects	Yes	Yes	Yes
Constant	Yes	Yes	Yes
Number of observations	848	1,932	1,850
Number of panel sample	368	804	776
Average rounds per panel sample	2.3	2.4	2.4
p-value (H ₀ : variables jointly insignificant)	.000	.000	.000

Source: Authors.

Note: ***1% **5% *10%.

Table 10. Estimated effects of key shocks on off-farm seed use across local/regional seed production scenarios

Agroecological Zones / Shocks	State-level certified seed production (% relative to theoretical state-level seed use in Table 1)		
	Minimum (0%, Kayin-state level in Table 1)	Average (4%, national level in Ta- ble 1)	Maximum (11%, Chin-state level in Table 1)
<i>Hills Zone</i>			
ln(Flood days) (late dry season)	-0.457* (0.280)	0.152 (0.346)	1.216 (0.835)
<i>Dry Zone</i>			
Violent events (late dry season) (yes = 1)	-0.270** (0.116)	-0.199** (0.093)	-0.084 (0.088)
	Presence of public seed farms/research farms in the township		
	No (0.000)	Average (0.357)	Yes (1.000)
<i>Dry Zone</i>			
ln (Flood days) (end of dry season)	-0.127** (0.064)	-0.066 (0.069)	0.046 (0.128)
<i>Delta Zone</i>			
ln(Flood days) (late dry season)	-0.417*** (0.162)	-0.347** (0.167)	-0.216 (0.204)
Violent events (previous monsoon season) (yes = 1)	-0.180** (0.077)	-0.167** (0.079)	-0.145 (0.131)

Source: Authors' computations based on Table 9.

Note: ***1% **5% *10%.

Table 11. Same PDS-LASSO models for Table 7 estimated for each of 3 major agroecological zone samples (Primary model - OLS with PDS-selected variables)

Variables	Dependent variable = 1 if the farmer used <i>off-farm</i> seeds in year <i>t</i> monsoon season rice production	
	2021–2022	2022–2023
	Coef. (std.err)	Coef. (std.err)
Violent events in township (previous monsoon season) (yes = 1)	–0.081** (0.033)	
Rainfall shocks (previous monsoon season) (one standard deviation away from historical average)		–0.079** (0.035)
Violent events in township (previous monsoon season) × 1pp higher relative share of state-level CS production	0.0011 (0.0009)	
Rainfall shocks (previous monsoon season) × 1pp higher relative share of state-level CS production		0.0016* (0.0010)
Other controls (approximated by LASSO)	Yes	Yes
Farmer fixed effects	Yes	Yes
Constant	Yes	Yes
Number of observations	2,620	3,038
Number of panel sample	1,310	1,519
Average rounds per panel sample	2.0	2.0
p-value (H ₀ : variables jointly insignificant)	.000	.000

Source: Authors.

Note: ***1% **5% *10%.

Table 12. Estimated effects of key shocks on off-farm seed use across local/regional seed production scenarios

Shocks	Dependent variable = 1 if the farmer used <i>off-farm</i> seeds in year <i>t</i> monsoon season rice production		
	State-level certified seed production (% relative to theoretical state-level seed use in Table 1)		
	Minimum (0%, Kayin-state level in Table 1)	Average (16%, national level in Ta- ble 1)	Maximum (76%, Mandalay-state level in Table 1)
<i>2021–2022 sample</i>			
ln (Violent events, previous monsoon season)	–0.081** (0.033)	–0.065** (0.025)	–0.002 (0.049)
<i>2022–2023 sample</i>			
Rainfall shocks (previous monsoon season) (one standard deviation away from historical average)	–0.078** (0.035)	–0.053* (0.029)	0.044 (0.061)

Source: Authors' computations based on Table 7.

Note: ***1% **5% *10%.

