Upgrade or Migrate: the Effects of Fertilizer Subsidies on Rural Productivity and Migration

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Rural development programs often emphasize investments in agriculture, but farmers may instead prefer to divest and leave. I explore how input subsidy programs facilitate structural transformation across two margins: agricultural upgrades and out-migration. First, I use a large-scale Zambian program to estimate a difference in differences and an instrumented difference in differences. I find that subsidies increased both fertilizer adoption (upgrades, +79%) and out-migration (+12%), and led to a 25% increase in income. Out-migration rose, funded by farmers re-selling subsidized inputs in the short term (+11%) and using income from productivity gains in the medium term (+14%). Second, I estimate a structural choice model that includes resale markets. The ISP paired with fertilizer resale markets outperforms alternative revenue-neutral counterfactual policies. Specifically, the ISP with resale increases migration out of agriculture more than an untargeted cash transfer. By contrast, a targeted cash transfer or an ISP without resale markets reduces migration and fertilizer use, slowing structural transformation. (**JEL:** R23, O33, Q12)

Rural areas are home to 80% of households living in extreme poverty.[1] Most of these households rely on farming as their primary source of income and lack the resources to migrate to areas with better economic prospects, or to upgrade their agricultural technology (Lagakos et al., 2023; Burke et al., 2019; Gollin et al., 2014).[2] Efforts to reduce poverty place a strong emphasis on enhancing agricultural productivity rather than encouraging migration. African states—and indeed many governments in all parts of the world—invest in rural areas by subsidizing inputs such as fertilizer, pesticides, and seeds, or by offering cash transfers. Although widespread, these input subsidy programs (ISPs) are controversial among economists because they could lead to an overuse of subsidized inputs or hinder productive out-migration, trapping individuals in rural areas. Despite an annual global investment of $540 billion[3] and making up 30% of agricultural budgets in Africa, ISPs are often assessed on their impacts on agriculture and omit ways in which they influence the movement of farmers out of agriculture—either into other areas or within rural areas—and thus accelerate the process of structural transformation.

This paper uses a large-scale Zambian ISP to understand the effects of anti-poverty programs on two of farmers' most productive investments: agricultural upgrading, proxied by the

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[1] From Castañeda et al. (2018), using 89 countries.

[2] See Harasty et al. (2015); Ghatak (2015); Balboni et al. (2022) for poverty traps.

[3] See Food and Agriculture Organization of the United Nations (2021) for world estimates.

adoption of fertilizer, and migration. Specifically I ask how a policy affecting one investment (upgrades) can relieve constraints affecting another (migration). I examine how households behave when facing a variety of linked investment opportunities. In doing so, I address the complexities of a practical policy problem: what policies can achieve a dual aim of improving agriculture outputs and alleviating rural poverty (Mason et al., 2013a). The Zambian ISP offers a unique opportunity to study these dynamics, as it enables us to observe how smallholders adjust their investments into agriculture or divest from it entirely in response to a large-scale, ongoing policy that began over two decades ago.[4]

The ISP in Zambia provides smallholders who are part of cooperatives with a limited number of vouchers at a 50% rebate to purchase fertilizer inputs.[5] In the early 2000s, the Zambian ISP represented 45% of the country's discretionary anti-poverty spending and about 20% of its agricultural budget (Mason et al., 2013a). Designed as an industrial policy, the Zambian ISP aimed to alleviate poverty in rural areas and increase food production in the country. Yet, by affecting farmers' income, the ISP could have impacts that extend beyond agriculture. For example, this income effect could influence farmers' migration decisions if it outweighs the higher opportunity cost of out-migration for ISP recipients. I explore the effects of the ISP on both agricultural upgrading and migration in three parts detailed below.

In the first part of the paper, I use a representative panel of Zambian smallholder farmers between 2000 and 2008 to estimate a difference in differences and test whether the ISP altered upgrading and migration decisions. To estimate the difference in differences, I exploit a natural experiment created by variations in the rollout of the policy over time and across space.

I find that the Zambian ISP had large direct impacts on agricultural productivity and indirect impacts on migration out of the areas that received the subsidy. Over the first four years, the ISP increased the share of households using fertilizer by 79%, leading to a 15% increase in yields. Surprisingly, the subsidy also increased the share of households divesting from agriculture, with an additional 4 percentage points (12%) increase in the number of households sending family members to migrate away from the areas with ISP over those years. These findings on out-migration are large, especially compared to Bryan et al. (2014) who find in Bangladesh that a subsidy designed to encourage out-migration during the lean season induces 22% of households to send out-migrants. I also find suggestive evidence of increased in-migration into areas that received the subsidy, as indicated by an increased probability of hosting members in the household. Overall, this transformation of the rural areas following the introduction of the ISP led to a 25% change in income

The effects of the ISP stem from various decisions that households make regarding their la-

[4]See the timeline of the ISP in Zambia since its start on Figure 1. The ISP's insights on individual responses are relevant for similar subsidies worldwide, such as India's fertilizer subsidies, the UK's fuel subsidy for farmers, and the EU's Common Agricultural Policy (40% of its budget).

[5]An estimated 8% of Zambia's smallholder farmers received the ISP in the 2003-2004 season compared to 56% in 2015 (Bwalya et al., 2015). Programs similar to the Zambian ISP are currently in place in a dozen African countries, making this analysis of relevance well beyond Zambia (Jayne et al., 2018).

bor allocation choices over time. In the short run, the following can occur: (i) ISP recipients can sell some (or all) of their vouchers to fund expenses such as migration, which aligns with the behavior of 45% of households in the sample; and (ii) farmers who did not receive the ISP can still purchase ISP-branded fertilizer through resale markets. Indeed, 3% to 5% of households that did not receive the subsidized vouchers in treated areas reported using fertilizer earmarked from the subsidy program; these figures likely represent a lower bound of the degree to which fertilizer transfers among farmers occur, largely because resales are officially prohibited. For households that invest all their vouchers in agriculture—i.e., choice (i)—earnings can increase in the medium run as they become more productive, thereby financing migration in later periods. 51% of households that received the subsidy and upgraded their technology without any out-migrants in 2004, had out-migrants by 2008, indicating a medium-term effect of investing in agricultural technology upgrades, to *in fine* invest in out-migration.

Both the subsidy's direct effects on agricultural upgrading and indirect effects on migration are consistent with four mechanisms, which I validate empirically. First, there is strong evidence of the existence of voucher resale markets, enabling ISP recipients to cash out their vouchers and migrate in the short run. I also find that these farmers in areas that receive the subsidy invest acquiring more productive assets—animals and machinery—and in the education of their children. Alternatively, farmers who choose to increase their investment in agriculture can purchase more fertilizer in these resale markets. Second, migration occurs both in the short and medium terms, implying that the ISP alleviates credit constraints for some farmers, leading to short-term migration, and that it boosts productivity for other farmers who can fund migration in the medium term after reaping the returns of their increased productivity. Specifically, 11% of households send migrants out within the year they receive the subsidy (i.e. extensive margin of outmigration in the short run), consistent with a relaxation of the credit constraint (Bryan et al., 2014; Ardington et al., 2009); 14% households send migrants out within four years of the introduction of the subsidy (i.e. extensive margin of outmigration in the medium term), consistent with structural change (Lewis et al., 1954; Gollin, 2014; Mazur and Tetenyi, 2024). Third, I document that farmers who received the vouchers—not their neighbors in treated areas—migrated at higher rates. Indeed, unlike cash-transfer programs that create inflation and price out non-recipients (Cunha et al., 2019), this ISP reduced fertilizer prices for ISP recipients and, through resale markets, also reduced the direct cost of upgrading for all farmers in treated villages. Fourth, there is suggestive evidence that specialization into upgrading and migration occurred both within and across households. That is, the comparatively more productive farmers stayed in ISP areas in the short run, and hosted in-migrants, and the farmers with the highest returns to migration left.

In the second part of the paper, I generalize the results from the natural experiment using a choice model that I estimate and compare with alternative policy counterfactuals. The model is static and incorporates key mechanisms highlighted in the first part of the paper. Specifically, I introduce resale markets that allow farmers to sell subsidized fertilizer to other farmers at a market price (World Bank, 2021; Mason and Jayne, 2013). Though these resale markets are often formally prohibited, governments typically lack the ability to enforce the prohibition. I endogenize the fertilizer resale price and account for the quantity of fertilizer made available through the ISP. Additionally, I incorporate a binding credit constraint that prevents farmers from borrowing against their migration income. Despite being static, the model captures out-migration occurring either immediately as a result of the relaxation of their credit constraint or in the medium run as a result of increased productivity. This feature of the model mimics my reduced-form findings, which are consistent with farmers migrating either as they become more productive over time or by monetizing their ISP vouchers in resale markets to relax their credit constraint. These implications of the model arise from the fact that farmers cannot borrow against future migration income but can use their agricultural surplus to fund migration. In this model, farmers with a binding credit constraint can use resale markets to generate enough liquidity to fund migration. By contrast, farmers who are most credit constrained may be better off funding their migration by first investing in improving the agricultural technology (by upgrading) and using the realized surplus in the medium run to migrate.

In the third part of the paper, I estimate the model using Maximum Likelihood and compare the effects of the current subsidy program with resale markets to three revenue-neutral counterfactual policies. I find that, due to documented frictions, an ISP with resale may be a preferred policy to increase both food production and income. The first counterfactual policy enforces the prohibition of resale markets; it reduces the number of households sending out-migrants (-4.71%) and substantially reduces the propensity to upgrade (-64.54%) because, under this scenario, one voucher pack can no longer be split across households. The second counterfactual policy provides cash to the 8% of households originally targeted by the subsidy; it results in both lower upgrade rates (-70.87%) and lower marginally outmigration rates (-5.32%). The third counterfactual policy is an untargeted cash transfer given to all farmers in treated areas; it decreases the extensive margin of out-migration (-5.32%) and has a large negative impact on the extensive margin of upgrades (-79.87%) compared to the baseline ISP with resale markets.

Assessing the overall welfare implications of these policies in an environment with market failures and externalities is complex. A back-of-the-envelope calculation suggests that the median and mean farming revenues are similar for the current ISP and the targeted cash-transfer program. Migration rates are statistically the same across counterfactual policies, but the type of ISP used in Zambia, with its (informal) resale potential, yields higher in-farm production. This result highlights the trade-off a planner faces between choosing an ISP with resale markets to increase available food for all Zambians and a cash-transfer program that leads to a small increase in income for treated villages.

