Intensification under input constraints: Estimating the heterogenous effects of hybrid maize adoption in Nepal

by Gokul P. Paudel, Vijesh V. Krishna, Dil Bahadur Rahut,
and Andrew J. McDonald

Intensification under input constraints: Estimating the heterogenous effects of hybrid maize adoption in Nepal

Gokul P. Paudel[1, *], Vijesh V. Krishna[2], Dil Bahadur Rahut[3], and Andrew J. McDonald[4]

ABSTRACT

Managerial practices for farming system intensification have received increased focus in research-and-development (R&D) initiatives. These technologies are proven to close the yield gaps in researcher-managed field trials and are recommended for farmer's adoption. However, not all farmers have the technical, financial, and social capital to adopt and benefit from these recommended technologies. Is the current level of productivity enhancement achieved by smallholder system intensification sufficient to sustain rural livelihoods? To this end, the study assesses the impacts of hybrid maize adoption on productivity and livelihoods in the mid-hill region of Nepal. We find that maize hybrid adoption increases crop productivity by 109%, making the crop profitable for smallholders and enhancing per capita food expenditure by 20%. Nevertheless, these benefits were unevenly distributed: relatively small farms (≤0.3 ha.) achieved greater gains in productivity and profitability from hybrid maize adoption, but only larger farms (>0.3 ha.) enjoyed the aggregate livelihood benefits of the technology. Increasing market access to material inputs did not significantly alter the observed patterns. More studies are required on the relationship between farm size and the livelihood impacts of sustainable intensification to facilitate R&D targeting and to ensure inclusive development.

Keywords: Sustainable intensification; Maize systems; Input constraints; Impact heterogeneity; Welfare outcomes; South Asia.

Selected paper for oral presentation at the
31st International Conference of Agricultural Economist (ICAE) August 17-31, 2021 – ONLINE.

---

[1] International Maize and Wheat Improvement Center (CIMMYT), Kathmandu, Nepal
[2] International Maize and Wheat Improvement Center (CIMMYT), Hyderabad, India
[3] Asian Development Bank Institute, Tokyo, Japan
[4] Cornell University, New York, USA

1. Introduction

The sustainable intensification of agriculture (SIA) is defined broadly as the process of producing more output from the same land area without damaging the environment, while improving livelihoods and food security (Godfray and Garnett, 2014; Rudel, 2020). The enhancement of system productivity through the efficient use of marketed inputs and natural resources forms the core of many SIA approaches (Haile et al., 2017). Some of the technologies useful for closing yield gaps through system intensification rely on the timely availability of quality external inputs, for example herbicides for weed management in Conservation Agriculture (CA) systems (Bouwman et al., 2020). Insufficient market access to critical inputs in many regions of the Global South, therefore, often impedes technological change (Guo et al., 2020).

There is a rich socio-economic literature on the adoption and impacts of SIA technologies in maize systems, with several dozen papers published annually (Garcia and Krishna, 2021; Kubitza and Krishna, 2020). However, most of these studies are confined to sub-Saharan Africa (SSA), and there is a significant information gap on the status and challenges faced by the maize farmers of South and Southeast Asia. In the recent past, many Asian countries have expanded maize production and diversified its use from food to the feed and fuel sectors, and maize has assumed the status of a cash crop in this region (Shiferaw et al., 2011). System intensification with hybrid maize technology necessitates well-developed input and output supply chains (Alia, 2017; Mango et al., 2018), and the timely availability of quality inputs, especially inorganic fertilizers, labor, and credit, is a prerequisite to ensuring an efficient production process (Alene and Hassan, 2006; Ghimire and Huang, 2015). However, the agriculture of several developing countries of South and Southeast Asia in general, and of Nepal in particular, are characterized by poorly developed seed systems (Gauchan, 2019; Spielman and Kennedy, 2016), a constrained supply of inorganic fertilizers (Ward et al., 2020), small and fragmented farms (Niroula and Thapa, 2007), and input shortages resulting in high cultivation costs (Paudel et al., 2019). These factors could limit the scope of the sustainable intensification of maize systems using hybrids as a technology component.

Compared to open-pollinated varieties (OPVs), hybrid maize possesses a high genetic yield potential due to heterosis (Flint-Garcia et al., 2009). Hybrid vigor drops with the reuse of farm-saved seeds, resulting in a perpetual market demand for seed that attracts private seed companies (Raghu et al., 2015; Spielman and Kennedy, 2016). Although hybrid maize is promoted and widely cultivated across several developing countries as a sustainable intensification technology due to its high land productivity potential and high nutrient-use efficiency (Devkota et al., 2016), the relative benefits of the technology are dependent upon the local agro-climatic and market conditions (Alene and Hassan, 2006; Kathage et al., 2015). Because not many socio-economic evaluations of maize production technologies have been carried out in South Asia in the last decade (Garcia and Krishna, 2021; Krishna et al., 2019), we know hardly anything about the relative advantage of adopting hybrid seed in countries like Nepal. Some of the experimental trials conducted in Nepal confirmed that by switching from local OPVs to hybrids, maize farmers could improve land productivity (Devkota et al., 2016, 2015). However, these experimental trials are inadequate for shedding light on the biophysical and socio-economic impacts of the technology across diverse farm types and production environments. Against this backdrop, the present study examines the adoption and impacts of hybrid maize among smallholder farmers of the mid-hills of Nepal, where maize grain is primarily used for household consumption. We hypothesize that the impacts of the technology on productivity and farmers' livelihoods are heterogenous, due to the severity of resource constraints and differential access to input markets.

The unique situation of Nepalese agriculture that shapes farmers' adoption of new technologies is discussed in the next section (Section 2). The data collection methods, summary of data used for the empirical analysis, and analytical framework are provided in Section 3. The empirical results are presented and discussed in Section 4. The last section (Section 5) concludes the study and provides policy recommendations.

2. Resource constraints and the history of hybrid maize dissemination in Nepal

Despite being an agrarian economy with two-thirds of its population dependent on agriculture for their livelihoods (MoAD, 2017; World Bank, 2020), food insecurity is rampant in Nepal. Two-thirds of Nepal's districts face food shortages every year (Joshi et al., 2012), and a quarter of the population lives in absolute poverty (NPC, 2017). Among the three distinct agro-ecological zones of the country, food insecurity is most pronounced in the mid-hill and mountain regions (Karki et al., 2015). Low agricultural productivity due to low adoption of modern production technologies has been identified as the primary reason for food insecurity and high poverty in the region (Bairagi et al., 2019; Ghimire and Huang, 2015). The adoption of technologies such as hybrid maize has the potential to improve food security and reduce rural poverty in Nepal by increasing crop productivity and profitability.

Maize is one of Nepal's major cereal crops, where it is grown for food, feed, and fodder (Bahadur et al., 2014; Tiwari et al., 2009). The average domestic consumption of maize grain as food in Nepal is about 3 kilograms per person per month (Ranum et al., 2014) and a substantial portion is also dedicated to livestock production (Paudel et al., 2014). The use of maize grain differs widely across the agro-ecological regions. In the mid-hills and mountains, it is mainly used for human consumption, unlike in the Terai region, where maize is primarily used for industrial purposes (e.g., for making poultry feed) (CBS, 2015; KC et al., 2015). Domestic demand cannot be met with the current level of maize production in Nepal. The average maize yield of Nepal is 2.6 tons/ha (as of 2018), which is less than half the global average (FAO, 2020; MoAD, 2017). Low crop productivity and high demand necessitate the import of maize (Timsina et al., 2016).

The history of hybrid maize adoption is relatively recent in Nepal. In 2003, the National Maize Research Program (NMRP) released the first maize hybrid ("Gaurav Hybrid") (SQCC, 2013), recommended for cultivation in the lowland agro-ecology (altitude <600m). Since then, seven hybrids have been developed and released by the NMRP through collaboration with the International Maize and Wheat Improvement Center (CIMMYT). However, hybrid seed production has taken place at a slow pace in the country, with a limited quantity of seed commercially available in the market (Adhikari, 2014). Furthermore, "Gaurav Hybrid" did not become popular with maize farmers (SQCC, 2013). Between 2010 and 2018, about 61 hybrid maize cultivars were registered by the Government of Nepal (SQCC, 2019), of which only eight were developed domestically. With an increasing demand for hybrid maize seed by farmers and a shortage of domestic supply, in 2011 the government liberalized the hybrid maize seed market, which presented an opportunity for regional seed companies to enter the Nepalese market and formally register maize hybrids.[5]

---

[5] An incident of severe crop loss due to spurious maize seed imported from India in 2009 induced a passionate debate on promoting locally improved varieties of crops in Nepal, shaping the seed policies of the government. Farmers from the Terai districts had been buying hybrid maize seeds from the bordering districts of India. In the winter of 2009, however, some of the varieties bought from across the border led to a heavy yield loss for thousands of Nepali farmers, as these varieties could not withstand the cold weather of the region (Adhikari, 2014). The resulting uproar prompted the government to regulate non-domestic seed companies, which are now required to conduct multi-location trials for at least two seasons or years to ensure the performance and yield stability of these varieties before they can be registered in the seed quality control section (SQCC) of the Government of Nepal, and the maize hybrid seed sold in the Nepalese market.

The reduction of dependence on cereal imports, including maize, has gained high political importance, as evidenced in the Government of Nepal's Agriculture Development Strategy (2015-2035) and Seed Sector Development Strategy (SQCC, 2013).[6] These strategies emphasize the intensification of internal productivity through developing and deploying high-yielding hybrids, improvements in crop management, and the efficient use of fertilizers. However, the country's ability to intensify maize productivity is affected by the constrained access to production inputs (Figure 1). Firstly, the Nepalese agriculture sector is suffering from an acute labor shortage due to the increasing trend of labor out-migration, which has increased five-fold in recent years from the year 2000 (Figure 1a). This accelerating trend of domestic labor loss has sharply increased rural wages by more than double (Figure 1b). Rising rural wages due to labor shortages have sharply increased production costs for all crops. Secondly, the average household landholding size has been reduced by 36% (Figure 1e), and the per capita landholding reduced by 31% during the last three decades (Figure 1d). Decreasing landholdings and land fragmentation have also prompted farmers to depend entirely on agriculture for their livelihoods. Thirdly, due to a nascent national seed system, the country relies heavily on imported hybrid maize seed, while the demand for hybrid maize seed has expanded from 20 tons in 2008 to 1,410 tons in 2017 (Figure 1c). This high dependence on the import of hybrid seed has created a trade deficit of almost US$ 4 million (Figure 1f) from the maize seed sector alone. Moreover, the price of the imported hybrid seed is high, and resource-constrained farmers may be unable to purchase a sufficient quantity of seed, limiting the scope of maize system intensification. Finally, due to underdeveloped industries, Nepal currently imports all inorganic fertilizers from other countries. Although the overall import of inorganic

---

[6] In the Government of Nepal's National Seed Vision (2013-25), the development of 12 hybrid maize varieties by the end of 2025 is envisaged. To meet this goal, the government actively promotes the development of the private seed sector in the country.

fertilizers, such as Urea, DAP, and Potash, has drastically increased over the last two decades (Figure 1g–i), it can only fulfill <50% of the current domestic demand.

[Figure 1 here]

3. Methodology

3.1. Data

The basis of this empirical study is a farm-household survey dataset collected from Nepal's mid-hill region's villages during October-November 2017. Face-to-face interviews using a structured questionnaire were implemented with a computer-assisted personal interview (CAPI) software, with several validation rules to minimize data entry errors and survey time. The questionnaire elicited information on the household's socio-economic status, cropping systems, inputs for maize cultivation and outputs, and sources of household income and expenditure.

The data comes from six districts from the mid-hills of Nepal: Doti, Surkhet, Palpa, Nuwakot, Kavre, and Illam, which were purposively selected based on the area under maize cultivation. The map of Nepal with the location of the selected districts is shown in Figure 2. The district-level maize acreage was quantified in consultation with the District Agriculture Development Offices, key informants, and agricultural input dealers (e.g., agro-vets, who sell maize seed to farmers). According to the Agriculture Knowledge Centers of the Government of Nepal, about 6.02% of the maize area is cultivated with hybrid seed in the selected districts (Appendix Table A1). In each district, the area under maize, and the extent of hybrid maize adoption in sub-districts (Village Development Committees or VDCs) were estimated based on the area under maize cultivation and an initial estimation of hybrid maize adoption among farmers. A total of 34 VDCs were purposively selected to include in the study, and 731 maize-growing farm-households were randomly selected from these VDCs for the survey. Here, we define hybrid maize adopters as farm-households that cultivated hybrid maize in any of their plots in 2017.[7] About 43% of sample households were adopters of the technology, and their over-representation was necessary for impact estimation, which was ensured through the purposive selection of VDCs.

[Figure 2 here]

3.2. Empirical framework

As economic agents, farmers are often assumed to be resource-constrained and rational, attempting to maximize their yields and profits through the judicious use of scarce resources like land, labor, and material inputs. Under this assumption, farmers adopt hybrid maize technology based solely on whether the expected benefit from hybrid adoption is higher than the non-adoption status quo with OPV cultivation (Abdoulaye and Wossen, 2018; Jaleta et al., 2018; Mishra et al., 2018, 2017, 2016; Shiferaw et al., 2014). For the empirical analysis, we restrict our analysis to monetary benefits, although non-monetary benefits (e.g., consumption utility) can also play a crucial role in determining farmers' adoption decisions (Krishna et al., 2013).