Appendix A: Estimation of Equation (3) through Least Absolute Shrinkage and Selection Operator (LASSO) and PDS-LASSO²³

The full translog production function (2) can suffer severe multicollinearity among input variables X_{ht} , as well as $X_{h,t-1}$ and X_{htc} . Such multicollinearity can arise either because many inputs are significant complements or substitutes to each other, or because the quantity of inputs used may not vary significantly between year t and year $t - 1$. LASSO-approaches are particularly effective in selecting the most influential variables X_{ht} among many highly collinear variables.

A.1. LASSO-approaches when all variables are exogenous (DLD-data)

In the agricultural production economics literature, input variables aggregated at administrative levels, such as districts, are more likely to be exogenous (see, for example, Gong 2018 and Meng et al. 2024) because endogenous responses at more disaggregated levels, such as farm-household levels, tend to be averaged out at aggregate levels. In the estimation of Equation (2) using DLD-data which are at district-levels, we therefore apply standard LASSO-approaches which are widely available for models consisting of exogenous variables only.

LASSO-approaches, originally developed by Tibshirani (1996), essentially penalize the number of explanatory variables over the overall fit of the model and identify parsimonious model specifications by dropping many variables that are deemed only marginally influential or not influential at all—either unconditionally or conditionally in the presence of other highly collinear variables. Among various LASSO-estimators, we primarily apply theory-driven, “rigorous” LASSO-approaches (RLASSO hereafter). The RLASSO is particularly suitable in facilitating causal inferences in the presence of many control variables and avoiding falsely identifying variables as influential when in truth they are not (for example, Ahrens et al. 2020).

The basic setup of the LASSO-estimator applied to Equation (2) for the DLD-data is to estimate parameters β ’s that satisfy the condition,

$$\begin{aligned} \widehat{\beta}_X(\lambda) &= \underset{\beta_X}{\operatorname{argmin}} \frac{1}{n} \sum_j \sum_t \varepsilon_{jt}^2 + \frac{\lambda}{n} \sum_X \psi_X |\beta_X| \\ \psi_X &= \frac{\sqrt{\frac{1}{n} \sum_j \sum_t [(\ln X)^2 \varepsilon_{jt}^2]}}{\sqrt{\frac{1}{n} \sum_j \sum_t (\ln X)^2} \sqrt{\frac{1}{n} \sum_j \sum_t \varepsilon_{jt}^2}} \text{ for each } X \\ &\in X_{jt}, X_{j,t-1}, X_{jtc} \text{ and interaction terms.} \end{aligned} \tag{A1}$$

where parameter n is the total number of observations. Notation λ is a penalization (also called “turning”) parameter that determines how much the number of estimated parameters is penalized in selecting the model. A larger (smaller) λ implies more (less) penalization and therefore leads to selecting fewer (more) parameters in the model. Notation p is the number of input parameters selected among X_{jt} , $X_{j,t-1}$ and X_{jtc} . Notation n represents the number of observations.

Notation ψ_X is called “loading” parameter, which is set specific to each variable $X (= X_{jt}, X_{j,t-1} \text{ and } X_{jtc})$ so that parameters β ’s are independent of the unit of each X . Furthermore, ψ_X in

²³ This section draws largely from Takeshima and Kishore (2025, Appendix B) and Takeshima and Kishore (2026, Online Appendix A).

(A1) is formulated to ensure the LASSO estimates are robust in the presence of potential heteroskedasticity and thus non-Gaussian process underlying the idiosyncratic shock ε , which can be common for agricultural production (Belloni et al. 2012, 2014). This is in contrast with the homoskedastic case, in which the same penalty loadings are used for all X (once each X is standardized).

Note, in our application of LASSO (A1) to production function (2), we always keep $\beta_S S_{jt}$, intercept and household fixed effects (meaning β_S for all S_{jt} , as well as intercept α , f_j) in the regression.