In the model, an ISP with resale markets offers advantages over alternative counterfactuals through four channels. First, the increased availability of fertilizer because of the ISP leads to a reduction in fertilizer prices for all farmers in the treated villages, which is an advantage over the cash-transfer counterfactuals.[6] Second, like cash transfers, the existence of resale markets for vouchers under the baseline policy (ISP with resale) provides liquidity to ISP recipients, relaxing their credit constraints and allowing them to make optimal choices. Third, the ability to split vouchers among multiple farmers within a village creates a snowball effect for the upgrade of agricultural technology through resale markets, providing an advantage over an ISP that lacks resale markets. Finally, impacts of an ISP extend to the medium run, as they increase both the fertilizer availability and farm productivity for upgraders, resulting in an income effect that further influences households' migration decisions.[7]

This paper contributes to three strands of literature. First, I contribute to a large literature that explores drivers of migration and show that even when targeting agricultural upgrades, ISPs can have large impacts on migration. I show that migration occurs as farmers use the ISP to fund migration in two ways: in the short run through fertilizer resale markets or in the medium run by generating a surplus from using the subsidized inputs on their farms. Previous studies tested the presence of either productivity-induced or liquidity-induced migration, making it difficult to distinguish between short-term credit drivers of migration (Gazeaud et al., 2023; Cai, 2020; Bazzi, 2017; Angelucci, 2015)[8] and long-term improvements in technology that fund migration (Bustos et al., 2016; Gollin et al., 2014; Ngai and Pissarides, 2007; Lewis et al., 1954). I quantify the relevance of these two channels, first by using the natural experiment that allows me to decompose short- and medium-term migration, and then by shutting down different channels in the structural estimation of counterfactuals. I show that, although medium term structural change is important in explaining migration, credit constraints affecting decisions in the short run are nevertheless binding for many farmers.

Second, I contribute to the literature on anti-poverty programs in economically poor countries. I build on a literature on rural markets and explicitly model well-documented market frictions in these areas. I consider a set of market frictions—fixed costs—that lead the ISP to affect migration and upgrade margins at higher rates than previously found (Carter et al., 2021; Jayne et al., 2018; Schmitz et al., 1997). The structural estimates indicate that unconditional cash transfers may not be as efficient in achieving specific policy objectives such as increasing in agricultural productivity because they do not address the costs associated with upgrading. By contrast, an ISP with resale markets can efficiently reallocate transfers by sorting beneficiaries based on their constraints. In the early stages of Zambia's ISP, the large transfer of fertilizer was documented as being too large for many of the smaller landholders, leading to a snowball effect in which one transfer could benefit multiple farmers when recipients sold a portion of their vouchers. Despite previously documented inefficiencies of the ISP (Jayne and Rashid, 2013; Xu et al., 2009), I show that only ISPs with resale markets result in efficiency gains and higher levels of both upgrading and migration compared to cash-transfer programs.

[6] By contrast, Cunha et al. (2019) show an *increase* in prices as a result of a cash transfer.

[7] In the model, I consider only agriculture and migration as options for farmers; however, in reality, cash could be invested in productive activities such as business creation, which I do not capture in this estimation.

[8] Alfano and Görlach (2024) measure how different policies affect climate-adaptation induced migration.

Finally, I add important insights to a booming literature in public economics documenting the importance of adjustment markets that mitigate undesirable aspects of policies. In this paper, I document how an industrial, place-based policy that in partial equilibrium could lead unproductive farmers to remain trapped in agriculture can increase migration out of these areas. This phenomenon occurs when resale markets allow farmers to turn an ISP into cash to fund expensive migration. Essentially, farmers convert a voucher program (the ISP) into a convex combination of a cash-transfer program for those who cash out on resale markets and an in-kind transfer to those who do not. This finding is in line with findings from Banerjee et al. (2023) and Aker (2017), who have shown that when cash- or in-kind transfer programs are not designed to meet recipients' needs, recipients use rotating savings and credit associations (ROSCAs) and tradable goods to obtain the amount of cash and goods they need. I further find that resale-market mechanisms enable farmers with comparatively higher returns in non-agricultural activities to sell their subsidized vouchers to those with comparatively higher returns in fertilizer-intensive agriculture, thereby generating income to fund their migration. Resellers use private information unavailable to the central planner to sell their vouchers. Previous studies have shown that these resale markets are important, and that they emerge in settings where beneficiary types are unobservable to the planner and when efficiency improvements are possible by reallocating transfers (Giné et al., 2022; Ravallion, 2021; Gadenne et al., 2021). In the baseline scenario, the ISP can be interpreted as a small cash transfer to prospective migrants and as an in-kind transfer to those with a comparative advantage in upgrading in the short run.

The remainder of the paper proceeds as follows: Section 2 presents the Zambian context, the data, and the empirical strategy for the natural experiment. Section 3 presents the direct effects of the ISP on upgrading and the indirect effects on migration using the natural experiment. Section 4 discusses potential mechanisms that generate these results. Section 5 generalizes these findings with a selection model. In Section 6, I estimate the choice model, compare an ISP with resale markets to other anti-poverty policies, discuss optimal policies, and conclude.

2 Context, data, and natural experiment

In this section, I describe the relevant institutional details of the Zambian agricultural system, the panel of post-harvest surveys I use in the paper, and the estimation strategy for the natural experiment. I examine the effects of the ISP on farming households' decisions to upgrade their agricultural technologies and their decision to migrate or send members to migrate. I focus on migration because it represents the extreme case of divestment from agriculture and has less measurement error than the intensification of non-agricultural rural activities. I use the ISP as a source of exogenous variation in liquidity in the short run and agricultural productivity in the long run, to understand how households' labor allocation decisions change because of the ISP.

2.1 The Zambian fertilizer input subsidy program

In 2001, the Zambian agricultural sector contributed 16% to the country's GDP; the sector employed about 72% of the Zambian labor force, with remarkably low productivity levels (Ritchie and Roser, 2020; Govereh et al., 2009). In response to low fertilizer take-up, the Zambian government, along with a dozen other African countries, pledged to increase the use of fertilizer and set up farmers' cooperatives (Jayne et al., 2018).

In the 2002-2003 agricultural season, Zambia launched the Fertilizer Support Program (FSP) aimed at increasing fertilizer use in the production of maize.[9] In its early years, the FSP accounts for 55% of the Zambian government's agricultural poverty reduction budget and therefore having poverty reduction as an implicit goal (Mason et al., 2013a).

The FSP offers vouchers for 50% rebates on the price of fertilizer inputs for a set quantity.[10] Farmers are required to pay upfront in cash the total value of the voucher, which is 50% of the value of the fertilizer they acquire. In the 2003-2004 agricultural season, the program provided a voucher that could be used to receive a 50% rebate on 400kg of fertilizer to each recipient farmer—that is, a total of eight 50 kg bags, four of them containing basal fertilizer and four containing top-dressing fertilizer, the amounts the government recommends be used on one hectare of maize (World Bank, 2010).[11] In the remainder of the paper, I focus on the 2003-2004 agricultural season as the main treatment season.

Area selection: In the 2003-2004 season, the ISP reached 8% of smallholders (see Figure 1). The fertilizer used for the ISP is imported by two suppliers chosen through a national bidding process.[12] When the inputs arrive in the country, they are stored in main depots and then transported to satellite depots by local transporters for distribution to farmers. The distribution process operates independently of the private network of providers. This separate logistical system, independent from the existing private providers, resulted in a lack of geographic targeting which has been a subject of criticism within the ISP (Resnick et al., 2016). However, areas with FSP recipients initially showed higher rates of fertilizer use. Despite the minimal targeting, Mason et al. (2013) reports instances of political clientelism: villages that received ISP had a higher probability of being located in areas that had voted for the incumbent.[13]

In the areas served, the FSP is implemented through cooperatives. This aspect of the program was designed to encourage the formation of cooperatives, which were uncommon in Zambia prior to the ISP.[14] Cooperatives make it easier for the country's agricultural authorities to reach farmers and are intended to enhance production, improve marketing, and increase the

[9]The FSP renamed Farmer Input Support Program (FISP), replaced a much smaller Fertilizer Credit Program.

[10]For completeness, the voucher was later increased to 60% then 76% starting in the 2010-2011 season.

[11]In the 2009-2010 season and afterward, the fertilizer supply was halved.

[12]Omnia Fertilizer Zambia and Nyiombo Investments repeatedly won the contracts (Mason et al., 2013a).

[13]I use these findings of political clientelism to test the robustness of the empirical strategy in Section 3.4.

[14]The ISP itself played a role in the creation of cooperatives, primarily established to help farmers access agricultural inputs (Mason et al., 2013a). This requirement stems from the Maputo Declaration, in which the Zambian government committed to fostering the creation of farmers' cooperatives, which were largely nonexistent before the ISP (Jayne et al., 2018; Policy Monitoring and Research Center, 2015).

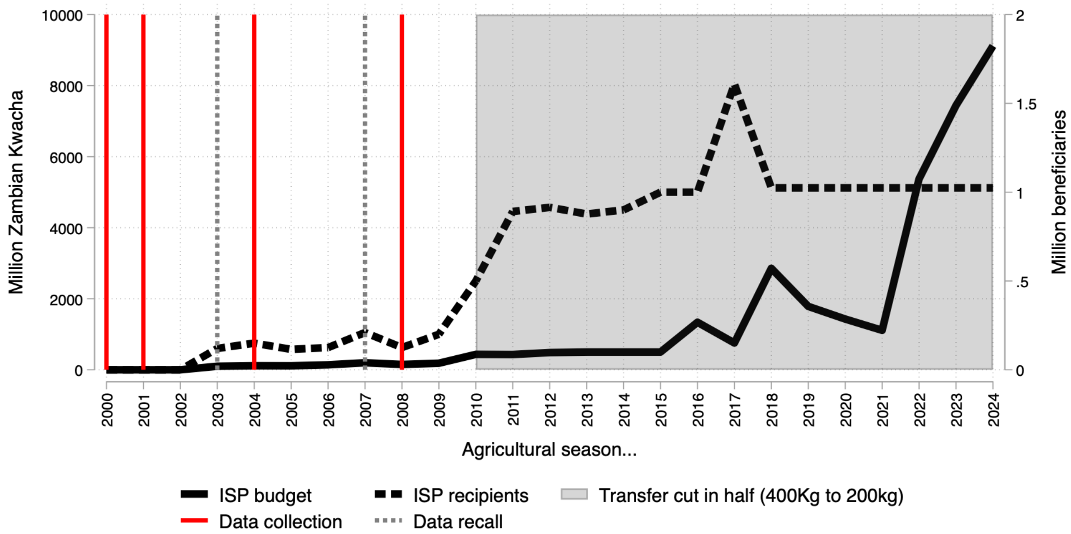


Figure 1: Time series of the number of intended beneficiaries, and costs of the ISP

Notes: This figure plots the evolution over time (from 2004 to 2024) of the budget and beneficiaries of the Zambian Input Subsidy Program (ISP). The solid-line series represents the budget allocated by the Ministry of Agriculture and Cooperatives to the ISP, corresponding to the left-hand y-axis. The dashed-line series represents the number of recipients of the ISP, corresponding to the right-hand y-axis. Solid vertical lines indicate the years of the post-harvest panel, while dashed vertical lines represent the years of recall for fertilizer use. The data source for this plot is the Ministry of Agriculture and Cooperatives of the Republic of Zambia.

technical efficiency of smallholders (Bernard and Taffesse, 2012).