Let us assume that $\hat{Y}$ is the difference in the net gain in the outcome variables between hybrid maize adopters and non-adopters. Then, $\hat{Y} > 0$ implies that the adoption of hybrid maize is more beneficial to the farmer than non-adoption. However, $\hat{Y}$ cannot be observed directly, and can only be expressed as the function of observed farm-level socio-economic attributes in a latent model (details of the empirical framework are provided as Supplementary Materials Text). However,

---

[7] Only six sample farmers (0.82%) grew both maize hybrids and OPVs on their farms in 2017 (i.e., partial adoption of the technology). The maize area allocated for hybrid maize was equal or greater than that allocated for non-hybrid maize varieties in all these farms. We considered them as the hybrid maize adopters in this study.

estimating the causal effect of hybrid adoption on the selected outcome indicators (e.g., maize productivity) is difficult due to the likelihood of an endogeneity problem. Finding the “true causal effect” of the technology adoption on key outcome indicators requires controlling observed and unobserved sources of heterogeneity between technology adopters and non-adopters (Angrist and Pischke, 2009; Wooldridge, 2010). Technology adopters and non-adopters may differ in their inherent individual skills and abilities. Failure to account for these heterogeneities may bias parameter estimates and result in false inferences. In this regard, the use of the ordinary least squares (OLS) method that can control only the observed heterogeneities while estimating the effect of technology adoption may lead to biased estimates. In this study, we used an endogenous switching regression (ESR) with a selection instrument to account for both sources of heterogeneity. To estimate the causal effect using ESR, the selection instrument should affect outcome indicators – maize productivity, gross margin, and per capita food expenditure (PCFE) – *only* through hybrid adoption. With the help of the instrumental variable, the ESR addresses the problem of endogeneity by estimating the selection equation with a binary adoption variable (first stage) and the outcome equation with a continuous variable (second stage) simultaneously, employing the full information maximum-likelihood estimation approach (Lokshin and Sajaia, 2004).

The instrumental variable used in this study is the number of years (duration) of availability of hybrid maize seed at the local input dealers. Local availability of the technology determines its adoption but might not affect the outcome variables directly. We assume that other farmers in the village gradually start adopting hybrid maize with the availability of the technology (hybrid seed at the village dealers) after witnessing the productivity gains in adopted farms. Nevertheless, one may assume that the duration of hybrid seed availability at the local dealers might not affect maize productivity, gross margin, and PCFE unless the technology is adopted. However, it is imperative to rule out the possibility that general economic development in the village does *not* determine both input supply chain formation and farmer income (Kubitza and Krishna, 2020). We included regional dummies and distance to input markets from households to capture the differences in the general economic development of the locality. Furthermore, we verified the suitability of our instrument by conducting a simple falsification test, following Di Falco et al. (2011). A good instrumental variable would be strongly associated with hybrid adoption, but not with the outcome indicators for non-adopters. This instrument falsification test suggested that our instrument satisfied the exclusion restriction for productivity and PCFE, but not for profitability (Appendix Table A2).

We estimated the average treatment effects on the treated (ATT) for the hybrid maize adopters and the average treatment effects on the untreated (ATU) for the non-adopters from ESR models. Furthermore, following Di Falco et al. (2011), we estimated the heterogeneity effects; hybrid maize adopters may have a different socio-economic profile than non-adopters, shaping the impact magnitude. Further details of the empirical framework are provided as Supplementary Materials Text.

4. Results and Discussion

4.1. Descriptive Statistics

The summary statistics of the input and output variables disaggregated by hybrid maize adopters (n = 311) and non-adopters (n = 420) are presented in Table 1, while the detailed maize enterprise budget is presented in Appendix Table A3. The seed cost for the hybrid adopters was about five times higher (NPR 8,665 or US$ 83 per ha.) than for non-adopters (NPR 1,731 or US$ 17 per ha.), and this could be one of the major limiting factors for hybrid maize dissemination among poor farm-households of the mid-hills of Nepal. Hybrid maize adopters also applied inorganic fertilizers at a significantly higher rate. Labor costs were also high, but the expenditure for land preparation (particularly the cost of tillage operations) was lower for adopters. The lower land preparation cost for adopters could be associated with mechanized tillage instead of human or animal traction. Due to higher expenditure on material costs and human labor, the total variable cost for hybrid adopters was significantly higher: on average, NRP 74,299 (US$ 714) per hectare for adopters against NRP 60,380 (US$ 581) per hectare for non-adopters. On the other hand, maize productivity was 93% higher (at 4,370 kg per ha.) for hybrid maize adopters than for non-adopters (at 2,261 kg per ha.). Albeit with higher variable costs, gains in crop productivity enabled hybrid adopters to secure a significantly higher gross margin (NPR 28,773 or US$ 277 per ha.) than non-adopters, who were losing money (gross margin NPR –2,930 or US$ –28 per ha.) on average. However, due to small farm size (0.27 ha.), the average incremental household income gain from hybrid adoption was relatively modest (NPR 7,769 or US$ 75). Adopting farm-households had a 29% higher PCFE (NPR 13,093 or US$ 126) than non-adopting ones (NPR 10,175 or US$ 98).[8]

[Table 1 here]

Selected socio-economic attributes of hybrid maize adopters and non-adopters are presented in Table 2 and further details in Appendix Table A4. The average farm size for maize growers in the study area was 0.42 ha., and the size was not statistically different between adopters and non-adopters. However, the adopters, on average, had a slightly larger area under maize cultivation (0.27 ha.) than the non-adopters (0.25 ha.). The hybrid adopters had more years of experience in

---

[8] The PCFE does not include expenditure on infrequent events such as marriage ceremonies.

cultivating maize. Among the adopters, a higher percentage of household heads were male (87% vs. 82% among non-adopters), and they were located closer to input markets (5.67 km) than the non-adopters (9.53 km). Closeness to markets could be one of the main drivers of the adoption of hybrid maize and the increased use of material inputs, including inorganic fertilizers. Moreover, the number of years since maize hybrid was first introduced in the village agro-vet (private input dealers) stores was significantly higher for hybrid maize adopters than for non-adopters. Finally, geographic differences were also observed for the adoption of hybrid maize. There was a high rate of adoption in the central hills, as compared to the eastern and mid-western hill districts of Nepal.

[Table 2 here]

Table 2 also includes a summary of variables such as a farmer's age, education, caste, and primary occupation across the two adoption categories. In the adopter group, the share of households belonging to the socially non-marginalized castes (such as *Chhetry* and *Brahmin*) was high at 61%. Among non-adopters, the share of households belonging to the marginalized castes (such as *Dalits* and *Janajatis*) was equal to that of the non-marginalized castes. There was no notable difference in perceived labor scarcity among adopters and others, but hybrid adopters were found to secure labor by providing higher wages for farming operations. A significantly higher percentage of adopters reported difficulty in finding draft animals for agricultural land preparation, leading to the increased use of mechanized tillage. Although there were no detectable differences in off-farm income, a higher percentage of adopters' farms had concrete houses, indicating that relatively wealthy households adopted hybrid maize (Table 1).

4.2. Adoption of Hybrid Maize in the Mid-hills of Nepal and Its Implications

The key results from the ESR model estimates for maize productivity, profitability, and PCFE are presented in Table 3, and the full models in Appendix Tables A5-A7. The ESR method employed jointly estimated the selection equation in the first stage and the outcome equation in the second stage as specified in the empirical framework section. The empirical estimation of the selection equation can be interpreted as that of normal probit coefficients. In Appendix Tables A5-A7, we also provide the OLS coefficients, in which the coefficient of hybrid maize adoption is found to be positive and statistically significant. Nevertheless, the correlation between the error term in the selection equation and the outcome equation is different from zero in the ESR model on maize productivity, indicating the existence of selection bias in using OLS (Lokshin and Sajaia, 2004). The correlation between the gross margin and the PCFE in the ESR framework, however, is not statistically significant, indicating the absence of selection bias in these models. We kept the ESR estimates, however, and derived treatment effects to gain insights into the heterogeneous effects of hybrid maize adoption with respect to key socio-economic variables, viz. landholding size and market access.

[Table 3 here]

Household heads with a higher number of years of experience in maize cultivation, farms where a higher rate of inorganic fertilizers in maize was applied, and households that paid high agricultural labor wages had a greater probability of adopting maize hybrids. Farm households that possessed concrete houses increasingly adopted hybrids. Farmers with better market access were found to have a higher chance of adoption. The instrumental variable – the duration of availability of hybrid maize seed with the local trader – was also statistically significant and positive. Finally, spatial heterogeneity in hybrid maize adoption was evident from the significant regional dummies in the selection models (Appendix Tables A5-A7). We do not over-interpret the adoption estimates, as our primary goal is to examine the impacts of adoption, and the selected models with binary dependent variables have severe limitations with regard to capturing the complex decision-making process concerning technology adoption (Garcia and Krishna, 2021; Glover et al., 2016).

The rest of Table 3 and Appendix Tables A5-A7 include the key estimates on maize productivity per ha., gross margin per ha., and PCFE for hybrid maize adopters and non-adopters, respectively. Farm size was negatively associated with maize productivity, indicating the higher productivity of small farms compared with large farms. In the literature, there is plenty of evidence for highly productive small farms, owing to better crop management (Bardhan, 1973; Carter, 1984; Chand et al., 2017; Wu et al., 2018). However, in our case, most sample farms were in the marginal farm category, with 93% farms operating under 1 ha., and hence better crop management could not be the only reason for the high productivity of smaller farms. Furthermore, the coefficient of farm size is positive (0.14) for non-adopters in the model with the gross margin per ha. as the dependent variable. Similarly, farm size is positively associated with PCFE among adopters: with a 1% increase in farm size, the PCFE of hybrid maize adopters increases by about 0.24%. Land is not only a factor of production but also an asset facilitating access to working capital, and hence has a conflicting role in enhancing productivity and profitability. Furthermore, the smallest farmers of the Nepal hills might be able to acquire production inputs in small doses as required, increasing not only maize productivity but also the variable cost of production.

In the ESR outcome equations, we have included some but not all possible indicators of input scarcity. The included ones are found to limit maize productivity. The productivity of hybrid maize adopters who faced difficulties in finding human labor was lower by 11%, and of non-adopters by

17% (Appendix Table A5).[9] This variable had also a significant negative effect on the household's PCFE. This finding is consistent with earlier studies in Nepal that showed that labor out-migration and shortages caused a significant delay in crop establishment and farm operations, and had a negative effect on crop productivity (Khanal, 2018; Khanal et al., 2015; Maharjan et al., 2013a, 2013b). Moreover, the marginal effects on productivity of inorganic fertilizers for hybrid maize adopters and non-adopters were similar, although the former applied more fertilizers and had higher nitrogen use efficiency (Devkota et al., 2016). Finally, an increase in the labor wage rate was found to be negatively associated with maize profitability for both adopters and non-adopters, which is unsurprising. However, a positive association between the wage rate and PCFE exists. Most farm households hire out their labor, and a higher wage rate enhances household income and hence food consumption.

The estimates of the impact of hybrid maize adoption on maize productivity, gross margin per hectare, and PCFE are presented in Table 4, together with the OLS estimates. The marginal effect of the OLS estimates after transformation would be a 74% increase in maize productivity, a 34% increase in gross margins per hectare, and a 14% increase in PCFE. The ESR values also showed significantly higher benefits for technology adoption. Here, we report the ATT and ATU values for adopters and non-adopters separately. The ATT values capture the difference in the outcome variables for hybrid adopters between the current estimates (with the adoption of the technology), and the estimates had they not adopted it. Similarly, the ATU values show the difference between the current estimates and the outcomes of the non-adopters had they adopted the technology. The estimates show that the adoption of hybrid maize has a significant and positive impact on maize

---

[9] The marginal effect of a dummy variable with the dependent variables in the log-form is calculated as 100*[exp(Coefficent)-1], following Giles (2011).

productivity, gross margins, and PCFE for adopting households. It would also have been beneficial for non-adopters had they adopted maize hybrids.

For adopters, the adoption of hybrid maize enabled households to increase maize productivity by 109% and PCFE by 20%. For non-adopters, adoption would have increased productivity by 66% and PCFE by 64%. Maize cultivation in the study area was not profitable for non-adopters, and this would also have been the case had the adopters not adopted the technology.

[Table 4 here]

Despite the statistically significant, positive ATT estimates, the crop income accrued to the household due to adoption was not high (NPR 10,622 or US$ 102) for sustaining a rural household, due to the small size of farm-holding. This could be one of the reasons for the relatively small increase in PCFE (NPR 1,982 or US$ 19 per household) for adopters. More research is required on whether this increase has helped farmers to cross over the poverty threshold. In the case of non-adopters, however, the use of maize hybrids could help them avoid financial losses from crop production. Hybrid maize adopters and non-adopters are systematically different, as indicated by the transitional heterogeneity (TH) estimates in Table 4, and a direct comparison of the impacts of hybrid maize on adopters and non-adopters without addressing the observed and unobserved heterogeneities would lead to biased estimates. In contrast, the positive and statistically significant values of TH for productivity and gross margin (ATT > ATU) show that hybrid maize adopters have the potential to realize higher productivity and gross margin. For PCFE, however, ATU > ATT, possibly because non-adopters face negative returns in the absence of the technology.