The literature has discussed various approaches for selecting the penalization parameter λ (Ahrens et al. 2020). These include (a) Information Criteria (Zou et al. 2007; Zhang et al. 2010), (b) K-fold cross-validation and h-step-ahead rolling cross-validation approach (Geisser 1975; Arlot & Celisse 2010), and (c) RLASSO approach (Belloni et al. 2012, 2014, 2016).

Among these methods, we use the RLASSO approach, which is considered more suitable for causal inference rather than forecasting and is shown to perform well in terms of type-I errors (mistakenly identifying parameters to be non-zero when they are actually zero (“false positive”)) (Ahrens et al. 2020). Unlike other approaches, RLASSO selects λ which, based on theoretical grounding, guarantees that optimal rates of convergence for parameter estimation are achieved, resulting size of the models have the same order as the true model, and selected parameters are consistently estimated (Ahrens et al. 2020). Specifically, λ in RLASSO is selected as (Jing et al. 2003; Belloni et al. 2012),

$$\lambda = 2\theta\sigma\sqrt{n}\Phi^{-1}\{1 - \gamma/(2p)\} \quad (\text{A2})$$

in which γ is the probability that a “false positive” does not occur, $\theta(> 1)$ is a constant slack parameter which is set at slightly greater than 1 (often 1.1 as in Ahrens et al. [2020]), σ is the standard errors of residual ε_{jt} from Equation (2).

References for Appendix A

- Ahrens A, CB Hansen & ME Schaffer. 2020. lassopack: Model selection and prediction with regularized regression in Stata. *Stata Journal* 20(1):176-235.
- Arlot S & A Celisse. 2010. A survey of cross-validation procedures for model selection. *Statistics Surveys* 4:40-79.
- Belloni A, D Chen, V Chernozhukov & C Hansen. 2012. Sparse models and methods for optimal instruments with an application to eminent domain. *Econometrica* 80:2369-2429.
- Belloni A, V Chernozhukov & C Hansen. 2014. Inference on treatment effects after selection among high-dimensional controls. *Review of Economic Studies* 81:608-650.
- Belloni A, V Chernozhukov, C Hansen & D Kozbur. 2016. Inference in high-dimensional panel models with an application to gun control. *Journal of Business & Economic Statistics* 34:590-605.
- Geisser S. 1975. The predictive sample reuse method with applications. *Journal of the American Statistical Association* 70: 320-328.
- Gong B. 2018. Agricultural reforms and production in China: Changes in provincial production function and productivity in 1978–2015. *Journal of Development Economics* 132:18-31.
- Jing BY, QM Shao & Q Wang. 2003. Self-normalized Cramér-type large deviations for independent random variables. *Annals of Probability* 31: 2167-2215.

- Meng M, L Yu & X Yu. 2024. Machinery structure, machinery subsidies, and agricultural productivity: Evidence from China. *Agricultural Economics* 55(2):223-246.
- Takeshima H & A Kishore. 2025. *Detecting cumulative effects of inputs within the flexible production function framework through LASSO shrinkage estimation: Implications for potassium fertilizer use in India*. IFPRI Discussion Paper 02332.
- Takeshima H & A Kishore. 2026. Estimating cumulative input effects in annual crop production: A LASSO-based panel data approach from India. *Agricultural Systems* 231, 104555.
- Tibshirani, R. 1996. Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society, Series B* 58: 267-288.
- Zhang Y, R Li & CL Tsai. 2010. Regularization parameter selections via generalized information criterion. *Journal of the American Statistical Association* 105: 312-323.
- Zou H, T Hastie & R Tibshirani. 2007. On the “degrees of freedom” of the lasso. *Annals of Statistics* 35:2173-2192.