The cooperatives involved in the subsidy program are preselected by District Agriculture Committees (DACs), and only farmers who are members of these cooperatives are eligible to participate. When the ISP first launched (which is the period covered by this study), it was intended to last for only three years, with recipients eligible to receive the subsidy for a maximum of two seasons.

Farmer selection: Farmers within cooperatives are selected by cooperative board members in collaboration with local extension officers from the Ministry of Agriculture and Cooperatives (MACO) (Mason et al., 2013a). The program targets smallholders with landholdings between one and five hectares, and recipients must be members of a cooperative, which requires paying a small fee (Mason et al., 2013a).[15] As a result, farmers who received the subsidy were generally wealthier than those who did not (World Bank, 2010). Farmers participating in the program receive vouchers that can be redeemed at designated ISP distribution points. These vouchers allow farmers to purchase fertilizer at half the cost. The median pecuniary value of the subsidy in 2004 is US$100 out of the $200 total value of the fertilizer. Each recipient receives an input pack containing 400 kg of fertilizer and 20 kg of hybrid maize seed.

Farmers were not self-selected; instead, the program's expansion to new villages was often influenced by budget limitations and logistical challenges, primarily due to the fact that only two companies were responsible for distributing fertilizer nationwide.

[15] Cooperatives were uncommon at the time, and the ISP was the way to expend their presence.

Timing of the program: The ISP began during the 2002-2003 agricultural season but was relatively small in its first year.[16] Farmers must procure inputs each agricultural season, meaning the program effectively resets each year. Vouchers are only valid for one agricultural season and do not carry over. As a result, any unused vouchers in a given year are forfeited and cannot be used in the following season.

The context of the ISP offers three key advantages for informing the estimation strategy. First, the ISP's supply chain, which operates independently from the existing commercial network, faces significant logistical challenges, limiting the government's ability to geographically target specific areas. In fact, as noted by Resnick et al. (2016), the ISP did not target specific geographic regions, a frequent criticism of the program. This lack of targeting reduces the likelihood of endogenous selection of recipients. Second, the arbitrary selection of newly formed cooperatives, combined with a budget cap (see Figure 1) and logistical constraints, introduces year-to-year variation in which villages receive the subsidy. This variation results in changes in subsidy recipients from one year to the next. Third, because farmers are selected for the ISP by representatives from the Ministry of Agriculture and Cooperatives (MACO) and cooperative boards at the community level, they are not chosen based on private information about their productivity. This non-optimal targeting, as highlighted by Mason et al. (2013a) and World Bank (2010), shows that selected farmers are typically wealthier, and 20% do not rely on farming as their primary activity.

For the remainder of this paper, I assume that once a farmer in a village participates in the ISP, the logistical barriers to providing the program to that village are overcome, and the program remains potentially available to the village in subsequent years. While it is possible that no smallholder participates in the program for various reasons, once a village is treated, I assume it remains treated for the duration of the policy. By 2008, roughly 30% of community headpersons reported some rotation in recipients, with different farmers within the community receiving the ISP each year. Table A.6 in the Appendix confirms that some villages appear treated in certain years but not in all subsequent years. Therefore, the estimation will highlight an intent-to-treat (ITT), where once a treatment is available in one area, it is considered treated from that point on.

Other concurrent programs: The FSP was the largest budget item of the kind on the government budget (see Table A.4). However, the Zambian government launched the Zambia Youth Empowerment Fund (ZYEF) in 2006, aimed at promoting economic empowerment by supporting income-generating activities for Zambians aged 16 to 30. The fund is designed to provide cooperatives with access to financial resources, encouraging youth participation in entrepreneurial and productive ventures. However, since this study focuses on the impact of the ISP on beneficiaries in 2004, the introduction of the ZYEF does not significantly influence the estimation in this context.

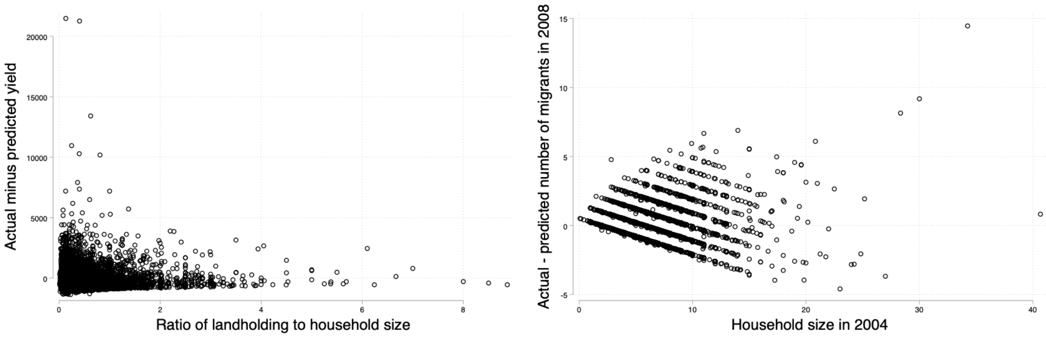
[16]The ISP is ongoing but it has undergone significant redesigns over the years.

2.2 Productivity dispersion at baseline and outside options

Smallholders are a majority of farmers in Zambia, but their productivity in agriculture varied vastly. The left panel of Figure 2 plots the difference between the linear projection of yields from Equation 1 (which regresses yields on landholdings and labor inputs) and the actual yields against the ratio of landholding to household size. If individuals with similar household sizes and landholdings are equally productive, their yields should be similar, and the difference between their predicted and realized yields (y-axis of the left panel of Figure 2) should not be large. Instead, there are substantial variations on the y-axis, and these variations occur across all ratios of landholding to household size (x-axis).

$$\text{Yields}_{2000,i} = \alpha + \beta_1 \text{land}_{2000,i} + \beta_2 \text{HHsize}_{2000,i} + \epsilon_i \tag{1}$$

$$\text{Migrants}_{2008,i} = \alpha + \beta_1 \text{land}_{2008,i} + \beta_2 \text{HHsize}_{2004,i} + \epsilon_i \tag{2}$$



(a) Dispersion in yields
1999-2000 season cross section

(b) Dispersion in migrant counts
2007-2008 season cross section

Figure 2: Dispersion of outcomes for farming households

Notes: This figure plots the dispersion of yields Panel (a) and in migrants Panel (b). The left panel plots the difference between the linear projection of yields from Equation 1 (which regresses yields on landholdings and labor inputs) and the actual yields against the ratio of landholding to household size. The right panel plots the difference between the actual number of migrants per household and the linear projection from Equation 2 (which regresses the number of migrants on landholding and household size).

While there could be numerous reasons for the dispersion in outcomes shown in Figure 2, the large dispersion in outcomes for farmers suggests potential gains from reallocating inputs (labor and land) for the least productive farmers, which could be facilitated by some farmers migrating away.

The right panel of Figure 2 illustrates the difference between the actual number of migrants per household and the linear projection from Equation 2 (which regresses the number of migrants on landholding and household size—analogous to Equation 1). The figure shows that by the end of the panel, many households have divested from agriculture to some extent.

2.3 Data, productivity dispersion, and outside options

Data

I use a panel of 6,922 rural households in Zambia. The data were collected between 1999 and 2008 by the Zambian Central Statistical Office and the Zambia Food Security Research Project at Michigan State University. This panel contains four waves. The 1999-2000 Post-Harvest Survey (PHS) serves as the baseline with three subsequent agricultural seasons: 2000-2001, 2003-2004, and 2007-2008. Of the 6,922 rural households surveyed in 1999-2000, 4,288 were surveyed every year of the panel. The PHS is a representative survey of farmers whose landholdings are of small or medium size—i.e., the survey is representative of rural households in the 1999-2000 season (Xu et al., 2009).[17]

The smallest sampling unit of the panel is a standard enumeration area (SEA). Typically, there is only one SEA in a village, except for seven villages with two SEAs each (out of 273). In what follows, I refer to these SEAs as villages (see tables A.1 and A.3).

Measurement

In this paper, I primarily focus on two features: agricultural technology upgrades, proxied by fertilizer adoption, and migration. I measure these in the following ways:

Upgrade: To measure agricultural technology upgrades, I use both a binary and a continuous measure. For the binary measure of upgrade (the extensive margin of upgrades), I use self-reported information on whether households used any fertilizer, focusing on households transitioning from not using fertilizer to using any quantity fertilizer. For the continuous measure of upgrade (the intensive margin of upgrade), I aggregate all quantities of fertilizer used across various sources, such as the ISP, commercial markets, and other alternative means.[18] To measure yields, I consider the quantity of maize produced per hectare of land owned, including both cultivated and fallow lands.

Migration: I construct several measures to capture the extensive and intensive margins of migration. First, I measure the out-migration of the entire household, *en masse* (the extensive margin of household migration). This binary decision is tracked by whether households moved out of the village; households that exit the sample for other reasons are not counted as migrant households. I use information on whether the household "moved out of standard enumeration area boundaries." Panel B2 of Table A.3 in the Appendix lists the two survey statuses that are used to define whether a household has migrated out of a village or not.[19] This definition of a migrant household does not include households that were not interviewed because they were

[17] Panel A of Table A.3 in the Appendix details the variable construction and the sampling frame.

[18] These alternative means include farmers using a few other sources such as left-over fertilizer from previous years or gifts. Quantities stemming from these sources are small in comparison to the quantities used that were from the ISP and commercial markets.

[19] The two statuses are "Moved out of SEA" and "Completed [the survey] after moving to another SEA", the latter only occurred in 2008, when the survey team tracked movers.

dissolved, refused to answer or were no-contact. This definition ensures that we are capturing the most narrow definition of household out-migration.[20]

Second, I measure individual migration which includes households hosting new members (in-migration) and sending members out (out-migration), capturing extensive margins. The measure of out-migration includes marriage, establishing a new household, and moving to other relatives. The measure of in-migration includes adult members who were not previously in the household, those who joined the household via marriage, and returnees. Intensive margins consider the number of migrating members. There is a high degree of confidence in the information used for individual migrants because the survey interviews remaining members about the migrants' reasons for leaving. Measures of individual out-migration are reliable, as they do not account for individuals who left the households and stayed in the village. All individual out-migrants used in the data are actual migrants who left the village—as reported by the household head who answered the survey. For the proxy measure of in-migration, these data measure members joining the households. These in-migrants may have come from the village.