We checked the robustness of our findings using the Inverse Probability Weighted Regression Adjusted (IPWRA) method.[10] The results are presented in Table 5. Consistent with the results from the ESR, the treatment effects for hybrid maize adoption on maize productivity, gross margin, and PCFE are statistically significant. The IPWRA results show that the adoption of maize hybrids increases crop productivity, gross margins, and PCFE by 1,586 kg/ha., NPR by 25,972 per ha. (US$ 250), and NPR by 1,747 (US$ 17), respectively. However, the impact magnitude is lower than that estimated in the ESR framework, possibly because unobserved heterogeneity was not accounted for in the IPWRA method.

[Table 5 here]

In sum, the OLS and ESR estimates presented in this section clearly indicate the significant positive productivity, gross margins, and welfare (i.e., PCFE) effects of hybrid maize adoption, even if farmers have several resource constraints. While our findings are similar to those of earlier studies conducted in other regions (Abdoulaye and Wossen, 2018; Ahmed et al., 2017; Becerril and Abdulai, 2010; Jaleta et al., 2018; Kassie et al., 2014; Manda and Alene, 2018; Mathenge et al., 2014), they also indicate that transition to maize hybrid technology will have modest benefits for smallholder farm-households working under severe resource constraints. Given that the per capita land availability of Nepal is less than 0.12 ha. (Figure 1), that maize is only one of several crops cultivated in the farming systems, and that the hybrid maize technology could increase gross margins by US$ 378 per ha. (US$ 45 per capita per season; ATT from Table 4), more assessments are required on the potential of the technology to reduce poverty and food insecurity in the mid-

---

[10] It should be noted that the IPWRA method captures only observed heterogeneity between hybrid maize adopters and non-adopters.

hill region of Nepal. The effects of the technology on the livelihoods of agricultural laborers should also be examined. Due to the heightened demand for human labor with adoption, the technology may also be beneficial for the labor-providing households of Nepal.

4.3. Heterogeneous effects of hybrid maize adoption

Technology adoption among maize farmers may have differential impacts across different socio-economic strata, depending on the degree of resource scarcity that the farmers face. In order to examine these heterogeneous effects, we stratified the data into different categories by (a) farm-size quartiles and (b) farmers' access to input markets. The results for the heterogeneous effects of hybrid maize adoption across these two categorical variables are presented in Tables 6 and 7.

[Table 6 and Table 7 here]

To assess the impacts of hybrid maize adoption on productivity, gross margin per ha. and PCFE across different farm sizes, we stratified the sample into four farm-size quartiles (Table 6). An inter-quantile ATT comparison shows unique patterns, demonstrating that the livelihood impacts of hybrid seed adoption are crucially dependent on the resource status. The same holds true for ATU. While the impacts of hybrid maize adoption on maize productivity and gross margins (for both ATT and ATU) across all the farm-sized quartiles are statistically significant at the 1% level for the adopting farms, the magnitude of the effects of the hybrid technology on productivity and gross margins (NPR per ha.) was considerably higher for the first quartile farms; the size of the effect diminishes in the third and fourth quantiles. On the other hand, the treatment effects of hybrid maize adoption on PCFE for the adopters' farms are positive and statistically significant only in the third and fourth quartile farms. The non-significant livelihood effects of hybrid maize adoption could be associated with a smaller area allocated to maize in the first and second quartile farms (an average of 0.15 ha.) than in the third and fourth quartile (0.35 ha.) farms. Irrespective of the high agronomic potential of hybrid maize technology, a certain minimum landholding size is required for its livelihood impacts to be manifested.

To assess the impacts of hybrid maize adoption across different farm sizes and levels of market access, we stratified our data into low and high access to a market with respect to large and small farms (Table 7). The impacts of hybrid maize adoption on maize productivity and gross margins were statistically significant, irrespective of the level of market access. Hybrid maize adoption did not enhance the PCFE of the smallest farms across both high and low market-access categories. This could, again, be due to the low level of household net economic benefit (i.e., gross margin per household) obtained by the smallest farms. Nevertheless, the PCFE of the largest farms is statistically significant across both the high and low market-access categories. The treatment effect results (ATU) were similar for non-adopters, which suggests that hybrid maize adopters across the small farm-size categories, with or without market access, did not benefit with respect to PCFE. In the context of Nepal, results suggest that farm size is a much more important determinant of livelihood effects than access to an input market.

5. Conclusion and policy implications

Farmers of rural Nepal face a constrained supply of several marketed inputs and natural resources, making the sustainable intensification of cereal systems a challenging endeavor. By examining hybrid maize adoption as a case of sustainable intensification by the smallholder farmers of Nepal’s rainfed mid-hills, we test the hypothesis that adoption of this technology enhances productivity, profitability, and household welfare, depending on factors such as the scale of operation. The current Nepalese context of rising on-farm wages (due mainly to labor out-migration), small farms, high dependency on maize hybrid seed imports, and limited availability of inorganic fertilizers, provides ample opportunities to test the aforementioned hypothesis. Our findings revealed that the constrained availability of inputs such as inorganic fertilizers, on-farm wage rates (labor scarcity) and market proximity were strongly associated with farmers' adoption of maize hybrids. Moreover, the adoption of maize hybrids increased on-farm productivity and profitability overall. However, we also found that hybrid maize adoption had heterogeneous effects, with relatively larger farms (the upper 50%, above 0.3 ha.) benefiting from adoption in terms of gains in productivity, profitability, and welfare outcomes. Smaller farms (the lower 50%, below 0.3 ha.) did not benefit with respect to welfare outcomes, although they were more productive than the larger farms. Even with increased market access, the scenario remains unaltered.

We derived three major policy implications for the smallholder farming systems in Nepal, which are not strictly in line with recommendations from previous studies on cereal system intensification. For example, Spielman et al. (2010) focused on opening up the input market as a precondition for the intensification of cereal systems in Ethiopia. However, our findings suggest a public-private partnership in R&D programs on sustainable intensification. A single and piece-wise intervention, a common method of disseminating proprietary technologies, is insufficient to improve rural livelihoods. R&D programs and government policies should target the diffusion of multiple sustainable intensification technologies, ensuring input access and addressing fundamental resource constraints. While the private sector plays a key role in making the technologies available, facilitating the adoption of multiple interventions requires public R&D and extension support. Only a multi-layering of technologies would offset the adverse effects of resource shortages. The incremental effect of technology combinations were observed earlier by

Mulenga et al. (2021), who showed that the fertilizer-dominant intensification strategy provided only a 30% incremental yield, whereas the combination of fertilizer, maize-legume diversification, and soil and water conservation provided an 88% incremental yield. It is to be expected that technology combinations are also likely to have highly positive returns in terms of profitability and rural livelihoods in countries like Nepal. This is our first recommendation derived from the empirical analysis.

Secondly, policies and R&D strategies aimed at targeting sustainable intensification technologies across farming communities should be developed. Takeshima et al. (2017) showed that an in-depth understanding of the returns from inputs is critical in formulating effective policies for the dissemination of agricultural inputs in developing countries. However, we found that as a technology, the returns to the adoption of hybrid maize varies widely across farming communities; farmers with the smallest landholdings, despite being highly productive, are unable to sustain their livelihoods from maize cultivation alone. More research is needed on the differential access to production resources across social groups and its implications for economic inequality. For example, the nature of our dataset does not allow us to examine the role of social marginalization with respect to gender. Burke and Jayne (2021) showed an association between social marginalization and low input quality: women farmers of Africa were found to be more likely to farm with lower quality seed and less fertilizer on marginal land. In Nepal, more studies need to be carried out on the roles played by male out-migration and the feminization of Nepalese agriculture on productivity and farm income.

Thirdly, smallholder farmers in the mid-hills of Nepal should be encouraged towards income diversification, and options should be provided to divert them towards alternative farming systems such as the vegetable or dairy sectors for the betterment of rural livelihoods. Despite such system diversification, a small landholding size might sometimes not be sufficient for households to raise themselves out of poverty. There have not been many studies made on the role of non-farm income in rural livelihoods in Nepal. However, studies conducted in other parts of the Global South are also valid here. Holden et al. (2004) observed that unconstrained access to low-wage, non-farm employment could improve household income more substantially than the provision of unconstrained access to credit for the purchase of farm inputs in the Ethiopian highlands; this observation is particularly relevant for the resource-constrained farming conditions of the mid-hills of Nepal. The structural transformation of the country requires more research and policy attention.

References

Abdoulaye, T., Wossen, T., 2018. Impacts of improved maize varieties in Nigeria: ex-post assessment of productivity and welfare outcomes. Food Secur. 10, 369–379.

Adhikari, J., 2014. Seed Sovereignty: Analysing the Debate on Hybrid Seeds and GMOs and Bringing About Sustainability in Agricultural Development. J. For. Livelihood 12, 33–46.

Ahmed, M.H., Geleta, K.M., Tazeze, A., Ahmed, M.H., 2017. The impact of improved maize varieties on farm productivity and wellbeing: evidence from the East Hararghe Zone of Ethiopia. Dev. Stud. Res. 4, 9–21.

Alene, A.D., Hassan, R.M., 2006. The efficiency of traditional and hybrid maize production in Eastern Ethiopia: An extended efficiency decomposition approach. J. Afr. Econ. 15, 91–116.

Alia, D.Y., 2017. Agricultural Input Intensification, Productivity Growth, and the Transformation of African Agriculture. Theses Diss. - Agric. Econ. 59. https//uknowledge.uky.edu/agecon_etds/59 170.

Angrist, J.D., Pischke, J.-S., 2009. Mostly harmless econometrics: An empiricist's companion. Princeton University Press, Princeton, NJ.

Bahadur, K.C.D., Gadal, N., Neupane, S.P., Puri, R.R., Khatiwada, B., 2014. Maize seed marketing chains and marketing efficiency along supply chains of the hills in Nepal. Int. J. Agric. Mark. 2, 26–33.

Bairagi, S., Mishra, A.K., Giri, A., 2019. Good agricultural practices, farm performance, and input usage by smallholders: Empirical evidence from Nepal. Agribusiness 35, 471–491.

Bardhan, P.K., 1973. Size, productivity, and return to scale: An analysis of farm-level data in Indian agriculture. J. Polit. Econ. 81, 1370–1386.

Becerril, J., Abdulai, A., 2010. The impact of improved maize varieties on poverty in Mexico: A propensity score-matching approach. World Dev. 38, 1024–1035.

Bista, D.R., Dhungel, S., Adhikari, S., 2016. Status of fertilizer and seed subsidy in Nepal: review and recommendation. J. Agric. Environ. 17, 1–10.

Bouwman, T.I., Andersson, J.A., Giller, K.E., 2020. Herbicide Induced Hunger? Conservation

Agriculture, Ganyu Labour and Rural Poverty in Central Malawi. J. Dev. Stud. 00, 1–20. https://doi.org/10.1080/00220388.2020.1786062

Burke, W.J., Jayne, T.S., 2021. Disparate access to quality land and fertilizers explain Malawi's gender yield gap. Food Policy 102002. https://doi.org/10.1016/j.foodpol.2020.102002

Carter, M.R., 1984. Farm size and productivity: An empirical analysis of peasant agricultural production. Oxf. Econ. Pap. 36, 131–145.

CBS, 2015. Annual household survey. Government of Nepal National Planning Commission Secretariat. Central Bureau of Statistics. Kathmandu, Nepal.

Chand, R., Prasanna, P.L., Singh, A., 2017. Farm size and productivity: Understanding the strengths of smallholders and improving their livelihoods. Econ. Polit. Wkly. 46, 5–11.

Devkota, K.P., McDonald, A.J., Khadka, A., Khadka, L., Paudel, G., Devkota, M., 2015. Decomposing maize yield gaps differentiates entry points for intensification in the rainfed mid-hills of Nepal. F. Crop. Res. 179, 81–94.

Devkota, K.P., McDonald, A.J., Khadka, L., Khadka, A., Paudel, G., Devkota, M., 2016. Fertilizers, hybrids, and the sustainable intensification of maize systems in the rainfed mid-hills of Nepal. Eur. J. Agron. 80, 154–167.

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. Am. J. Agric. Econ. 93, 825–842.

FAO, 2020. Food and Agriculture Organization. Statistical Database. Retrived date May 5, 2020. http://www.fao.org/faostat/en/#data/QC.

Flint-Garcia, S.A., Buckler, E.S., Tiffin, P., Ersoz, E., Springer, N.M., 2009. Heterosis is prevalent for multiple traits in diverse maize germplasm. PLoS One 4(10), e7433. https://doi.org/10.1371/journal.pone.0007433

Garcia, E.J., Krishna, V. V., 2021. Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. Agron. Sustain. Dev.