Appendix B: Illustration of LASSO process

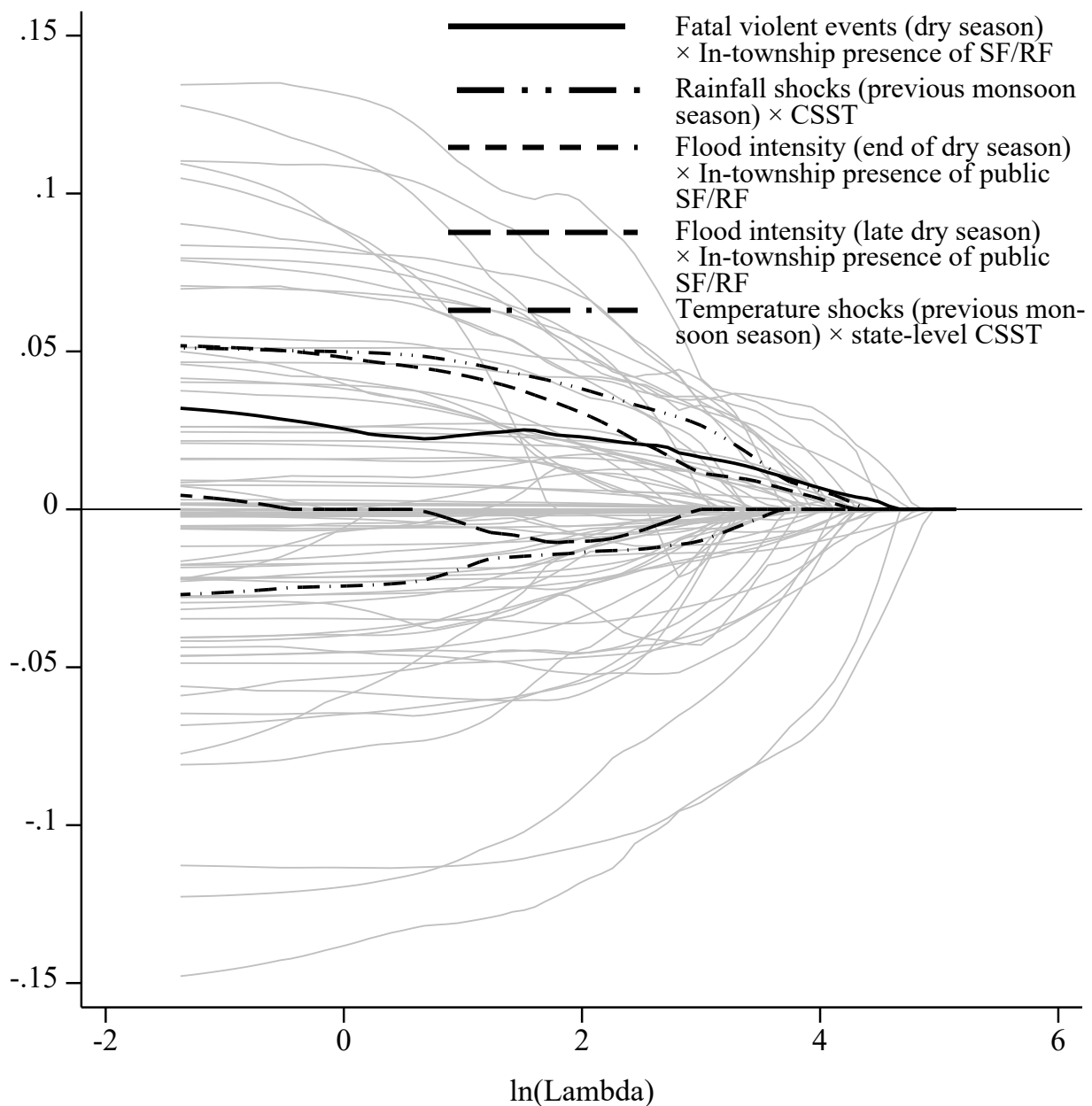


Figure 4. LASSO plots for all variables used as potential predictors of off-farm seed use (Equation (3))^a

Source: Authors.

Note: SF/RF = dummy variable of whether seed farms/research farms exist in the township of respondents. CSST = state-level certified seed production relative to theoretical seed use.

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