Treatment: The primary level of treatment is at the village level but I also show results at the household level as robustness checks. I consider a village treated if at least one of its households receives the fertilizer through the ISP; on average, treated villages had 20% of its households receiving the subsidy. For the ISP, I create an indicator variable for households in villages receiving the subsidy, and a variable for the cash amount received, based on the quantity acquired through the Food Reserve Agency (FRA) and the subsidized share of the costs to farmers (0.5 in 2004 and 0.6 in 2008). The panel contains observations from the following agricultural seasons: 1999-2000, 2000-2001, 2003-2004, and 2007-2008. There are no surveys in the season 2002-2003 and 2007-2008 agricultural seasons, however I can identify the treatment status of households (i.e., whether they received the ISP) based on respondents' recall in the 2003-2004 and 2007-2008 agricultural seasons respectively. Out of the 78 villages that received the ISP in 2004, 33 (42%) continued receiving the subsidy in 2008, and 55 villages received the ISP in 2008 for the first time.[21] Although there are only two data points after the introduction of the subsidy (for the 2003-2004 and 2007-2008 panel waves), I observe whether households received the subsidy in the previous year (i.e., in the 2002-2003 and 2006-2007 agricultural seasons). In practice, the dataset only misses treatment status in the 2004-2005 and 2005-2006 agricultural seasons, however, for the estimation I do not make use of data from recall as measurement errors may be systematically larger for recall years. Table A.2 in the Appendix shows descriptive statistics on intensive margins of migration and the ISP. In 2001, no household received the ISP. Migration rates were highest for households that received the ISP, and the rates increased over time.

[20]Note that some households may have moved out of the standard enumeration area but stayed in the village.

[21]For more details on the breakdown of treatment, see Table A.6 in the Appendix.

2.4 Empirical strategy: a DID across villages across villages

I use the gradual roll-out of the ISP by the Zambian government to estimate the causal change in behavior across upgrading and migration outcomes for households that received the subsidy in 2004. Notably, some areas received the ISP in 2004, others by 2008, and some never did during the study period.[22]

To leverage the staggered roll-out of the subsidy, I use the estimation strategy of Callaway and Sant'Anna (2021). In the analysis, I consider three cohorts of villages: i) villages that did not receive the subsidy (pure control), ii) villages that received the subsidy in 2004 (early treatment), and iii) villages that began to receive the subsidy in 2008 only (late treatment). The primary focus of the analysis is the cohort of villages that received the subsidy in 2004 (early treatment), which are the villages for which I show the results. Following Callaway and Sant'Anna (2021), the control group is a combination of the late treatment villages (treated in 2008) and the pure control villages (never treated) to estimate the short-term effects of the subsidy. More specifically, the control group in 2004 is composed of both the late treatment cohort and the pure control cohort while for the the medium-term effects of the subsidy, the control group in 2008 consists of the pure control group only (Callaway and Sant'Anna, 2021). The average ITT across years is a weighted average of the 2004 cohort effects and the 2008 cohort effects.

A village is considered to have been treated if at least one household in the village received the subsidy. Thus the difference-in-differences estimates measure an ITT, and they are a lower bound of the actual treatment-on-the-treated effect. I estimate the following equation:

$$Y^c_{h,t} = \alpha^c + \sum_{c=2004}^{2008} \beta^c_t \mathbb{1}_{\{t \geq c\}} + \gamma_h X^{2001}_h + \epsilon_{h,t} \tag{3}$$

Where t, is each year of the panel: 1999-2000, 2000-2001, 2003-2004, 2007-2008. c is the treatment cohort for the village: never treated ($c = \infty$), treated in 2004 ($c = 2004$), and treated in 2008 ($c = 2008$). X^{2001}_h is a vector of households characteristics at baseline (in 2001) including the size of the household for all specifications, and fertilizer use at baseline for agricultural outcomes. $\mathbb{1}_{\{t \geq c\}}$ is a binary variable equal to one for any year following the year a village receives the ISP. $Y^c_{h,t}$ measures outcomes that capture whether a household upgraded its agricultural technology either by starting to use fertilizer (binary decision), or by increasing the amount of fertilizer used (continuous decision), which can impact their yields; and whether changes occurred along five margins of migration. These margins are as follows: whether there was in-migration or out-migration within a household (extensive margins); whether the number of in-migrants or out-migrants changed (intensive margins);, and whether the full household

[22]Some farmers recall receiving the subsidy during the agricultural seasons of 2002-2003 and 2006-2007. However, these recalls are not part of the classification for the treatment and control groups. Including the recall years in the classification would only impact 13 of the 279 treatment villages (see Table A.1) and may introduce non-classical measurement error.

out-migrated (migrated *en masse*). The standard errors are clustered at the village level.

Following Sant'Anna and Zhao (2020); Callaway and Sant'Anna (2021), I estimate Equation 3 using doubly robust difference-in-differences estimator based on stabilized inverse probability weighting and ordinary least squares.

For β_t^c to provide unbiased estimates of the causal effect of the ISP on the outcomes, two key assumptions must be satisfied: (i) conditional parallel trends must hold, and (ii) there must be no anticipation effects.

Conditional parallel trends: Figure 3 presents raw averages at the treatment group level, showing the share of upgraders, the share of migrants at both the extensive and intensive margins, and yields from 2000 to 2008. Observations before the dashed vertical line represent the pre-trends. The plots reveal unconditional parallel trends prior to the introduction of the subsidy, followed by a divergence after its implementation in the 2002-2003 agricultural season. Therefore, I estimate Equation 3 controlling only for household size, and household migration, which may affect the number of potential migrants a household can send.

No anticipation: This assumption is more difficult to verify empirically and could be a concern in this context. However, anecdotal evidence and findings from Mason et al. (2013a) suggest that the clientelism surrounding the program meant that areas and households had limited knowledge of how the program would be implemented. Given these rollout uncertainties, the "no anticipation" assumption may reasonably hold. [23]

To understand further how the treatment and control groups compare, I show in Table A.5 of the Appendix the difference between the early treatment, the late treatment, and the pure control cohorts. These differences in levels do not threaten the validity of the estimates, but they are important for understanding the rollout of the ISP. The villages that received the early treatment (in 2004) bear most resemblance to villages that received a late treatment (in 2008), compared to pure control villages (see column 5 and 6; p-values of the t-tests comparing early treatment, late treatment, and the pure control groups). However, the early treatment group (2004 treatment) is on average richer and the size of households is larger than the later treatment group (2008 treatment), as shown by the significant p-values in column (6). Households with higher incomes also have household heads with more years of education. While this difference in the number of years of education of the household head is significant, it is small in magnitude, with only 0.3 years of education difference between the early and late treatment cohorts ($p - value = .03$). To account for these imbalances, I control for household size in all my econometric specifications.

I plot, then estimate in-sample pre-trends using the panel's 1999-2000 and 2000-2001 years (see Figure fig:parallelchecks for plots), and I check for out-of-sample pre-trends (different households, same areas) across villages. To that end, I use repeated cross sections of post-

[23]In Section 3.4, I estimate alternative specifications using political clientelism and a "Hausman intrument" to identify exogenous variation in the likelihood of receiving the subsidy and find results consistent with the main estimates.

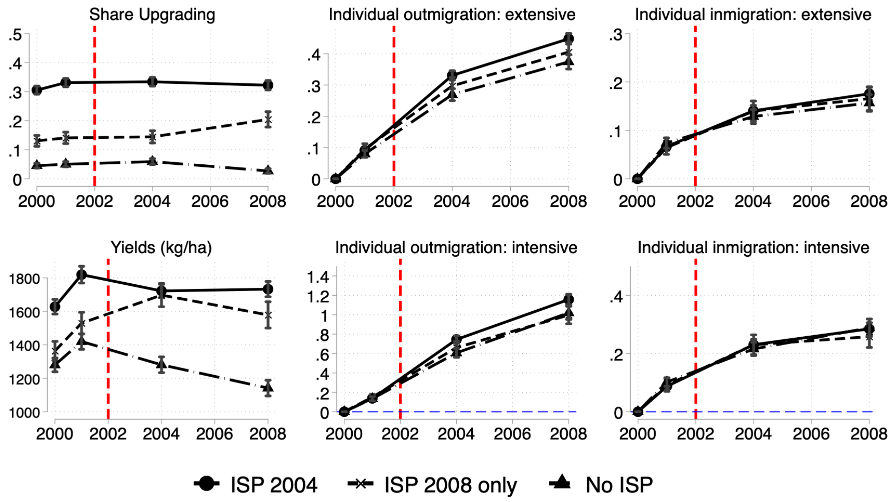


Figure 3: Raw time series of main outcomes

Notes: This figure plots the raw outcome over the panel years—between 2000 and 2008. Each raw outcome is plotted, aggregated at the year level, for the three treatment groups: villages that received the ISP in 2004 ("ISP 2004"), in 2008 but not in 2004 ("ISP 2008 only"), and those that never received the ISP ("No ISP"). The outcome variables are displayed in each graph's subtitle. The X-axis represents the years, and the Y-axis represents the outcome variables. A dashed vertical line indicates the year of the ISP introduction. The data spans the 1999-2000, 2000-2001, 2003-2004, and 2007-2008 agricultural seasons. Confidence intervals are also plotted for each year.

harvest surveys in the years 1995-1996, 1997-1998, 1998-1999, see Figure 5.

3 Results of the natural experiment: effects of the ISP on upgrading and migration

In this section I present the resulting change in agricultural upgrade and migration decisions induced by the ISP. First, I show the causal and impacts of the ISP on agriculture-specific outcomes, in line with prior research on subsidies for agricultural upgrades (Carter et al., 2021). Second, I show important and novel causal effects of the ISP on household migration decisions. I find that both upgrading and migration increased substantially as a result of the ISP.

3.1 Results: direct effects on upgrading

Prior to looking at migration outcomes, I show that the subsidy program, which was designed to move the needle on the adoption of fertilizer, did indeed improve agricultural outcomes.

Figure 4 shows the difference-in-differences results on agricultural technology upgrades (fertilizer use), household member inflow (labor in farms), and maize yields in villages that received the subsidy in 2004.[24]

[24]Figure 4 shows the in-sample pre-trend (from the 1999-2000 season to the 2000-2001 season). Further checks (out of sample) are shown in Figure 5. Table 2 reports the results shown in Figure 4 in a table format.

The propensity of increasing upgrades in villages that received the subsidy increased by an aggregate 79%. This effect of the ISP on upgrading is a composite of a short-term effect (observed in 2004 for households that received the ISP in 2004) and a medium-term effect effect (observed in 2008 for households that received the ISP in 2004). In the short run, upgrades improved for all households in treated villages—including households that did not receive the ISP—by 1 percentage point across all households of treated villages, implying a 5% increase in the likelihood that a household upgraded its agricultural inputs (see Figure 4). Within four years of the introduction of the ISP, the upgrade rate rose by 23 percentage points (71%), suggesting a significant and positive medium-term intensification of upgrades, beyond the immediate short-term effect of the ISP, which initially targeted 20% of farmers within treated areas. This increase in the likelihood of upgrading is coupled with a 57 kg increase in the quantity of fertilizer used by farmers. As a result of this increase in input use, maize yields for farmers in treated areas increased by 249kg per hectare (15%). This increase in productivity is in the order of magnitude of estimates by Mazur and Tetenyi (2024), who find a 25% increase in yields due to the introduction of a fertilizer ISP across 10 African countries.