Gauchan, D., 2019. Seed sector development in Nepal: Opportunities and options for improvement., in: Ganesh Thapa, Anjani Kumar, P.K.J. (Ed.), Agricultural Transformation in Nepal: Trends, Prospects, and Policy Options. Singapore: Springer Nature Singapore Pte Ltd, pp. 199–230.

Ghimire, R., Huang, W., 2015. Household wealth and adoption of improved maize varieties in Nepal: A double-hurdle approach. Food Secur. 7, 1321–1335.

Giles, D.E., 2011. Interpreting dummy variables in semi-logarithmic regression models: exact distributional results. University of Victoria, Department of Economics, Working Paper EWP 1101.

Glover, D., Sumberg, J., Andersson, J.A., 2016. The adoption problem; or why we still understand so little about technological change in African agriculture. Outlook Agric. 45, 3–6. 5

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philos. Trans. R. Soc. B Biol. Sci. 369, 6–11.

Guo, Q., Ola, O., Benjamin, E.O., 2020. Determinants of the adoption of sustainable intensification in southern african farming systems: A meta-analysis. Sustainability 12, 3276. https://doi.org/10.3390/SU12083276.

Haile, M.G., Wossen, T., Tesfaye, K., von Braun, J., 2017. Impact of Climate Change, Weather Extremes, and Price Risk on Global Food Supply. Econ. Disasters Clim. Chang. 1, 55–75.

Holden, S., Shiferaw, B., Pender, J., 2004. Non-farm income, household welfare, and sustainable land management in a less-favoured area in the Ethiopian highlands. Food Policy 29, 369–

392.

Jaleta, M., Kassie, M., Marenya, P., Yirga, C., Erenstein, O., 2018. Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. Food Secur. 10, 81–93.

Joshi, K.D., Conroy, C., Witcombe, J.R., 2012. Agriculture, seed, and innovation in Nepal: industry and policy issues for the future. Project Paper, International Food Policy Research Institute, Washington, DC.

Karki, T.B., Sah, S.K., Thapa, R.B., Mcdonald, A.J., 2015. Identifying pathways for improving household food self-sufficiency outcomes in the Hills of Nepal. PLoS One 10, e0127513. https://doi.org/10.1371/journal.pone.0127513.

Kassie, M., Jaleta, M., Mattei, A., 2014. Evaluating the impact of improved maize varieties on food security in Rural Tanzania : Evidence from a continuous treatment approach. Food Secur. 6, 217–230.

Kathage, J., Kassie, M., Shiferaw, B., Qaim, M., 2015. Big constraints or small returns? Explaining nonadoption of hybrid maize in Tanzania. Appl. Econ. Perspect. Policy 38, 113–131.

KC, G., Karki, T.B., Shrestha, J., Achhami, B.B., 2015. Status and prospects of maize research in Nepal. J. Maize Res. Dev. 1, 1–9.

Khanal, U., 2018. Why are farmers keeping cultivatable lands fallow even though there is food scarcity in Nepal? Food Secur. 10, 603–614.

Khanal, U., Alam, K., Khanal, R.C., Regmi, P.P., 2015. Implications of out-migration in rural agriculture: A case study of Manapang village, Tanahun, Nepal. J. Dev. Areas 49, 331–352.

Krishna, V. V., Feleke, S., Marenya, P., Abdoulaye, T., Erenstein, O., 2019. A Strategic Framework for Adoption and Impact Studies in the CGIAR Research Program on Maize (MAIZE). Texcoco, Mexico: CIMMYT - IITA. Available online at https://repository.cimmyt.org/handle/10883/20220.

Krishna, V. V, Drucker, A.G., Pascual, U., Raghu, P.T., King, E.D.I.O., 2013. Estimating compensation payments for on-farm conservation of agricultural biodiversity in developing countries. Ecol. Econ. 87, 110–123.

Kubitza, C., Krishna, V. V., 2020. Instrumental variables and the claim of causality: Evidence from impact studies in maize systems. Glob. Food Sec. 26, 100383. https://doi.org/10.1016/j.gfs.2020.100383.

Lokshin, M., Sajaia, Z., 2004. Maximum likelihood estimation of endogenous switching regression models. Stata J. 4, 282–289.

Maharjan, A., Bauer, S., Knerr, B., 2013a. Migration for labour and its impact on farm production in Nepal. Working Paper IV. Center for the study of labor and mobility. Kathmandu, Nepal.

Maharjan, A., Bauer, S., Knerr, B., 2013b. International migration, remittances and subsistence farming: Evidence from Nepal. Int. Migr. 51, 249–263.

Manda, J., Alene, A.D., 2018. Impact of improved maize varieties on food security in Eastern Zambia: A doubly robust analysis. Rev. Dev. Econ. 1–20.

Mango, N., Mapemba, L., Tchale, H., Makate, C., Dunjana, N., Lundy, M., 2018. Maize value chain analysis: A case of smallholder maize production and marketing in selected areas of Malawi and Mozambique. Cogent Bus. Manag. 5, 1–15.

Mathenge, M.K., Smale, M., Olwande, J., 2014. The impacts of hybrid maize seed on the welfare of farming households in Kenya. Food Policy 44, 262–271.

Mishra, A.K., Khanal, A.R., Pede, V.O., 2017. Is direct seeded rice a boon for economic performance? Empirical evidence from India. Food Policy 73, 10–18.

Mishra, A.K., Kumar, A., Joshi, P.K., Alwin, D., 2016. Impact of contracts in high yielding varieties seed production on profits and yield: The case of Nepal. Food Policy 62, 110–121.

Mishra, A.K., Kumar, A., Joshi, P.K., Souza, A.D., Tripathi, G., 2018. How can organic rice be a boon to smallholders? Evidence from contract farming in India. Food Policy 75, 147–157.

MoAD, 2017. Statistical information on Nepalese agriculture. Ministry of Agricultural Development, Kathmandu, Nepal.

MoAD, 2016. Agriculture Development Strategy 2015 to 2035, Ministry of Agriculture Development, Kathmandu, Nepal.

MoF, 2018. Economic Survey 2018/19. Ministry of Finance, Government of Nepal. Kathamndu, Nepal.

MoLE, 2018. Labour migration for employment. A status report for Nepal, Ministry of Labor and Employment, Government of Nepal, Kathmandu, Nepal.

Mulenga, B.P., Ngoma, H., Nkonde, C., 2021. Produce to eat or sell: Panel data structural equation modeling of market participation and food dietary diversity in Zambia. Food Policy 102035. https://doi.org/10.1016/j.foodpol.2021.102035.

Niroula, G.S., Thapa, G.B., 2007. Impacts of land fragmentation on input use, crop yield and production efficiency in the mountains of Nepal. L. Degrad. Dev. 18, 237–248. https://doi.org/10.1002/ldr.

NPC, 2017. Sustainable development goals. Government of Nepal, National Planning Commission (NPC), Kathmandu, Nepal.

NRB, 2019. Nepal Rastra Bank 2019. Available at: https://www.nrb.org.np/fxmexchangerate.php. last accessed October 2019.

Paudel, G., Teufel, N., Christian, B., Mcdonald, A., Singh, D.K., 2014. Hybrid maize for food and feed security in mixed farming systems of western Nepal: An ex-ante assessment. Poster presented at Tropentag, Prague, Czech Republic.

Paudel, G.P., KC, D.B., Rahut, D.B., Justice, S.E., McDonald, A.J., 2019. Scale-appropriate mechanization impacts on productivity among smallholders: evidence from rice systems in the mid-hills of Nepal. Land Use Policy 85, 104–113.

Raghu, P.T., Erenstein, O., Böber, C., Krishna, V. V., 2015. Adoption and Outcomes of Hybrid Maize in the Marginal Areas of India. Q. J. Int. Agric. 54, 189–214.

Ranum, P., Pe˜a-Rosas, J.P., Garcia-Casal, M.N., 2014. Global maize production, utilization, and consumption. Ann. N. Y. Acad. Sci. 1312, 105–112.

Rudel, T.K., 2020. The variable paths to sustainable intensification in agriculture. Reg. Environ. Chang. 20. https://doi.org/10.1007/s10113-020-01720-8

SEAN, 2019. Seed Entrepreneur Association of Nepal. Kathmandu, Nepal.

Shiferaw, B., Kassie, M., Jaleta, M., Yirga, C., 2014. Adoption of improved wheat varieties and impacts on household food security in Ethiopia. Food Policy 44, 272–284.

Shiferaw, B., Prasanna, B.M., Hellin, J., Bänziger, M., 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Secur. 3, 307–327.

Shrestha, R.K., 2010. Fertilizer policy development in Nepal. J. Agric. Environ. 11, 126–137.

Spielman, D.J., Byerlee, D., Alemu, D., Kelemework, D., 2010. Policies to promote cereal intensification in Ethiopia: The search for appropriate public and private roles. Food Policy 35, 185–194.

Spielman, D.J., Kennedy, A., 2016. Towards better metrics and policymaking for seed system development: Insights from Asia's seed industry. Agric. Syst. 147, 111–122.

SQCC, 2019. Notified and denotified varieties till date. Seed Quality Control Center, Government of Nepal, Kathmandu.

SQCC, 2013. National Seed Vision 2013-2025. Government of Nepal, Ministry of Agricultural Development, National Seed Board, Seed Quality Control Centre, Hariharbhawan, Lalitpur, Nepal.

Takeshima, H., Adhikari, R.P., Shivakoti, S., Kaphle, B.D., Kumar, A., 2017. Heterogeneous returns to chemical fertilizer at the intensive margins: insights from Nepal. Food Policy 69, 97–109.

Timsina, K.P., Ghimire, Y.N., Lamichhane, J., 2016. Maize production in mid hills of Nepal: from food to feed security. J. Maize Res. Dev. 2, 20–29.

Tiwari, T.P., Virk, D.S., Sinclair, F.L., 2009. Rapid gains in yield and adoption of new maize varieties for complex hillside environments through farmer participation I. Improving options through participatory varietal selection (PVS). F. Crop. Res. 111, 137–143.

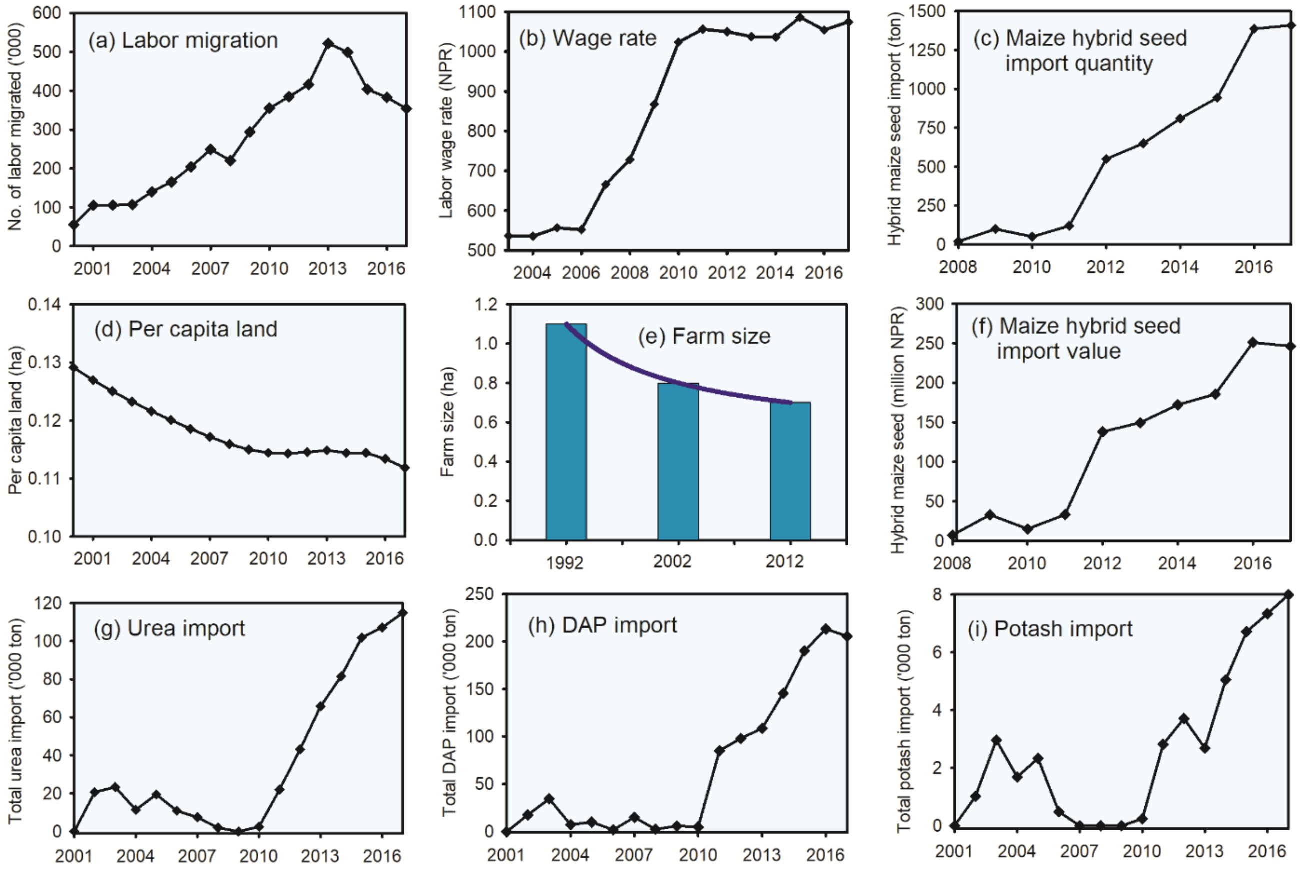
Ward, P.S., Gupta, S., Singh, V., Ortega, D.L., Gautam, S., 2020. What is the intrinsic value of fertilizer? Experimental value elicitation and decomposition in the hill and terai regions of Nepal. Food Policy 90, 101809. https://doi.org/10.1016/j.foodpol.2019.101809.