Finally, I find that the ISP also increased the household's labor supply, as measured by the likelihood that households host in-migrants (proxied by the household hosting additional adult members to assist with activities)[25]. When labor markets are not fully functioning, this in-migration margin can be a way to increase labor supply (Singh et al., 1986). Panel 1 of Figure 4 shows that the ISP increases the propensity for a household to host any additional member (extensive margin) by a statistically meaningful 3 percentage points in both the short and medium runs.

Households that upgraded in 2004 were on average wealthier at baseline than both those that did not upgrade and those that upgraded by 2008. Upgrader households that remained upgraders through 2008 are substantially wealthier at baseline, more educated, larger, and hold more land. These findings are consistent with prior work that show that farmers in various African countries do not adopt improved production technologies due to credit constraints (Balboni et al., 2022), exposure to risk (Donovan, 2021; Alfano and Görlach, 2024) and land market frictions (Acampora et al., 2022). They are also the most likely to have out-migrants by 2008, and to have larger household sizes. These households are less likely to be headed by women. These findings are consistent with households needing to pay for the half the price of the fertilizer out of pocket (disqualifying the most credit-constrained households). See more details in Table A.9 of the Appendix.

[25]While in-migrants may engage in household work, they free up labor units that can then participate in agricultural activities.

3.2 Results: indirect effects on migration

In what follows, I present the results on the indirect effects of the ISP on household propensity to relocate, individual propensity to out-migrate, and the number of out-migrants. I show that the input subsidy decreased the likelihood of a household migrating *en masse* (i.e., relocating everyone in the household). At the same time, the subsidy increased both the extensive and intensive margins of individual out-migration.

I find that households are less likely to migrate *en masse*, which is consistent with the increased opportunity costs of migrating and the opportunity to benefit from the place-based transfer of the ISP. These households' best response is to stay, and, thus, households' propensity to move fell— -3 percentage points, i.e. a -19% change, (Figure 4).

I find that individuals are more likely to out-migrate from areas that received the subsidy either primarily to join relatives or for income-generating activities, rather than for marriage purposes. This finding implies that the ISP triggered a diversification of income sources for households in treated villages, leading to a divestment away from agriculture. The probability that a household has at least one out-migrant increases by 4 percentage points (12%) across years (ITT; see Panel 2 of Figure 4). This increase in the extensive margin of individual migration is coupled with an increase in the intensive margin of individual out-migration, with an increase of .08 in the number of individuals per household who out-migrate in treated villages (whether the households received the ISP or not). Panel 3 of Figure 4 plots these findings.

Out-migrants in 2004 were on average from households that were more educated, larger, and had more agricultural input endowments than households that had out-migrants by 2008. These differences are consistent with households with out-migrants in 2004 being less credit constrained than those migrating in 2008 to fund expensive migration. In early ISP-treated villages, households with migrants in 2008 used the extra years to generate income to fund migration.[26]

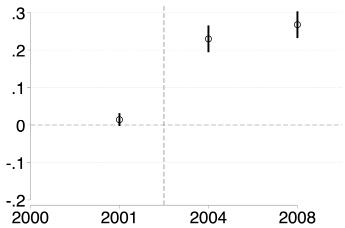
3.3 Results: indirect effects on other investments

This paper examines the effects of an input subsidy on structural transformation, with a focus on agricultural and migration outcomes. Structural transformation occurs as agriculture becomes more productive and labor reallocates away from the sector. Out-migration from agriculturally active areas is the most extreme form of sectoral movement, though labor reallocation can still take place without migration.

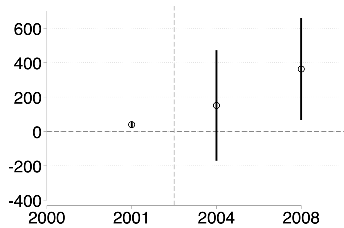
In the analysis that follows, I estimate the effects of the ISP on investments that may signal sectoral shifts, particularly in education, the accumulation of productive assets (such as livestock and machinery), and business activities. I estimate Equation 3 using Callaway and

[26]In Section A.4 of the appendix, I show averages for a range of variables for groups of households with out-migrants leaving in 2004 and out-migrants leaving in 2008, as well as households with in-migrants. I show these averages at baseline (in 2001) and at endline (in 2008). More details are available in Table A.10 of the Appendix.

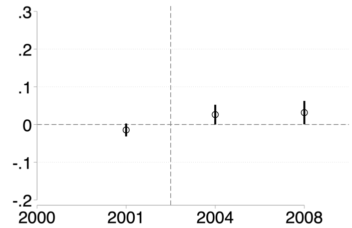
Panel 1: Direct effects on upgrading: difference-in-differences results



(a) Upgrade (Fertilizer use)

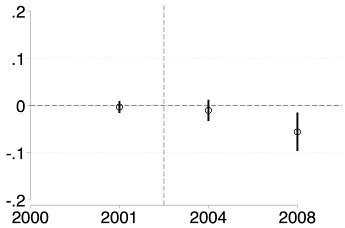


(b) Kg Maize Harvest/Ha

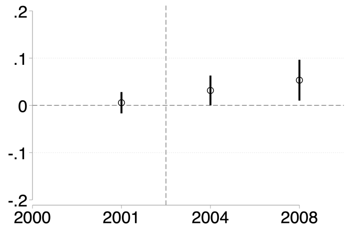


(c) In-migration, extensive

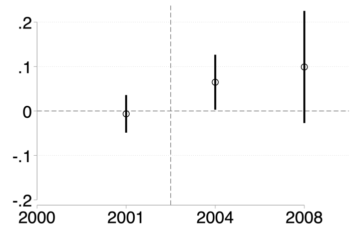
Panel 2: Indirect effects on migration: difference-in-differences results



(d) HH out-migration

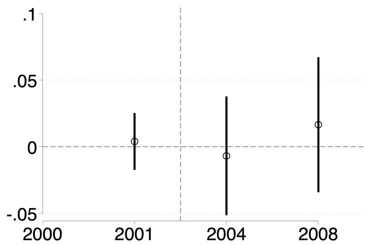


(e) Out-migration, extensive

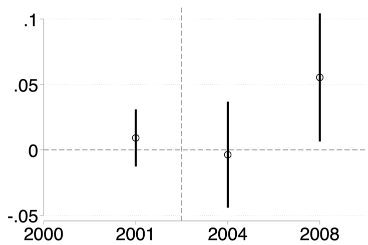


(f) Out-migration, intensive

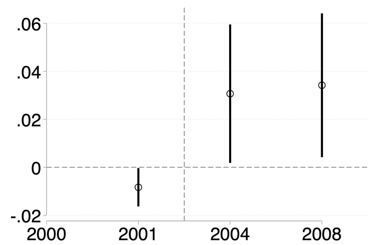
Panel 3: Reasons to out-migrate: difference-in-differences results



(g) Out-migration: marriage



(h) Out-migration to relatives



(i) Out-migration to work

Figure 4: Difference-in-differences (Callaway and Sant'Anna, 2021)

Notes: This figure plots the results from the difference-in-differences estimation from Equation 3 at the household level for the 2004 treatment cohort within treated areas using Callaway and Sant'Anna (2021). Dependent variables are given in each graph's subtitle. The vertical line is the year of the introduction of the subsidy. Each point estimate is the corresponding β_t^{2004}. β_{2001}^{2004} should not be statistically different from zero for the parallel trend to hold. Data are taken from the 1999-2000, 2000-2001, 2003-2004, and 2007-008 agricultural seasons. Results are shown for areas treated in 2004. Standard errors are clustered at the village level and asymptotically derived from influence functions.

Sant'Anna (2021). Table 1 presents the results.

The findings reveal a significant expansion in education (0.33 additional years) for 12 to 16-year-olds over the four years of the program. Even if farmers remain in the agricultural sector, increased education can enhance agricultural productivity (Gille, 2020). I estimate the effects on education by restricting the sample to children aged 12 to 16 in 2004 and estimate the difference in education levels by 2008. I estimate the effects at the individual level, and I do not include children under 12 because there is limited information on them.

I also find increased investment in productive assets (1076 thousand ZKs) in areas that receive the subsidy. These productive assets include livestock and machinery. However, the parallel trend assumption does not hold as strongly for these specific assets. By contrast, income from business activities does not differ significantly between areas that received the subsidy and those that did not.

Overall, these results suggest that farmers in areas receiving the subsidy are migrating at higher rates and investing in non-agricultural activities, while also investing in assets that increase agricultural productivity, both of which are consistent with the process of structural transformation. As a result, I find an increase in total net income, which increases by 751 (i.e. 25%), primarily in the short run.

Table 1: Short- and medium-term effects on additional, non-migration investments

	(1) Education level	(2) Productive assets	(3) Animal sales	(4) Business income	(5) Net income (all sources)
Intent to treat	.33	1076	119	-748	751
(2004 & 2008)	(.19)	(329)	(25)	(613)	(393)
Short term	.46	576	68	-1486	779
(2004 effect)	(.3)	(331)	(19)	(1141)	(650)
Medium term	.21	1659	178	45	212
(2008 effect)	(.33)	(431)	(39)	(549)	(346)
Number HHs	668	7690	7690	5604	5604
Number of villages	314	394	394	394	394
Controls: HH size	Yes	Yes	Yes	Yes	Yes
Pretrend p-value	.52	.03	.33	.94	.54

Notes: The table shows estimates for secondary outcomes for farmers treated in 2004. Each column is an outcome, estimated using Equation 3 and Callaway and Sant'Anna (2021). Outcomes are in column (1), the education levels of households members who were aged 12 to 16 in 2004, which restrict the sample size; in column (2) is the value in thousands of Zambian Kwachas of animal and machinery assets, in column (3) the sales of live or dead animals, in column (4) gross business income, and in column (5) the net income across all sources (including fishing and retail) The ITT is the effect aggregated across the years 2004 and 2008. The short-term effects are the effects in the year of the treatment (i.e. 2004). The medium-term effects are effects four years after the initial treatment (i.e. 2008). Standard errors are clustered at the village level and asymptotically derived from influence functions. The pretrend p-value stems from the Chi-square test.

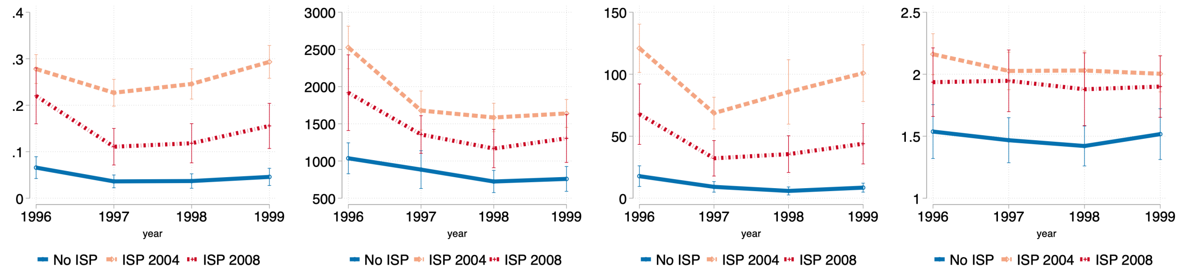
3.4 Robustness: out-of-sample parallel trends, SUTVA, household level analysis, alternative identification.

I turn to testing the robustness of the difference-in-differences estimates. First, I complement the data going back 13 years prior to the introduction of the ISP to show that out-of-sample trends in agricultural outcomes are parallel for that period. I then present a test for the Stable Unit Treatment Values Assumption (SUTVA) using fertilizer prices, and show household level treatment-on-the-treated estimates. Finally, I show—using voting behavior as an instrument for receiving the ISP—that the Local Average Treatment Effect (LATE) is qualitatively similar to the ITT estimates of the difference in differences.

Out-of-sample parallel trends in agriculture in years preceding the panel

I use repeated cross-sections of the Post-Harvest Survey (PHS) between 1990 and 1999 to further investigate the parallel trend assumption in the difference-in differences estimation above. Figure 5 shows the evolution over time (from 1996 to 1999) of different treatment groups.

Trends are parallel prior to the introduction of the subsidy for the quantity of fertilizer used,[27] the quantity of maize harvested, and the total landholdings of the farmers.



(a) Upgraders (b) Kg maize /ha (c) Kg fertilizer used (d) Landholdings

Figure 5: Parallel trends for agriculture outcomes by villages

Notes: The figure plots historical data using prior cross sections (out-of-sample) of the Post-Harvest Survey (PHS) from 1990 to 1999. Each graph plots the yearly average of one variable (given in each graph's subtitle) for villages that never received the subsidy, villages that received the subsidy in 2004, and villages that received the subsidy by 2008. The term "upgraders" refers to households that used any fertilizer on their farm. Each marker represents the average of the variable for the year. The 2004 treatment villages is the main treatment group. The control group is made up of a combination of the 2008 treatment cohort and never treated villages.

Stable unit treatment value assumption (SUTVA)

One concern with the difference-in-differences estimation is the potential violation of the Stable Unit Treatment Values Assumption (SUTVA). In the context of the Zambian ISP, such a violation could lead to spillovers across villages (the primary treatment units), impacting both

[27] The quantity of fertilizer used by farmers is subject to greater volatility because I pool together data on all types of fertilizer. The amount of fertilizer required per acre varies, depending on the type of fertilizer used (basal and top dressing). Some types must be used in greater quantities; some types must be used in smaller quantities.

migration and agricultural upgrading estimates. Specifically, if SUTVA holds we should see changes in prices within treated villages, but not across villages, which would be a threat to the identification. To assess spillovers, I analyze price variations of commercial fertilizer in 2004 (the year of the treatment) in provinces that have high and low treatment densities; note that these regions are larger units than villages. If there were spillovers across treatments, then fertilizer prices in provinces with a large number of treated villages would likely have been lower than those in provinces with a fewer treated villages.

Figure A.10 shows that fertilizer prices did not significantly change for the "pure control" households in high-density ISP-recipient regions, which does not reject that the SUTVA assumption holds.

Household-level analysis

If the main channels of migration occur through resale markets and prices, the effects at the area level should qualitatively replicate the findings of the household-level analysis. And so, another way to check the robustness of the results is to rerun the analysis at the household level, rather than at the village level. These results estimate an average treatment on the treated (TOT). Panel 1 of Figure 6 shows the extensive margin of individual migration (on the left) and the likelihood of upgrading (on the right).

The results are qualitatively the same, showing an increase both in the propensities for a household (i) to send individual out-migrants and (ii) to upgrade its agricultural technology. At the same time, on the right of Panel 1 in Figure 6, I show that households that received the ISP were positively selected based on their likelihood to upgrade their agricultural technology. This positive selection is consistent with the finding that households that received the subsidy in 2004 were more likely to have already upgraded their agricultural technology in 2001.

The outcomes also show that households that received the subsidy in 2004 had more of their income coming from in-farm activities in 2004, but that their off-farm activities did not statistically differ from those of households that did not receive the subsidy. The right-hand panel of Figure 6 shows the difference in income for households that received the ISP in 2004 and those that did not, in both 2004 and 2008 (i.e., after the introduction of the subsidy).[28]

Instrumenting receiving the ISP: political clientelism, and "Hausman instrument"

While the difference-in-difference estimation allows for some selection into treatment, a strong assumption for an unbiased estimation of the causal effect of the subsidy is that we are able to truly identify the areas that received the subsidy. For example, the difference-in-difference estimation may be biased if some of the areas have access to the subsidy but are not identified as such.[29]

[28]There are no pre-periods for the income estimates, and so results needs to be taken with considerable caution

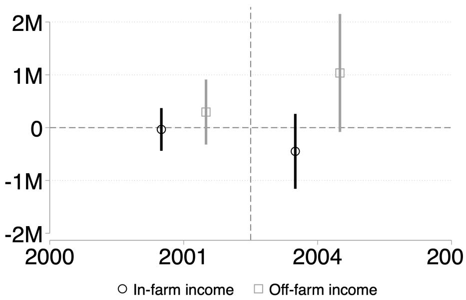
[29]This bias may be especially present if the sampling is biased.

Panel 1: Treatment-on-the-treated estimates (household-level).

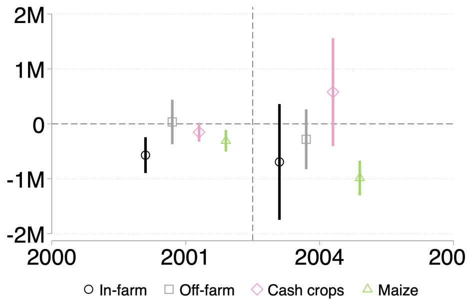
(a) Individual out-migration

(b) Likelihood of upgrading

Panel 2: Heterogeneity analysis on income (household level).



(c) Treated vs. non-treated



(d) Out-migration vs. other HHs

Figure 6: Individual Out-migration, extensive margin (household-level analysis)

Notes: The table shows estimates for the difference-in-differences estimation at the household level within treated areas using Callaway and Sant'Anna (2021). Dependent variables are given in each graph's subtitle. Using panel data for the 1999-2000, 2000-2001, 2003-2004, and 2007-2008 agricultural seasons. Respondents' recalled information is used for the 2003-2004 and 2006-2007 seasons. The figure shows that households that received the subsidies were more likely to migrate than the households that did not receive the subsidies. Standard errors are clustered at the village level and asymptotically derived from influence functions.

To address this potential bias, I use the fact that the ISP was subject to political clientelism (Mason et al., 2013, 2017), and the prices of fertilizer in neighboring villages of the district—which broadly falls under the "Hausman instruments" (Berry and Haile, 2024)—to estimate an alternative instrumental variable strategy.[30] I find that the results from the IV are qualitatively consistent with the difference-in-differences estimates in Section 3.

For election outcomes, I matched all households in the sample to constituency-level results from the presidential elections of 1996, 2001, and 2006, corresponding to the panel years 2000, 2004, and 2008, respectively. For the distance to the nearest ISP supplier, I used the distance to the provider from which households that received the ISP fertilizer. For households that

[30]The Hausman instrument relies on price variations for a product with a stable demand. In this context, a price change reflects changes in costs rather than shifts in demand. While this estimation could be subject to bias if the demand curve shifts, these biases are likely small. More importantly, they differ from potential biases in the difference-in-differences estimation. Thus, if the effects measured using the Hausman instrument are qualitatively similar to those from the difference-in-differences approach, this would strengthen the robustness of the results.

did not receive the subsidy but lived in areas where at least one household member did, I averaged the distance for all households that obtained fertilizer through the ISP. In areas where no household received the ISP, I imputed the distance by averaging the distances to providers from other households in the district. With that, I estimate the effects with the following model:

$$T_{h,t} = \pi_0 + \pi_1 V_{c,t} * dist_{h,t} + \pi_2 \frac{\sum_{j \neq i \in \text{dist}} Price_j}{N_{dist} - 1} + \theta_1 V_{c,t} + \theta_2 dist_{h,t} + \nu_h + \eta_t + u_{h,t}$$
$$Y_{h,t} = \alpha + \beta \widehat{T}_{h,t} + \nu_h + \eta_t + \epsilon_{h,t} \tag{4}$$

Where Y_k is alternatively extensive and intensive margin of individual out- and inmigration at the household level, ; $T_{h,t}$ is the endogenous variable, equal to 1 if the household received the ISP; $V_{c,t}$ is a dummy variable equal to 1 if the household lives in a constituency won by the incumbent president at the previous elections; $dist_{h,t}$ distance to closest buying point; ν_h household fixed effect; η_t time fixed effect. Standard errors are clustered at the household level.

I estimate a local average treatment effect (LATE) on farmers who receive the ISP due to the voting behavior of their constituency but also supplier competition. I find an increased LATE of 0.6 percentage point higher in the likelihood of having an individual out-migrant, and a LATE of 1.43 more out-migrants—showing the persistence of the results on out-migration.[31]

There are two ways to interpret this instrument. A first interpretation is a measure of the effort produced by the governments to reach constituents that are far away from subsidized inputs' providers. If the first stage of the IV estimation yields a positive coefficient, then, we can infer that the incumbent's administration is making more efforts to reach its constituents who voted for the incumbent than its constituents who did not vote for him. An alternative interpretation of the IV could be a measure of the incumbent's administration likelihood to place input providers closer to constituents who voted for the incumbent president. Both of these interpretations suggest that a positive coefficient in the first stage demonstrates political clientelism in the allocation of subsidies.

This IV estimation is a local average treatment effect (LATE) on households that benefited from the program due to their votes and their proximity to an FRA buying point[32].

Relevance condition: Mason et al. (2013) showed that areas in constituencies won by the Movement for Multi-Party Democracy (MMD) at presidential receive more quantity of fertilizer at a subsidized price, i.e. fertilizers are used as a reward voting behaviors. Mason et al. (2017) find that this political impact occurs for constituency won by the incumbent, rather than gradually with the margin of the win.[33] The FRA being the main distributor of subsidized fertilizer, and a major tool for political clientelism, therefore the interaction will capture most of the existing political clientelism.

[31] Note that the DID results are at the village level, while the IV estimates are at the household level.

[32] Distance to FRA buying point is measured at the community level and taken at the 2008 survey. The network of FRA buying points is therefore fixed, and the election results vary over the years 2001 and 2006.

[33] In the estimation I use the data from presidential elections preceding each survey dates, the clientelism is about rewarding a vote for an incumbent.