Wooldridge, J.M., 2010. Econometric analysis of cross section and panel data. MIT Press, Cambridge, MA.

World Bank, 2020. "Public Banks" South Asia Economic Focus (April). The World Bank. https://doi.org/10.1596/978-1-4648-1566-9

Wu, Y., Xi, X., Tang, X., Luo, D., Gu, B., Kee, S., Vitousek, P.M., Chen, D., 2018. Policy distortions , farm size , and the overuse of agricultural chemicals in China. Proc. Natl. Acad. Sci. U. S. A. 27, 1–6.

Figure 1. Indicators of input scarcity in Nepalese agriculture.



Sources: (a) Labor migration (MoLE, 2018); (b) Labor wage rates (MoF, 2018); (c) Hybrid maize seed imports (SEAN, 2019); (d) Per capita land (MoAD, 2017); (e) Farm size (MoAD, 2016); (f) Hybrid maize seed value (SEAN, 2019); (g) Urea import (Bista et al., 2016; MoAD, 2017; Shrestha, 2010); (h) DAP import (Bista et al., 2016; MoAD, 2017; Shrestha, 2010); (i) Potash import (Bista et al., 2016; MoAD, 2017; Shrestha, 2010).

Notes: Monetary values are adjusted for inflation and are for the year 2010. Exchange rate: US$ 1 = NPR 104, during the survey year 2017 (NRB, 2019).

Figure 2. Map of Nepal showing sampled districts, agro-ecological zones, and regional boundaries.

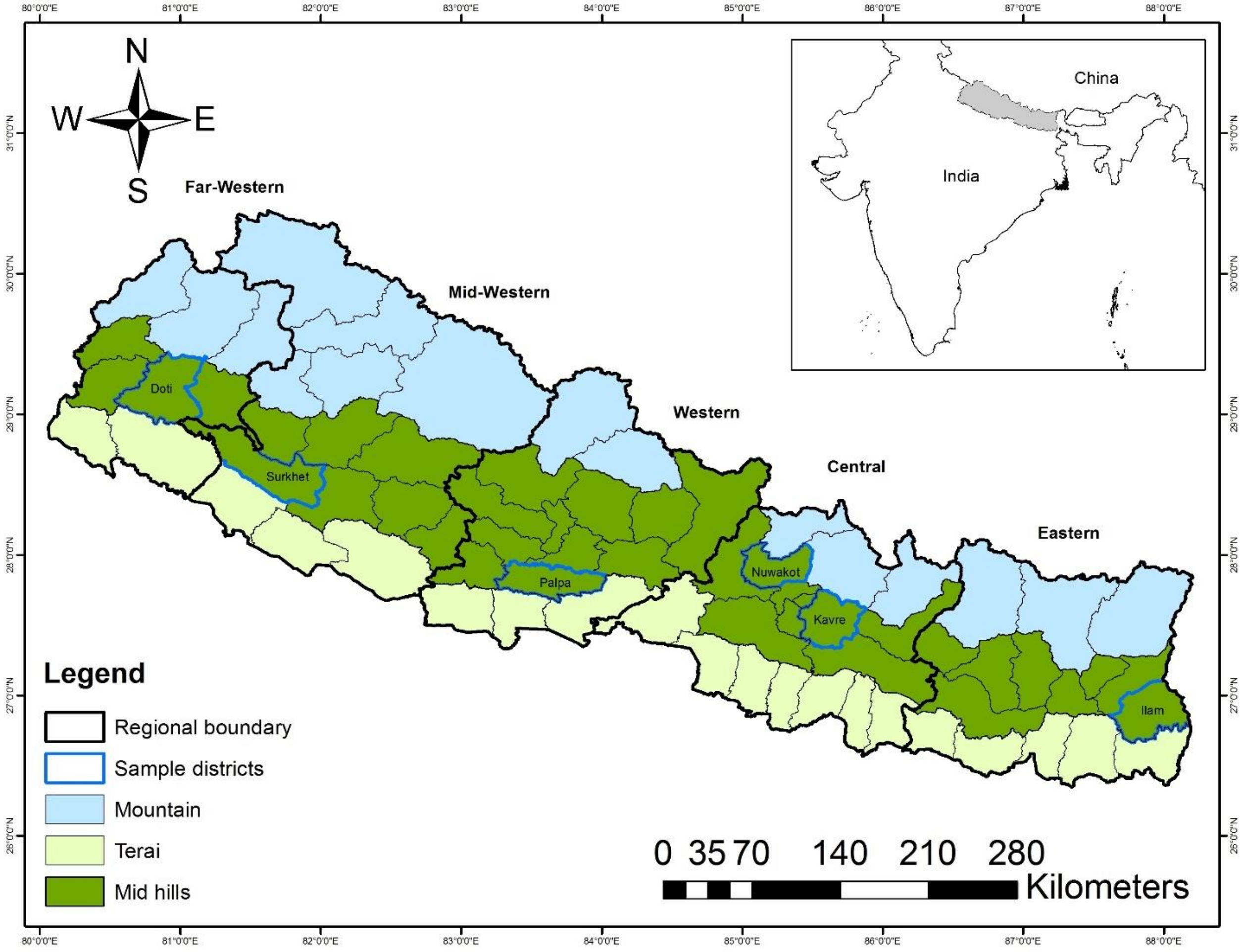


Table 1. Inputs, outputs, and outcome variables across sample households.

Outcome variables	Mean (Std. error) Full sample [N=731]	Adopters [N=311]	Non-adopters [N=420]	Difference, %
Hybrid maize adoption, dummy [1 = adopted on farm, 0 = not adopted]	0.43	1.00	0.00	
Material cost, in NPR/ha	39,041 (574)	43,726 (864)	35,572 (722)	+22.92***
Labor cost, in NPR/ha	27,261 (710)	30,572 (1,042)	24,809 (950)	+23.23***
Total variable cost, in NPR/ha	66,302 (1,118)	74,299 (1,686)	60,380 (1,426)	+23.05***
Maize productivity, in kg/ha	3,158 (76)	4,370 (122)	2,261 (69)	+93.31***
Gross revenue, in NPR/ha	76,860 (1,838)	10,3071 (3,123)	57,451 (1,670)	+79.41***
Gross margin, in NPR/ha	10,559 (1,848)	28,773 (3,177)	-2,930 (1,951)	NA; +***
Per capita food expenditure [PCFE], in NPR	11,416 (309)	13,093 (569)	10,175 (322)	+28.68***

Notes: ***: significantly different between adopter and non-adopter groups at 1% level. †The household inputs and cash paid for the labor are estimated from the dataset. Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019). NA: Not applicable.

Table 2. Selected socio-economic attributes of sample respondents.

Variables	Mean (std. error)			Difference, %
	Full sample [N=731]	Adopters [N=311]	Non-adopters [N=420]	
Farm size, in ha.	0.42	0.44	0.40	+8.83
	(0.01)	(0.02)	(0.02)	
Maize area, in ha.	0.26	0.27	0.25	+10.40**
	(0.01)	(0.01)	(0.01)	
Gender of household head, dummy [1 = male, 0 = female]	0.84	0.87	0.82	+5.38*
Household dependency ratio, [i.e., household size / economically active members]	1.58	1.56	1.59	–1.89
	(0.02)	(0.03)	(0.03)	
Caste of household, dummy [1 = socially non-marginalized, 0 = others]	0.54	0.61	0.50	+22.12***
Education of household head, in years in school	5.94	5.91	5.96	–0.96
	(0.16)	(0.24)	(0.21)	
On-farm labor wage rate, in NPR	635.51	651.30	623.81	+4.41*
	(7.64)	(11.30)	(10.30)	
Off-farm income, in ‘000 NPR/household	295.09	303.93	288.56	+5.33
	(9.97)	(19.01)	(10.17)	
Distance to the nearest input market from house, in km	7.88	5.67	9.53	–40.49***
	(0.30)	(0.34)	(0.43)	
NPK fertilizer applied, in kg/ha[†]	70.43	105.26	44.63	+135.84***
	(3.57)	(6.12)	(3.79)	
Perceived labor scarcity, dummy [1 = difficult, 0 = otherwise]	0.70	0.67	0.72	–6.54
House type, dummy [1 = concrete, 0 = others]	0.17	0.23	0.13	+80.91***
Duration of availability of hybrid maize seed with local input dealer (number of years)	3.92	4.07	3.80	+7.11**
	(0.05)	(0.07)	(0.08)	

Notes: For all the socio-economic variables included in the analyses, please see Appendix (Table A4). ***, **, and * indicate that the difference between adopters and non-adopters is significantly different at 1%, 5%, and 10% levels respectively. [†]NPK includes the amount of nitrogen, phosphorus, and potassium applied through different forms of fertilizers such as Urea, DAP, and Potash. Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019).

Table 3. Endogenous Switching Regression model estimates – the key findings.

Variables	Selection model$^{\#}$	Outcome models					
		On Productivity		On Profitability		On PCFE	
		Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Farm size, log	-0.069	-0.205***	-0.114**	-0.059	0.143***	0.239***	0.010
	(0.103)	(0.061)	(0.053)	(0.061)	(0.046)	(0.092)	(0.078)
Gender of household head	0.180	-0.101	0.039	-0.112	0.079	0.059	-0.102
	(0.162)	(0.084)	(0.075)	(0.083)	(0.065)	(0.126)	(0.111)
Caste of household	0.106	4E-04	0.083	0.041	0.002	0.223***	0.118
	(0.124)	(0.061)	(0.057)	(0.061)	(0.049)	(0.092)	(0.085)
Household dependency ratio	-0.078	-0.033	-0.014	-0.035	0.030	-0.137	-0.031
	(0.112)	(0.059)	(0.050)	(0.059)	(0.043)	(0.089)	(0.075)
Education of household head	0.006	0.004	-0.017***	0.014*	0.012*	-0.033**	-0.033***
	(0.017)	(0.008)	(0.009)	(0.008)	(0.007)	(0.012)	(0.013)
On-farm labor wage rate	9E-04**	-2E-04	-1E-04	-0.001***	-0.001***	0.001**	0.001***
	(4E-04)	(2E-04)	(2E-04)	(2E-04)	(2E-04)	(3E-04)	(3E-04)
Off-farm income, log	-0.021	-0.013	0.014	-0.014*	0.005	2E-04	0.018
	(0.019)	(0.008)	(0.010)	(0.008)	(0.009)	(0.013)	(0.016)
Distance to the nearest input market from house	-0.038***	-0.008	-0.010**	-0.014**	-0.002	0.012	0.001
	(0.011)	(0.007)	(0.005)	(0.007)	(0.004)	(0.010)	(0.008)
NPK fertilizer applied, log	0.085***	0.001	0.004	-0.020**	-0.020***	-0.013	0.033***
	(0.012)	(0.010)	(0.006)	(0.009)	(0.005)	(0.015)	(0.011)
Perceived labor scarcity	-0.218	-0.119*	-0.192***	-0.114	-0.062	-0.333***	-0.432***
	(0.138)	(0.069)	(0.064)	(0.068)	(0.055)	(0.103)	(0.096)
House type	0.378**	0.051	0.133	0.040	-0.021	0.142	0.244*
	(0.169)	(0.073)	(0.087)	(0.073)	(0.075)	(0.111)	(0.131)
Duration of availability of hybrid maize seed with local input dealer	0.138***						
	(0.042)						
Wald χ^2		237.22***		113.70***		302.950***	

Notes: For the complete set of ESR estimates, please see Appendix Tables A5-A7. ***, **, and * indicate that coefficients are significantly different at 1%, 5%, and 10% levels respectively. Standard errors of coefficients in parentheses. $^{\#}$This particular selection model is taken from ESR model on maize productivity. The selection model estimated with other outcomes are slightly different.

Table 4. Effects of hybrid maize adoption, OLS and ESR estimates.

Outcome variables	OLS coefficient of hybrid maize adoption (Std. error)	Sub-samples in ESR [effect type]	Mean values (Std. errors) in NPR, across decision stages in ESR		Average treatment effect in ESR	
			Adopt	Not to adopt	Magnitude	% effect
Maize productivity, in kg/ha.	0.522***	Adopters [ATT]	4,054	1,939	2,115***	+109.08
	(0.045)		(80)	(39)	(64)	
		Non-adopters [ATU]	3,327	1,999	1,327***	+66.38
	ME: +74%		(87)	(31)	(70)	
		Heterogeneity effects [TH]	728	-60		
			(122)	(50)		
Gross margin, in NPR/ha.	0.291***	Adopters [ATT]	19,729	-19,610	39,340***	NA, +
	(0.042)		(1,804)	(1,210)	(1,501)	
		Non-adopters [ATU]	5,690	-8,399	14,089***	NA, +
	ME: +34%		(1,816)	(1,300)	(1,932)	
		Heterogeneity effects [TH]	14,040	-11,211		
			(2,619)	(1,835)		
PCFE, in NPR	0.129*	Adopters [ATT]	11,651	9,669	1,982***	+20.50
	(0.069)		(419)	(392)	(368)	
		Non-adopters [ATU]	14,323	8,750	5,572***	+63.68
	ME: +14%		(626)	(304)	(628)	
		Heterogeneity effects [TH]	-2,672	919		
			(812)	(489)		

Notes: *** Statistically significant at 1% level. ATT stands for average treatment effect on the treated, ATU for average treatment effect on the untreated, and TH for heterogeneity effects. ME stands for the marginal effect, which was computed as 100*[exp (Coefficient)-1], following Giles (2011). Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019). The full ESR and OLS models associated with the estimates are shown in Appendix Tables A5-A7.

Table 5. Effects of hybrid maize adoption, using Inverse Probability Weighted Regression (IPWR) Adjusted method.

Outcome variables	Average treatment effect on the treated (Std. error)	% deviation of ESR estimates from IPWR estimates[#]
Maize productivity, in kg/ha.	1,586*** (176)	+25.01
Gross margin, in NPR/ha.	25,972*** (4,735)	+33.98
PCFE, in NPR	1,747*** (575)	+11.86
Other control variables	Yes	
Number of observations	731	

Notes: *** Statistically significant at 1% level. Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019). [#]Estimated as [(ESR estimates – IPWR estimates) / ESR estimates] *100.

Table 6. Heterogeneous effects of hybrid maize adoption across farm size quartiles.

	Average treatment effects (Std. error)		
Farm size quartiles [range in ha.]	Maize productivity, in kg/ha	Gross margin, in NPR/ha	PCFE, in NPR
ATT			
First quartile [≤0.2 ha.]	2,553***	48,076***	499
	(187)	(3,766)	(967)
Second quartile [0.2 – 0.3 ha.]	2,582***	50,175***	651
	(133)	(2,863)	(666)
Third quartile [0.3 – 0.5 ha.]	2,006***	38,651***	2,902***
	(94)	(2,469)	(549)
Fourth quartile [>0.5 ha.]	1,581***	25,206***	2,749***
	(97)	(2,335)	(825)
ATU			
First quartile [≤0.2 ha.]	2,123***	32,778***	434
	(140)	(3,547)	(795)
Second quartile [0.2 – 0.3 ha.]	1,505***	12,811***	5,582***
	(155)	(3,155)	(1,125)
Third quartile [0.3 – 0.5 ha.]	1,174***	12,513***	6,278***
	(101)	(3,116)	(877)
Fourth quartile [>0.5 ha.]	519***	-3,120	10,093***
	(143)	(5,266)	(2,274)

Notes: *** Statistically significant at 1% level. ATT stands for average treatment effect on the treated, and ATU for average treatment effect on the untreated. Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019).

Table 7. Heterogeneous effects of hybrid maize adoption across farm sizes and market access.

Farm size categories with market access		Average treatment effect (Std. error)		
		Maize productivity, in kg/ha	Gross margin, in NPR/ha	PCFE, in NPR
ATT				
Small farms	low market access	2,740***	44,121***	1,057
[≤0.3 ha]	[>4.0 km distance]	(156)	(2,961)	(777)
	high market access	2,395***	54,130***	93
	[<4.0 km distance]	(166)	(3,577)	(876)
Large farms	low market access	1,825***	37,345***	2,851***
[>0.3 ha]	[>4.0 km distance]	(85)	(2,306)	(417)
	high market access	1,867***	24,929***	2,823**
	[<4.0 km distance]	(123)	(2,579)	(1,151)
ATU				
Small farms	low market access	1,927***	21,824***	4,144***
[≤0.3 ha]	[>4.0 km distance]	(122)	(2,833)	(904)
	high market access	1,561***	25,705***	130
	[<4.0 km distance]	(211)	(5,061)	(930)
Large farms	low market access	756***	9,207**	5,958***
[>0.3 ha]	[>4.0 km distance]	(113)	(3,945)	(1,076)
	high market access	1,240***	5,611	9,396***
	[<4.0 km distance]	(124)	(3,678)	(1,616)

Notes: ***,** Statistically significant at 1% and 5% levels, respectively. ATT stands for the average treatment effect on the treated, and ATU for the average treatment effect on the untreated. Exchange rate 1 US$ = NPR 104, during the survey year 2017 (NRB, 2019).

Intensification under input constraints: Estimating the heterogenous effects of hybrid maize adoption in Nepal

Appendix

Supplementary Tables

Table A1. Maize area and hybrids area share in the study areas.

Districts	Total maize area [ha.]	Hybrid maize area[†] [ha.]	Name of the popular hybrid maize varieties[††]
Doti	3,502	310	TX-369, Bioseed 9220, Rajkumar, Nutan, Khumal hybrid-2, KYM-33, KYM-35
Surkhet	15,251	480	TX-369, Bioseed 9220, Rajkumar, Nutan, Khumal hybrid-2, KYM-33, KYM-35
Palpa	21,583	960	TX-369, Bioseed 9220, Rajkumar, Nutan, Khumal hybrid-2, KYM-33, KYM-35
Nuwakot	20,450	2,100	Bio 9621, DKC 7074, Bisco 940, Godavari 989, Early-2, Khumal hybrid-2, KYM-33, KYM-35
Kavre	25,354	2,600	Bio 9621, DKC 7074, Bisco 940, Godavari 989, Early-2, Khumal hybrid-2, KYM-33, KYM-35
Illam	31,395	620	C-1921, Godavari 989, Early-2, KYM-33, KYM-35
Total	117,535	7,070	
% area under hybrid maize cultivation	–	6.02	

Source: [†]Agriculture Knowledge Centers of Government of Nepal. [††]Varieties registered by the Seed Quality Control Section (SQCC), Government of Nepal. However, there might be several other unregistered varieties grown by the farmers buying from the Indian bordering districts due to the porous borders.

Table A2. Validity test for selection instrument.

Variables	Dependent variable (1=hybrid maize adoption)	Maize productivity among non-adopters, in kg/ha.	Gross margin among non-adopters, in NPR/ha.	Per capita food expenditure among non-adopters, in NPR
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Constant	–0.505*** (0.137)	2185.78*** (177.21)	–14147.52*** (4946.34)	10596.05*** (823.10)
Duration of availability of hybrid maize seed with local input dealer [No. of years]	0.081*** (0.033)	19.71 (42.87)	2950.22*** (1196.73)	–110.79 (199.14)
Wald test on instrumental variable	LR – χ^2 = 6.16	F-stat = 0.21	F-stat = 6.08	F-stat = 0.31
Number of observations	731	420	420	420

***Significant at 1% level. Exchange rate US$ 1=NPR 104 during the survey year 2017 (NRB, 2019).

Table A3. Enterprise budgets and welfare indicators for hybrid maize adopters and non-adopters in the mid-hills of Nepal.

Variables	Mean (Std. error) Full sample [N=731]	Adopters [N=311]	Non-adopters [N=420]	Difference, %
Inputs				
Land preparation cost, in NPR/ha	17030.28 (311.92)	15815.30 (417.69)	17929.94 (441.48)	–11.79***
Seed cost, in NPR/ha	4681.01 (188.38)	8665.06 (274.42)	1730.90 (132.40)	+400.61***
Fertilizer cost, in NPR/ha	4573.28 (233.73)	6807.95 (405.08)	2918.57 (245.77)	+133.26***
Labor cost in NPR/ha	27260.79 (710.39)	30572.27 (1041.51)	24808.72 (949.88)	+23.23***
Other cost, in NPR/ha	12756.47 (316.80)	12438.05 (470.01)	12992.24 (427.77)	–4.27
Material cost, in NPR/ha	39041.04 (573.81)	43726.37 (864.12)	35571.66 (722.37)	+22.92***
Total variable cost, in NPR/ha	66301.83 (1117.90)	74298.64 (1686.34)	60380.38 (1426.49)	+23.05***
Outputs				
Maize productivity, in kg/ha	3158.23 (75.80)	4370.25 (121.52)	2260.76 (69.40)	+93.31***
Gross revenue, in NPR/ha	76859.72 (1838.24)	103071.20 (3123.25)	57450.73 (1670.12)	+79.41***
Gross margin, in NPR/ha †	10557.89 (1847.95)	28772.57 (3176.92)	-2929.66 (1950.73)	NA; +***
Gross margin, in NPR/household	3382.24 (569.50)	7696.49 (963.95)	187.64 (645.78)	+4001.73***
Welfare indicator				
Per capita food expenditure [PCFE], in NPR	11416.22 (309.06)	13092.75 (568.50)	10174.78 (322.40)	+28.68***

***, **, and * indicate that the difference between adopters and non-adopters is significantly different at 1%, 5%, and 10% levels respectively. †The household inputs and cash paid for the labor were estimated from the dataset. Exchange rate US$ 1 = NPR 104 during the survey year 2017 (NRB, 2019).

Table A4. Household-level socioeconomic attributes of hybrid maize adopters and non-adopters in the mid-hills of Nepal.

Variables	Mean (Std. error)			Difference, %
	Full sample [N=731]	Adopters [N=311]	Non-adopters [N=420]	
Farm size, in ha.	0.42 (0.01)	0.44 (0.02)	0.40 (0.02)	+8.83
Maize area, in ha.	0.26 (0.01)	0.27 (0.01)	0.25 (0.01)	+10.40**
Age of household head, in years	48.77 (0.40)	49.16 (0.62)	48.47 (0.52)	+1.42
Gender of household head, dummy [1=male, 0=female]	0.84	0.87	0.82	+5.38*
Household size, in numbers	5.69 (0.08)	5.65 (0.11)	5.73 (0.11)	–1.34
Household dependency ratio, [i.e., household size/economically active members]	1.58 (0.02)	1.56 (0.03)	1.59 (0.03)	–1.89
Caste of household, dummy [1=non-marginalized caste, 0=others]	0.54	0.61	0.50	+22.12***
Education of household head, in years	5.94 (0.16)	5.91 (0.24)	5.96 (0.21)	–0.96
Years of farming experience, in years	25.85 (0.43)	26.65 (0.68)	25.26 (0.55)	+5.51*
Occupation of household head, dummy [1=farming, 0=others]	0.59	0.59	0.59	–0.09
Credit access, dummy [1=yes, 0=no]	0.97	0.97	0.97	+0.54
On-farm labor wage rate, in NPR	635.51 (7.64)	651.30 (11.30)	623.81 (10.30)	+4.41*
Off-farm income, in ‘000 NPR/household	295.09 (9.97)	303.93 (19.01)	288.56 (10.17)	+5.33
Distance to the nearest input market from house, in km	7.88 (0.30)	5.67 (0.34)	9.53 (0.43)	–40.49***
NPK mineral fertilizer applied, in kg/ha[†]	70.43 (3.57)	105.26 (6.12)	44.63 (3.79)	+135.84***
Farmyard manure application, dummy [1=yes, 0=no]	0.93	0.93	0.93	-0.78
Number of migrated members, in numbers	0.34	0.32	0.36	–12.04
Membership in groups or cooperatives, dummy [1=yes, 0=no]	0.69	0.70	0.69	+1.87
Perceived labor scarcity, dummy [1 = difficult, 0 = otherwise]	0.70	0.67	0.72	–6.54
Number of livestock holdings, in TLU[#]	2.08 (0.05)	2.10 (0.07)	2.06 (0.06)	+2.26
Draft animal availability, dummy [1=difficult, 0=easy]	0.27	0.39	0.18	+116.79***
Use mechanized tillage, dummy [1=yes, 0=no]	0.37	0.50	0.27	+83.62***

Variables	Mean (Std. error)			Difference, %
	Full sample [N=731]	Adopters [N=311]	Non-adopters [N=420]	
House type, dummy [1=concrete, 0=others]	0.17	0.23	0.13	+80.91***
Own mobile phone, dummy [1=yes, 0=no]	0.95	0.96	0.95	+1.12
Own television, dummy [1=yes, 0=no]	0.93	0.94	0.91	+3.04
Own irrigation pumps, dummy [1=yes, 0=no]	0.30	0.29	0.30	–6.10
Household’s access to electricity	0.99	0.99	0.98	+0.80
Household’s access to piped drinking water, dummy [1=yes, 0=no]	0.92	0.90	0.93	–3.54*
Grow rice, dummy [1=yes, 0=no]	0.57	0.55	0.58	–4.80
Grow wheat, dummy [1=yes, 0=no]	0.33	0.34	0.32	+7.04
Grow vegetables, dummy [1=yes, 0=no]	0.36	0.42	0.31	+36.09***
Farms located in eastern hills, dummy [1=yes, 0=otherwise]	0.08	0.01	0.13	–99.22***
Farms located in central hills, dummy [1=yes, 0=otherwise]	0.67	0.78	0.59	+32.34***
Farm located in mid-west hills, dummy [1=yes, 0=no]	0.06	0.02	0.09	–81.24***
Farms located in far-west hills, dummy [1=yes,0=no]	0.01	0.01	0.01	–54.98
Duration of availability of hybrid maize seed with local input dealer, in number of years	3.92 (0.05)	4.07 (0.07)	3.80 (0.08)	+7.06**

***, **, and * indicate that the difference between adopters and non-adopters is significantly different at 1%, 5%, and 10% levels respectively. Exchange rate US$ 1= NPR 104 during the survey year 2017 (NRB, 2019). †NPK includes the amount of nitrogen, phosphorus, and potassium applied through different forms of fertilizers such as Urea, DAP, and Potash. #TLU stands for tropical livestock units (Pica-ciamarra et al., 2007).