I find results that are qualitatively consistent with the difference-in-differences estimates, despite measuring a Local Average Treatment Effect (LATE) on farmers who received the treatment based on their proximity and voting behavior, rather than an Intent-to-Treat (ITT) estimate as in the difference-in-difference analysis.

Exclusion restriction: Voting behavior and distance taken independently both could be endogenous factors influencing access to ISP through other channels. First, voting patterns may influence public goods provision, such as roads, which could affect migration beyond the ISP's impact (Burgess et al., 2013; Easterly and Ross, 1997). However, since constituencies cover broader areas than villages, village-level voting patterns are likely to have a limited impact on constituency-level outcomes, reducing bias. Second, proximity to FRA buying points may correlate with access to other agricultural programs like PAM, a smaller-scale initiative for vulnerable smallholders with less than one hectare (Chirwa and Dorward, 2013). While proximity to fertilizer providers may not directly affect migration, their location in areas with better market access could bias estimates. To address this, I control for distance to urban centers and relevant landmarks.

The interaction between distances to program's fertilizer collection points and the voting outcome should minimize most biases. Mason et al. (2013) found PAM, which may be correlated with distance to FRA buying points, to be largely free from political manipulation. Even if non-related policies are sensitive to election results, they are unlikely to be affected by FRA proximity.

Instrumented difference in differences

In this final robustness check, I combine the difference-in-difference estimation from Section 2.4 with the instrumental variable strategy to estimate an instrumented difference in difference.

First, I estimate the first stage of from Equation 4, instrumenting treatment in 2004 (c = 2004) and treatment in 2008 (c = 2008) with (a) the interaction between distances to program's fertilizer collection points and the voting outcome and (b) the prices of fertilizer in villages within the same district as the each household's village following "Hausman instruments" strategies (Berry and Haile, 2024). using a linear probability model. Second, I rank households based on their predicted likelihood of receiving the ISP and code the top 10% as treated. I then assign to treatment the all villages from which these households come from. As a final step, I estimate (Callaway and Sant'Anna, 2021) on the village level assignment for the predicted treatment that stem from the IV. This method relates to the fuzzy difference-in-differences estimation by De Chaisemartin and d'Haultfoeuille (2018) and estimates a local average treatment effect (LATE).[34]

[34]Because there could be misclassification stemming from the first stage of the estimation, the estimate may exhibit some bias as shown by Denteh and Kédagni (2022). This bias should be small considering the relevance of the first stage F-statistics.

Table 2: Short- and medium-term migration

Panel 1: Callaway and Sant'Anna (2021) DID (main specification, village level)

	(1)	(2)	(3)	(4)	(5)	(6)
		Out-migration			In-migration	
		HH	Individual		Individual	
		left	any	count	any	count
ISP (ITT estimate)		-.03	.04	.08	.03	-.01
(2004 & 2008)		(.01)	(.02)	(.04)	(.01)	(.04)
Short term		-.01	.03	.06	.03	.02
(2004 effect)		(.01)	(.02)	(.03)	(.01)	(.05)
Med. term		-.06	.05	.1	.03	-.04
(2008 effect)		(.02)	(.02)	(.06)	(.02)	(.05)
N HHs		7690	7690	7690	7690	7690
N villages		394	394	394	394	394
Controls		Yes	Yes	Yes	Yes	Yes
Pretrend pval		.38	.38	.71	0.18	0.02

Panel 2: Instrumental variable (robustness, household level)

	(1)	(2)	(3)	(4)	(5)	(6)
		Out-migration			In-migration	
	ISP	HH	Individual		Individual	
		left	any	count	any	count
ISP (LATE)		.1	.6	1.43	.09	1.81
(2004 & 2008)		(.12)	(.2)	(.44)	(.14)	(.49)
Instruments						
MMDwon×dist.	$5.02 \cdot 10^7$					
	$(2.31 \cdot 10^7)$					
Avg(Price Fert.)$_{-i}$	$7.37 \cdot 10^7$					
	$(1.51 \cdot 10^7)$					
N HHs	7859	7859	7859	7859	7859	7859
N villages	394	394	394	394	394	394
Controls	Yes	Yes	Yes	Yes	Yes	Yes
F-stat	25.8					

Panel 3: DIDIV using IV from Panel 2 (robustness, village level)

	(1)	(2)	(3)	(4)	(5)	(6)
		Out-migration			In-migration	
		HH	Individual		Individual	
		left	any	count	any	count
ISP (LATE)		-.02	.04	.15	.03	-.09
(2004 & 2008)		(.01)	(.02)	(.05)	(.02)	(.06)
Short term		.01	0	.01	.01	.15
(2004 effect)		(0)	(.01)	(.02)	(.01)	(.04)
Med. term		0	.01	.02	.01	.04
(2008 effect)		(.01)	(.02)	(.03)	(.01)	(.05)
N HHs	7859	7690	7690	7690	7690	7690
N villages	394	394	394	394	394	394
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Pretrend pval		.02	0.83	.62	.69	0

Notes: The table shows estimates for farmers treated in 2004. ISP stands for input subsidy program. Columns (2) show the estimates for household out-migration moving entirely at the extensive margin, columns (3) whether the household has any out-migrants, columns (4) the number of out-migrants within households, columns (5) whether the household has any additional members, and finally columns (6) the number of additional individuals added to the household. For each outcome, I report the difference-in-differences (DID) estimates at the village level (Equation 3) in Panel 1, instrumental variable (IV) estimates at the household level (Equation 4) in Panel 2, and instrumented DID estimates (DIDIV) in Panel 3. Main effects aggregate estimates from 2004 and 2008. Short-term effects are for 2004, and medium-term effects are for 2008. Panel 2 instruments receipt of the ISP in 2004, and estimate the effect across years. Standard errors (SE) are in parenthesis, and clustered at the village level. The SE for the DIDIV are obtained via bootstrap. Pre-trend p-values are from the Chi-square test. Controls include baseline household size for DID, and for IV/DIDIV, controls include incumbent election victory and the head of household's education level.

4 Mechanisms: structural transformation, resale markets, and price effects

Section 3 show that the ISP in Zambia increased both upgrading and migration in villages that received the ISP. In this section, I examine mechanisms by which the ISP may directly impact agricultural upgrades and indirectly affect migration, and discuss alternative explanations. These mechanisms are incorporated into the second part of the paper focused on modeling the behavior of farmers when they receive the subsidy.

4.1 Structural transformation vs. liquidity constraints

One of the key findings in the literature on structural transformation is that various factors such as labor-saving technologies, rural overpopulation, and productivity shocks can drive people to migrate out of rural areas (Bustos et al., 2016; Lewis et al., 1954; Imbert et al., 2022). However, in contexts in which households are trapped in agriculture—even if they would be better off out-migrating—the distinction between labor-saving and labor-augmenting technologies may not be the primary concern. Indeed, farmers can make sequential choices that lead to increased out-migration even with labor-augmenting technologies. Specifically, they may invest in agriculture first, then reap the returns from their investment (income effects), and ultimately use these earnings to finance migration.

In Section 3, I showed the results of the the intent-to-treat, pooling both the short- and medium-term, indirect effects on migration. Table 2 shows the ITT effects, and disaggregates the results across short- and medium-term margins using Callaway and Sant'Anna (2021). I show the results for households that received the subsidy in 2004, the treatment of focus in the analysis. Column (1) shows the results for the likelihood that households relocating *en masse*. Column (2) shows the likelihood that households have at least one out-migrant (the extensive margin of individual out-migration). Column (3) shows the change in the number of out-migrants (the intensive margin of individual out-migration). Columns (4) shows the results for the corresponding proxy for the extensive margin of individual out-migration and Column (5) corresponds to the proxy for the intensive margin of individual in-migration. I proxy for in-migration by using the addition of adult household members into the household.

The ITT effect of the ISP on the likelihood of *en masse* migration is primarily driven by households changing their migration decision in the medium run, consistent with the change in opportunity costs of migrating in 2008.

Individual migration decisions in the medium-term are consistent with structural transformation. Out-migration effects in the medium run are 14% for the extensive margin (vs. 12% for the ITT) and 12% for the intensive margin (vs. 12% in the ITT). The proxy of in-migration indicates that the effects in the medium run are 22% for the extensive margin (vs. 23% in the ITT) and -9% for the intensive margin (vs. -2% in the ITT).

4.2 Resale markets allow recipients to cash out the ISP

One mechanism consistent with migration occurring in the year of the subsidy is that farmers can relax their liquidity constraints by using resale markets. Households that change their members' migration decisions in the year they receive the subsidy (i.e. 2004) resell their subsidized fertilizer to households that in turn double down on investing in the agricultural technology. The Zambian agricultural system operates through cooperatives, through which farmers receive vouchers to purchase a set amount of subsidized fertilizer; this system creates a market for vouchers among farmers outside of these cooperatives.

Although there are no direct data on resale markets, there is strong evidence of their existence. Among households that invest in agriculture in 2004, 51% had out-migrants by 2008, indicating a medium-term effect of agriculture technology upgrades on migration. An estimated 12% of ISP recipients do not engage in agriculture as their main economic activity (World Bank, 2010); these recipients may be likely to resell vouchers. Moreover, descriptive statistics on the self-reported use of fertilizer are consistent with the existence of resale markets.[35] Many farmers report using substantially larger or substantially smaller quantities of subsidized fertilizer than they should have received. Furthermore, some farmers who report not being part of the ISP recipient group report having fertilizer from the program (see figures A.8 and A.8 in the Appendix).

Table 2 shows the contribution of short term migration decisions to the ITT estimates. Specifically, I find that households do not change their decision to migrate *en masse* in the short term. For all estimates of individual levels of margins of migration, the short-term effects, prior to the realization of increased productivity, contribute as much as the medium-term. These short term effects imply that farmers are able to relax their credit constraint immediately as receive the ISP, consistent with the existence of resale markets which can allow for the monetization of vouchers. The ITT estimates show short-run out-migration effects of 11% at the extensive margin (vs. 12% in the pooled ITT) and 13% at the intensive margin (vs. 12% in the pooled ITT). For the proxy of in-migration, medium-run effects are 23% at the extensive margin (vs. 23% in the ITT), and 3% at the intensive margin (vs. -2% in the ITT).

To further show the likelihood of the existence of these input resale markets in the absence of direct evidence, I use data from a similar ISP for maize farmers in Mozambique, a country bordering Zambia. Using a large randomized control trial, Carter et al. (2021) estimate the long-term effects of ISPs on fertilizer adoption. A notable 30% of vouchers intended for the treatment group were ultimately redeemed by members of the control group after the original recipients chose not to redeem their vouchers.[36] This fact implies that without a strict control

[35] Some households (3–5% in treated areas) report buying ISP-fertilizer through resale markets without receiving the subsidy, indicating voucher resale. Figures A.8 show basal fertilizer use on farms. The ISP voucher fertilizer has lower quality variance and is generally better than other commercial fertilizers, making it appealing for resale (Mason et al., 2013a).