Table A5. OLS and endogenous switching regression models for hybrid maize adoption and impact on maize productivity: Full model.

Variables	OLS	Endogenous switching regression		
	Maize productivity, in kg/ha, log	Selection model	Maize productivity, in kg/ha, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Hybrid maize adoption, dummy [1 = adopted on farm, 0 = not adopted]	0.522***	–	–	–
	(0.045)			
Farm size, log	-0.136***	-0.069	-0.205***	-0.114**
	(0.036)	(0.103)	(0.061)	(0.053)
Farm size squared	0.014	0.160***	0.085	0.006
	(0.019)	(0.056)	(0.068)	(0.039)
Age of household head	0.020	-0.004	0.028	0.024
	(0.015)	(0.042)	(0.019)	(0.023)
Age squared	-3E-04*	-2E-04	-3E-04	-3E-04
	(1E-04)	(4E-04)	(2E-04)	(2E-04)
Gender of household head	-0.022	0.180	-0.101	0.039
	(0.058)	(0.162)	(0.084)	(0.075)
Caste of household	0.051	0.106	4E-04	0.083
	(0.043)	(0.124)	(0.061)	(0.057)
Household size	0.002	-0.023	-0.009	-0.008
	(0.012)	(0.034)	(0.018)	(0.016)
Household dependency ratio	-0.026	-0.078	-0.033	-0.014
	(0.039)	(0.112)	(0.059)	(0.050)
Education of household head	-0.006	0.006	0.004	-0.017***
	(0.006)	(0.017)	(0.008)	(0.009)
Years of farming experience	0.004	0.016*	-2E-05	0.004
	(0.003)	(0.009)	(0.005)	(0.005)
Occupation of household head	-0.026	-0.046	-0.080	0.036
	(0.044)	(0.125)	(0.060)	(0.059)
Credit access	-0.057	0.124	-0.282*	0.112
	(0.120)	(0.331)	(0.174)	(0.156)
On-farm labor wage rate	-4E-05	9E-04**	-2E-04	-1E-04
	(1E-04)	(4E-04)	(2E-04)	(2E-04)
Off-farm income, log	-0.001	-0.021	-0.013	0.014
	(0.007)	(0.019)	(0.008)	(0.010)
Distance to the nearest input market from house	-0.013***	-0.038***	-0.008	-0.010**
	(0.004)	(0.011)	(0.007)	(0.005)
NPK fertilizer applied, log	0.006	0.085***	0.001	0.004
	(0.004)	(0.012)	(0.010)	(0.006)
Farmyard manure application	-0.208**	-0.255	0.080	-0.410***
	(0.086)	(0.262)	(0.123)	(0.120)
Number of migrated members	0.017	0.102	0.061	0.006
	(0.037)	(0.105)	(0.048)	(0.052)
Membership in groups or cooperatives	-0.049	-0.108	0.010	-0.120*
	(0.048)	(0.139)	(0.069)	(0.065)
Perceived labor scarcity	-0.160	-0.218	-0.119*	-0.192***
	(0.047)	(0.138)	(0.069)	(0.064)
Number of livestock holdings	0.040***	0.019	0.031	0.041**
	(0.016)	(0.050)	(0.025)	(0.021)
Draft animal availability	-0.041**	0.329***	-0.073	-0.020
	(0.049)	(0.136)	(0.066)	(0.073)

Variables	OLS	Endogenous switching regression		
	Maize productivity, in kg/ha, log	Selection model	Maize productivity, in kg/ha, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Use mechanized tillage	0.024 (0.057)	0.296* (0.168)	0.057 (0.089)	0.002 (0.075)
House type	0.065 (0.057)	0.378** (0.169)	0.051 (0.073)	0.133 (0.087)
Own mobile phone	-0.085 (0.093)	-0.021 (0.262)	-0.131 (0.136)	0.020 (0.122)
Own television	-0.197** (0.089)	-0.046 (0.250)	-0.237* (0.139)	-0.069 (0.114)
Own pumps	-0.038 (0.048)	-0.210 (0.143)	-0.013 (0.068)	-0.038 (0.065)
Household’s access to electricity	0.068 (0.200)	0.256 (0.636)	-0.057 (0.386)	-0.064 (0.234)
Household’s access to piped drinking water	0.291*** (0.079)	0.232 (0.218)	0.423*** (0.100)	0.121 (0.114)
Grow rice	-0.010 (0.048)	-0.269** (0.140)	0.074 (0.073)	0.014 (0.066)
Grow wheat	0.059 (0.045)	-0.100 (0.127)	0.088 (0.060)	0.021 (0.063)
Grow vegetables	-0.092** (0.047)	0.020 (0.134)	-0.095 (0.066)	-0.072 (0.065)
Farms located in eastern hills[#]	0.249*** (0.095)	-2.671*** (0.782)	-1.652 (1.589)	0.343*** (0.126)
Farms located in central hills	0.686*** (0.065)	0.106 (0.175)	0.877*** (0.086)	0.643*** (0.091)
Farms located in mid-west hills	-0.131 (0.104)	-1.043*** (0.317)	-0.008 (0.256)	-0.109 (0.131)
Farms located in far-west hills	-0.085 (0.222)	-0.298 (0.649)	0.053 (0.421)	-0.089 (0.264)
Duration of availability of hybrid maize seed with local input dealer		0.138*** (0.042)		
Constant	7.016*** (0.479)	-0.799 (1.424)	7.251*** (0.716)	6.984*** (0.670)
F-stat	17.00***			
R-squared	0.476			
$\text{Ln}\sigma_1$			-0.829*** (0.040)	
$\rho_{1\mu}$			0.010 (0.309)	
$\text{Ln}\sigma_0$				-0.665*** (0.043)
$\rho_{0\mu}$				-0.326* (0.200)
Wald - χ^2			237.22***	
Log-likelihood			-850.17	
No of observations	731	731	311	420

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level. Exchange rate US$ 1=NPR 104 during the survey year 2017 (NRB, 2019). [#]Western hills is the base category.

Table A6. OLS and endogenous switching regression models for hybrid maize adoption and impact on gross margin. Full model.

Variables	OLS	Endogenous switching regression		
	Gross margin, in NPR/ha, log	Selection model	Gross margin, in NPR/ha, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Hybrid maize adoption, dummy [1 = adopted on farm, 0 = not adopted]	0.291*** (0.042)	–	–	–
Farm size, log	0.049 (0.034)	-0.067 (0.103)	-0.059 (0.061)	0.143*** (0.046
Farm size squared	-0.032* (0.018)	0.158*** (0.057)	0.019 (0.067)	-0.057* (0.034)
Age of household head	0.024* (0.014)	-0.010 (0.042)	0.029 (0.019)	0.017 (0.020)
Age squared	-2E-04* (1E-04)	-1E-04 (4E-04)	-3E-04 (2E-04)	-2E-04 (2E-04)
Gender of household head	0.005 (0.053)	0.177 (0.163)	-0.112 (0.083)	0.079 (0.065)
Caste of household	0.014 (0.039)	0.095 (0.124)	0.041 (0.061)	0.002 (0.049)
Household size	-0.013 (0.011)	-0.021 (0.034)	-0.020 (0.018)	-0.014 (0.014)
Household dependency ratio	0.001 (0.036)	-0.076 (0.112)	-0.035 (0.059)	0.030 (0.043)
Education of household head	0.013** (0.006)	0.003 (0.017)	0.014* (0.008)	0.012* (0.007)
Years of farming experience	0.001 (0.003)	0.017* (0.009)	0.001 (0.005)	-1E-04 (0.004)
Occupation of household head	-0.078** (0.040)	-0.047 (0.125)	-0.139** (0.060)	-0.041 (0.051)
Credit access	-0.124 (0.110)	0.132 (0.332)	-0.340** (0.173)	-0.035 (0.136)
On-farm labor wage rate	-0.001*** (1E-04)	0.001** (4E-04)	-0.001*** (2E-04)	-0.001*** (2E-04)
Off-farm income, log	-0.004 (0.006)	-0.021 (0.020)	-0.014* (0.008)	0.005 (0.009)
Distance to the nearest input market from house	-0.008** (0.003)	-0.041*** (0.011)	-0.014** (0.007)	-0.002 (0.004)
NPK fertilizer applied, log	-0.020*** (0.004)	0.085*** (0.012)	-0.020** (0.009)	-0.020*** (0.005)
Farmyard manure application	-0.098 (0.079)	-0.263 (0.261)	0.096 (0.122)	-0.195* (0.104)
Number of migrated members	0.022 (0.034)	0.089 (0.104)	0.040 (0.048)	0.037 (0.045)
Membership in groups or cooperatives	0.104** (0.045)	-0.089 (0.139)	0.075 (0.069)	0.080 (0.056)
Perceived labor scarcity	-0.083* (0.044)	-0.234* (0.138)	-0.114 (0.068)	-0.062 (0.055)
Number of livestock holdings	0.018 (0.015)	0.012 (0.050)	0.035 (0.024)	0.005 (0.018)
Draft animal availability	0.010 (0.045)	0.329** (0.137)	-0.016* (0.066)	0.033 (0.062)

Variables	OLS	Endogenous switching regression		
	Gross margin, in NPR/ha, log	Selection model	Gross margin, in NPR/ha, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Use mechanized tillage	0.093* (0.052)	0.267 (0.167)	0.144* (0.088)	0.062 (0.065)
House type	-0.015 (0.052)	0.385** (0.168)	0.040 (0.073)	-0.021 (0.075)
Own mobile phone	-0.030 (0.086)	-0.004 (0.263)	-0.183 (0.135)	0.041 (0.106)
Own television	-0.094 (0.082)	-0.058 (0.249)	0.014 (0.138)	-0.064 (0.099)
Own pumps	0.065 (0.044)	-0.191 (0.143)	0.025 (0.067)	0.101* (0.056)
Household's access to electricity	-0.072 (0.184)	0.319 (0.644)	-0.223 (0.383)	-0.059 (0.202)
Household's access to piped drinking water	0.036 (0.072)	0.232 (0.218)	0.120 (0.099)	-0.087 (0.099)
Grow rice	-0.045 (0.044)	-0.270* (0.141)	0.003 (0.073)	-0.069 (0.056)
Grow wheat	-0.024 (0.042)	-0.092 (0.126)	0.018 (0.059)	-0.058 (0.055)
Grow vegetables	-0.060 (0.044)	0.027 (0.134)	-0.151** (0.066)	-0.022 (0.057)
Farms located in eastern hills$^{\#}$	-0.012 (0.087)	-2.680*** (0.798)	-0.793 (1.577)	-0.099 (0.102)
Farms located in central hills	0.171* (0.060)	0.089 (0.174)	0.376*** (0.086)	0.062 (0.079)
Farms located in mid-west hills	0.070 (0.095)	-1.034*** (0.320)	0.351 (0.253)	-0.019 (0.110)
Farms located in far-west hills	-1.350*** (0.204)	-0.316 (0.645)	-0.232 (0.418)	-1.771*** (0.228)
Duration of availability of hybrid maize seed with local input dealer		0.136*** (0.043)		
Constant	11.620*** (0.441)	-0.690 (1.428)	11.822*** (0.709)	11.857*** (0.579)
F-stat	8.520***			
R-squared	0.313			
Lnσ_1			-0.836*** (0.042)	
$\rho_{1\mu}$			0.068 (0.311)	
Lnσ_0				-0.814*** (0.036)
$\rho_{0\mu}$				-0.175 (0.121)
Wald - χ^2			113.70***	
Log-likelihood			-791.577	
No of observations	731	731	311	420

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level. Exchange rate US$ 1=NPR 104 during the survey year 2017 (NRB, 2019). $^{\#}$Western hills is the base category.

Table A7. OLS and endogenous switching regression models for hybrid maize adoption and impact on per capita food expenditure (PCFE). Full model.

Variables	OLS	Endogenous switching regression		
	PCFE, in NPR, log	Selection model	PCFE, in NPR, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Hybrid maize adoption, dummy [1 = adopted on farm, 0 = not adopted]	0.129*	–	–	–
	(0.069)			
Farm size, log	0.091*	-0.079	0.239***	0.010
	(0.055)	(0.104)	(0.092)	(0.078)
Farm size squared	0.024	0.160***	-0.071	0.077
	(0.029)	(0.057)	(0.102)	(0.059)
Age of household head	-0.075***	-0.007	-0.053*	-0.073**
	(0.023)	(0.042)	(0.028)	(0.034)
Age squared	5E-04**	-1E-04	4E-04	4E-04
	(2E-04)	(4E-04)	(3E-04)	(3E-04)
Gender of household head	-0.064	0.164	0.059	-0.102
	(0.088)	(0.163)	(0.126)	(0.111)
Caste of household	0.173***	0.100	0.223***	0.118
	(0.065)	(0.124)	(0.092)	(0.085)
Household size	0.006	-0.020	0.028	-0.012
	(0.018)	(0.034)	(0.027)	(0.024)
Household dependency ratio	-0.065	-0.080	-0.137	-0.031
	(0.059)	(0.112)	(0.089)	(0.075)
Education of household head	-0.037***	0.002	-0.033**	-0.033***
	(0.009)	(0.017)	(0.012)	(0.013)
Years of farming experience	0.013***	0.017*	0.002	0.017**
	(0.005)	(0.009)	(0.007)	(0.007)
Occupation of household head	0.024	-0.051	0.088	0.003
	(0.066)	(0.125)	(0.091)	(0.087)
Credit access	-0.123	0.130	-0.221	-0.101
	(0.183)	(0.333)	(0.261)	(0.232)
On-farm labor wage rate	0.001***	0.001**	0.001**	0.001***
	(2E-04)	(4E-04)	(3E-04)	(3E-04)
Off-farm income, log	0.003	-0.021	2E-04	0.018
	(0.010)	(0.020)	(0.013)	(0.016)
Distance to the nearest input market from house	0.008	-0.041***	0.012	0.001
	(0.006)	(0.011)	(0.010)	(0.008)
NPK fertilizer applied, log	0.026***	0.084***	-0.013	0.033***
	(0.006)	(0.012)	(0.015)	(0.011)
Farmyard manure application	-0.507***	-0.262	-0.322*	-0.526***
	(0.131)	(0.260)	(0.185)	(0.179)
Number of migrated members	-0.111**	0.083	-0.083	-0.147*
	(0.056)	(0.104)	(0.072)	(0.078)
Membership in groups or cooperatives	-0.202***	-0.087	-0.195*	-0.176*
	(0.074)	(0.138)	(0.104)	(0.096)
Perceived labor scarcity	-0.424***	-0.230*	-0.333***	-0.432***
	(0.072)	(0.138)	(0.103)	(0.096)
Number of livestock holdings	0.049**	0.011	-0.033	0.093***
	(0.025)	(0.050)	(0.037)	(0.031)
Draft animal availability	0.095	0.330***	0.277***	-0.168
	(0.074)	(0.136)	(0.100)	(0.110)

	OLS	Endogenous switching regression		
Variables	PCFE, in NPR, log	Selection model	PCFE, in NPR, log	
			Adopters	Non-adopters
	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)	Coefficient (Std. error)
Use mechanized tillage	0.015 (0.087)	0.260 (0.167)	-0.140 (0.133)	0.087 (0.112)
House type	0.267*** (0.087)	0.385** (0.167)	0.142 (0.111)	0.244* (0.131)
Own mobile phone	-0.142 (0.142)	0.006 (0.262)	0.236 (0.204)	-0.239 (0.182)
Own television	-0.025 (0.136)	-0.064 (0.249)	-0.244 (0.208)	0.110 (0.169)
Own pumps	-0.192*** (0.073)	-0.191 (0.143)	-0.093 (0.102)	-0.273*** (0.097)
Household's access to electricity	-0.275 (0.304)	0.276 (0.650)	-0.427 (0.578)	-0.172 (0.347)
Household's access to piped drinking water	-0.311*** (0.120)	0.229 (0.217)	-0.313** (0.150)	-0.321* (0.170)
Grow rice	-0.827*** (0.073)	-0.266* (0.145)	-0.730*** (0.111)	-0.871*** (0.102)
Grow wheat	-0.091 (0.069)	-0.073 (0.127)	-0.009 (0.089)	-0.135 (0.094)
Grow vegetables	0.282*** (0.072)	0.037 (0.136)	0.611*** (0.099)	0.071 (0.097)
Farms located in eastern hills$^{\#}$	0.242* (0.144)	-2.700*** (0.809)	1.691 (2.383)	0.174* (0.205)
Farms located in central hills	-0.162* (0.098)	0.083 (0.174)	-0.018 (0.129)	-0.231 (0.136)
Farms located in mid-west hills	0.876*** (0.158)	-1.063*** (0.326)	0.272 (0.389)	1.023*** (0.203)
Farms located in far-west hills	-0.722** (0.338)	-0.302 (0.642)	-0.914 (0.631)	-0.740* (0.394)
Duration of availability of hybrid maize seed with local input dealer		0.127*** (0.045)		
Constant	12.798*** (0.729)	-0.704 (1.433)	12.364*** (1.074)	12.432*** (1.001)
F-stat	12.38***			
R-squared	0.398			
Lnσ_1			-0.426*** (0.040)	
$\rho_{1\mu}$			-0.015 (0.334)	
Lnσ_0				-0.280*** (0.035)
$\rho_{0\mu}$				-0.027 (0.260)
Wald - χ^2			302.950***	
Log-likelihood			-1147.121	
No of observations	731	731	311	420

***Significant at 1% level; **Significant at 5% level; *Significant at 10% level. Exchange rate US$ 1=NPR 104 during the survey year 2017 (NRB, 2019). $^{\#}$Western hills is the base category.

Supplementary Materials Text

Empirical framework

Let us assume that $\hat{Y}$ is the difference in net gain in the outcome variables between hybrid maize adopters and non-adopters, as described in section 3.2 (main text). Then, $\hat{Y} > 0$ implies that the adoption of hybrid maize is more beneficial to the farmer than non-adoption. However, $\hat{Y}$ cannot be observed directly, and can only be expressed as the function of observed farm-level socio-economic attributes in a latent model; it can be presented as:

$$\hat{Y} = \beta Z_i + \varepsilon_i, \qquad \begin{Bmatrix} \tau = 1, & if\ \hat{Y} > 0 \\ 0, & otherwise \end{Bmatrix} \tag{1}$$

Here, τ_i is a binary indicator variable that takes a value of 1 if household i adopts hybrid maize and 0 otherwise. β is the vector of parameters to be estimated, Z_i is a vector of farm-level socio-economic attributes that determine hybrid maize adoption, and ε_i is the error term that is assumed to be normally distributed. In the framework of Equation (1), described above, estimating the causal effect of hybrid adoption on outcome indicators, maize productivity, profitability, and PCFE is difficult in our case due to the likelihood of an endogeneity problem. In this regard, the use of the ordinary least squares (OLS) method to estimate the causal effect of technology adoption may provide biased estimates. Therefore, estimating the true causal effect of technology adoption requires controlling for observed and unobserved heterogeneity between technology adopters and non-adopters (Wooldridge, 2010).

Technology adopters and non-adopters may differ in their inherent individual skills and abilities. Failure to account for such unobserved and observed heterogeneity may bias parameter estimates and result in false inferences. In this study, we used an endogenous switching regression (ESR) to account for both sources of heterogeneity. To measure the causal effect of technology adoption using ESR, an instrument is required that affects outcome indicators, maize productivity, gross margin, and PCFE through hybrid maize adoption. Our instrument in this study is “number of years (duration) of availability of hybrid maize seed with local input dealers,” as described in section 3.2.

Given the conceptual framework described in Equation (1) and section 3.2, the outcome function, conditional on adoption, can be specified as an ESR framework in the following ways:

$$Regime1: \; Y_{1i} = f(HM, Z, \beta_1) + \varepsilon_{1i}, \qquad if\ \tau_i = 1 \tag{2}$$

$$Regime2: \; Y_{2i} = f(Z, \beta_2) + \varepsilon_{2i}, \qquad if\ \tau_i = 0 \tag{3}$$

Where Y_{1i} represents outcome indicators (maize productivity, gross margins (per ha. and per household) and PCFE) for hybrid maize adopters and Y_{2i} for non-adopters; ε_i is the error term of the outcome variables. The variable HM represents the adoption of hybrid maize, while Z represents a farmer’s household-level socio-economic attributes. β_1 and β_2 are the vectors of the parameters to be estimated that determines the maize productivity, gross margin per ha., gross margin per household, and PCFE for hybrid maize adopters and non-adopters, respectively. Finally, a dummy variable τ_i measures the adoption status ($\tau_i = 1$, implies that the farmer is a hybrid maize adopter). The error term in selection Equation (1) and in outcome equations (2) and (3) are assumed to have a trivariate normal distribution with mean zero and covariance matrix (Ω) in the following way:

$$\Omega = \begin{pmatrix} \sigma_\mu^2 & \sigma_{1\mu} & \sigma_{2\mu} \\ \sigma_{\mu 1} & \sigma_1^2 & . \\ \sigma_{\mu 2} & . & \sigma_2^2 \end{pmatrix}$$

where, $\sigma_\mu^2 = var(\mu_i), \sigma_1^2 = var(\varepsilon_1), \sigma_2^2 = var(\varepsilon_2), \sigma_{1\mu} = cov(\mu_i, \varepsilon_1), \sigma_{2\mu} = cov(\mu_i, \varepsilon_2)$. Further, σ_μ^2 is estimable up to a scale factor and can be assumed to have a value of 1 (Maddala, 1983). Additionally, if the correlation between the error term in the selection equation and the outcome equation is different from zero ($corr(\mu_i, \varepsilon_1) \neq 0$ and $corr(\mu_i, \varepsilon_2) \neq 0$), then it indicates the existence of selection bias (Lokshin and Sajaia, 2004). ESR addresses the selection bias by estimating the inverse Mills ratios (λ_{1i} *and* λ_{2i}) and the covariance terms ($\sigma_{1\mu}$ *and* $\sigma_{2\mu}$), and by including them in an auxiliary regression in equations (2) and (3). If $\sigma_{1\mu}$ *and* $\sigma_{2\mu}$ are significantly different from zero, then the absence of selection bias is rejected (Lokshin and Sajaia, 2004). The ESR model estimates can then be used to estimate treatment effects or the average treatment effect on the treated (ATT) households as:

$$E(Y_{1i}|\tau_i = 1) = f(HM, Z, \beta_1) + \lambda_{1i}\sigma_{1\mu} \qquad (4)$$

$$E(Y_{2i}|\tau_i = 0) = f(HM, Z, \beta_2) + \lambda_{2i}\sigma_{2\mu} \qquad (5)$$

$$E(Y_{2i}|\tau_i = 1) = f(HM, Z, \beta_2) + \lambda_{1i}\sigma_{2\mu} \qquad (6)$$

$$E(Y_{1i}|\tau_i = 0) = f(HM, Z, \beta_1) + \lambda_{2i}\sigma_{1\mu} \qquad (7)$$

The average treatment effect on the treated (ATT) is then defined as the difference between Equation (4) and Equation (6) and can be expressed as:

$$ATT = E(Y_{1i}|\tau_i = 1) - E(Y_{2i}|\tau_i = 1) \qquad (8)$$

Similarly, the average treatment effect on the untreated (ATU) for the households that did not adopt hybrid maize is the difference between equations (7) and (5). This captures the difference between the amount hybrid maize non-adopters would have benefited had they adopted and the observed maize productivity, gross margins, and PCFE they obtained without adoption. The ATU can then be presented as:

$$ATU = E(Y_{1i}|\tau_i = 0) - E(Y_{2i}|\tau_i = 0) \qquad (9)$$

Furthermore, following Di Falco et al. (2011), we also computed the heterogeneity effects using conditional expected outcomes in Equations (4) to (7). This is important since hybrid maize adopters may have different socio-economic attributes from non-adopters, even if they did not adopt hybrid maize, due to unobserved factors. For this purpose, a base heterogeneity effect (BH) is defined as the difference between Equations (4) and (7) for the hybrid maize adopters:

$$BH_1 = E(Y_{1i}|\tau_i = 1) - E(Y_{1i}|\tau_i = 0) \quad (10)$$

Similarly, the base heterogeneity effect for hybrid maize non-adopters is the difference between Equations (5) and (6) and can be expressed as:

$$BH_2 = E(Y_{2i}|\tau_i = 1) - E(Y_{2i}|\tau_i = 0) \quad (11)$$

Finally, the transitional heterogeneity is the difference between Equations (10) and (11) and can be represented as:

$$TH = BH_1 - BH_2 \quad (12)$$

References

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. Am. J. Agric. Econ. 93, 825–842.

Lokshin, M., Sajaia, Z., 2004. Maximum likelihood estimation of endogenous switching regression models. Stata J. 4, 282–289.

Maddala, G.S., 1983. Limited-dependent and qualitative variables in economics. Cambridge Cambridge Univ. Press. New York.

NRB, 2019. Nepal Rastra Bank 2019. Available at: https://www.nrb.org.np/fxmexchangerate.php. last accessed October 2019.

Pica-ciamarra, U., Otte, J., Chilonda, P., 2007. Livestock policies, land and rural conflicts in Sub-Saharan Africa. L. Reform 1, 19–33.

Wooldridge, J.M., 2010. Econometric analysis of cross section and panel data. MIT Press, Cambridge, MA.