[36] Author's calculations from Carter et al. (2021). Some farmers may not have redeemed their vouchers due to insufficient liquidity, allowing control farmers to redeem them instead.

for the adherence of farmers to the randomization, ISP vouchers may have been transferred through resale markets. This is particularly relevant for the Zambian ISP, as it shows that vouchers can transfer outside the intended population, influencing both patterns of fertilizer take-up and general equilibrium effects examined in this study.

Finally, villages with the most likely resellers are also those with the most households sending out-migrants in the short run. This gap in potential resellers tapers off as time goes by (see Figure A.13 in the Appendix).

4.3 Suggestive specialization across migration and upgrades

A final mechanism relates to correlational evidence suggesting that the households' specialization in farming or off-farm activities based on comparative advantage may lead to increases in both agricultural and migration outcomes. Following the start of the ISP in 2004, I can distinguish four groups of farming households: those that respond to the ISP by changing (a) their out-migration decision, (b) their in-migration decision, (c) both their out- and in-migration decisions simultaneously, and (d) those with no changes in their migration decisions.

To estimate the effects of the subsidy on specialization, I focus on treated areas, and estimate a difference in differences across households with out-migrants, and households with no out-migrants. I examine choices made and the share of income coming from agriculture. I find that households with out-migrants divest from maize production (see the second graph of Panel 2 in Figure 6) and diversify their activities by weakly investing more in cash crops (though this result has limited statistical power). By contrast, households that do not receive the subsidy, end up with some agriculture inputs, but remain more constrained than treated households, preventing them from divesting from agriculture in the short run.

4.4 Assessing alternative mechanisms

There are many reasons that may lead to the increase in migration observed within areas that received the ISP. In what follows, I present alternative mechanisms, and show why they are not consistent with the evidence highlighted in the paper.

Potential pricing out of non-recipients of ISPs

One possible mechanism is increased migration from non-recipient households that lose their competitiveness in the local market as ISP recipients become more productive due to the reduction in input costs. To test whether this alternative mechanism has merit, I estimate a difference in differences in which the treatment is at the household level, rather than at the area level. I specifically compare households in treated areas that received the vouchers to households in treated areas that did not receive the vouchers.

I find that farmers who did not receive the vouchers were not priced out. Instead, those who received the vouchers were able to migrate in the short run. Indeed, households that received the vouchers were substantially more likely to migrate in the short run than households that did not receive vouchers—ruling out the possibility that migration occurs in households that did not receive the subsidy and were priced out of agriculture. This finding implies that the resale channel dominates the pricing-out channel (see Panel 1 of Figure 6).[37]

Additionally, the subsidy lowers input costs for farmers with vouchers, providing an option to fund migration through resale. This price reduction can benefit farmers without vouchers because they can purchase fertilizer in resale markets, with the commercial price acting as a ceiling. This contrasts with cash-transfer programs, which tend to increase commodity prices in general equilibrium. (Angelucci and De Giorgi, 2009).

Migration may occur due to an intensification of the ISP in treated areas

An alternative mechanism that can explain the long-term effects of the ISP in a village can be a succession of short-term effects in villages that received the subsidy over several years. To rule out this mechanism, I limit the 2004 sample of treated villages to villages that receive the subsidy in 2004 and not in 2006-2007 or 2007-2008. Here, I limit the control group to those never treated. By limiting the sample this way, I ensure that no village is receiving the subsidy in subsequent years, and therefore only one effect can be observed: the effect of receiving the subsidy in a one-shot policy shift.

Figure A.14 in the Appendix shows that the effects of the subsidy in the short run (i.e. for areas that received the ISP only in 2004) persist through 2008. Though underpowered, the analysis reveals both short- and medium-term effects of the ISP, even in areas treated only once—thus ruling out the possibility that the medium-term effects are merely a succession of short-term effects. The effects of the ISP on extensive margins are as follows: (i) for households migrating *en-masse*, -.024 percentage points in 2004 and -.028 in 2008; (ii) for households sending out-migrants, .03 percentage points in 2004 and .011 in 2008; and (iii) for households hosting in-migrants, .04 percentage points in 2004 and -.015 in 2008. These effects suggests that the medium-term effects on out-migration (both *en-masse* and individual) are a combination of successive, short-term effects and a substantial, purely medium-term effect.

[37] Farmers who received the ISP were not only more likely to change their migration decision indirectly; they were also more likely to change their upgrading decision to adopt fertilizer in their agricultural technology. The right panel of Figure 6 shows that these treated households in treated areas are far more likely to adopt fertilizer than their non-treated counterparts.

5 A choice model: upgrading or migrating

This section builds on the natural experiment and explores a crucial aspect of this paper's mechanisms: informal resale markets. These secondary resale markets are anecdotally important,[38] and are consistent with the results of the natural experiment, but the econometrician cannot observe them. The model provides the structure to understand these resale markets as a primary mechanism driving the labor allocation choice across upgrading and migration.

In this setting, farmers respond to the ISP across several margins. A mere back-of-the-envelope estimate of the importance of resale markets or alternative policies would overlook these strategic behaviors, which the model incorporates. In the remainder of the paper, which is made up of the model and its estimation I carefully consider this response across several margins as found in the results observed in the natural experiment. I outline and estimate the channels leading to farmers' decisions between upgrading and migrating. This analysis allows for a comparison of the impacts of the ISP with resale to other policies typically used in rural settings in countries with large populations of smallholders.

The setup

I model the joint decision of a single household across migration and the upgrading of its agricultural technology from a traditional to a fertilizer-based technology. The household (indexed i) behaves like a firm and maximizes its surplus across all its options. Figure 7 summarizes the joint decision considered in the model: the decision to use or not fertilizer and the decision on how many migrants to send in two environments.

Households differ in their factor endowments and have multiple labor units. Their unconstrained choices are driven by productivity differentials in available technologies. The price of fertilizer is endogenous, influenced by whether the ISP is available in the village and the total quantity available of fertilizer available in the village.[39] The model incorporates three key features: i) farmers cannot borrow to finance migration, even when it is profitable;[40] ii) the availability of fertilizer in the village is constrained by the total commercial and subsidized quantities supplied; and iii) resale markets allow farmers to buy and sell subdivided quantities of fertilizer.

Labor allocation: The household has L_i units of labor. It decides on units of labor $L_{i,A}$,

[38] These resale are explored by Mason and Tembo (2015) and other policy publications.

[39] The total quantity sums fertilizer coming from the subsidy program and from the commercial channels, mirroring the implementation of the program in Zambia. The ISP in Zambia changed the supplied quantities of fertilizer in villages that received the program, because these ISP providers did not coordinate with commercial providers (see Section 2). In this model, both the commercial and the ISP providers are assumed to supply a homogeneous fertilizer and there is no distinction in their quality.

[40] In the model, I assume that fertilizer use is not constrained in the same way. Bryan and Morten (2019) show that there is systematic (and perhaps differential) underinvestment in migration, and that small subsidies can have substantial positive effects on out-migration.

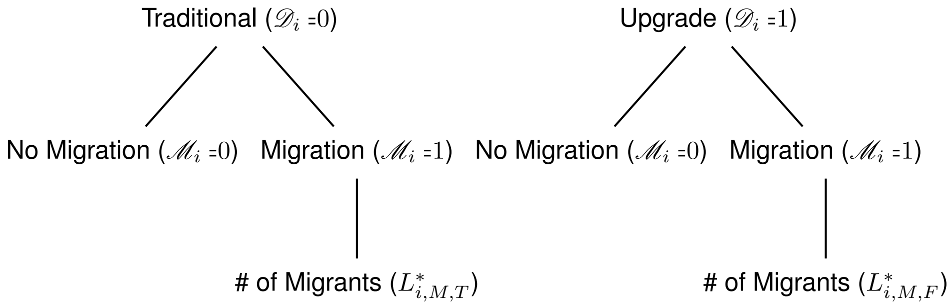


Figure 7: Household i Set of Choices in the Static Model

Notes: This figure is a diagram of the decisions a household makes in the model. In this model the household makes three joint decisions: 1) whether to upgrade its technology by using fertilizer ($\mathscr{D}_i$), 2) whether to send any migrants (binary decision $\mathscr{M}_i$), and 3) how many migrants to send.

$L_{i,M}$ to allocate to agriculture, and to migration respectively. $L_{i,A} \in [0, L_i]$[41] such that the household can divide an individual member's time across activities: $L_{i,A} + L_{i,M} = L_i$. Within a household, workers are homogeneous. If the household allocates any labor to agriculture, it has to choose between two technologies: i) the traditional technology which uses labor ($L_{i,A}$) and land (X_i) as inputs, and ii) a fertilizer technology that requires fertilizer as an additional input. Both agricultural technologies produce a homogeneous output.

Migration: The surplus generated by the labor allocated to migration is $\pi^M = L_{i,M} \cdot \tilde{w}_i - c_i^M$, where $\tilde{w}_i = (w_i - m_v)$, with w_i being each household's member's wage at destination. The wage at destination is assumed to be normally distributed, meaning that there are heterogeneous wages at destination for different households, reflecting variations in skills and education. m_v is the marginal cost of migration; it is a function of the village in which the household lives. c_i^M is the fixed cost of migration, which can be interpreted as the initial cost that the first migrant leaving the household has to incur to find a dwelling at their destination. This cost is composed of the average cost to get to the closest city c_i, and a shock j_i.

5.1 The household's optimization problem

Traditional agriculture: The production function for the traditional technology is $Y_i^T = a \cdot L_{i,A}^{\gamma} X_i^{\delta}$, where a is the productivity of the traditional technology (same for all households), $L_{i,A}$ the labor units allocated to agriculture, γ is the output elasticity of labor in the traditional agriculture, X_i the total available landholdings for a household i, and δ the elasticity of land. The surplus stemming from the traditional technology alone is $\pi_i^T = paL_{i,A}^{\gamma} X_i^{\delta}$.

Upgraded agriculture: The production function for the fertilizer-intensive technology is $Y_i^F = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta}$, the profit function stemming from selling the production is $\pi_i^F = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q_v(F_i)$, where p is the price of maize, A_i is the household's idiosyncratic productivity, F_i the total amount of fertilizer used on the farm, X_i the landholdings of the

[41] It is conceptually straightforward to add inmigration into the model, and its estimation. However, in the data, in-migration is quantitatively small. For simplicity, I abstract from it in the model.

household, it is made up of the quantity received via the subsidy and the quantity traded in resale or commercial markets at a price q_v.

I make the simplifying assumption that fertilizer is subsidized at 100%, and so the household receives a quantity of fertilizer $\bar{f}$ for free.[42] When the planner introduces a fertilizer subsidy (i.e. $\bar{f} > 0$) by distributing vouchers, the household can either choose to use the subsidized fertilizer in their agricultural production (i.e. $\mathscr{D}_i = 1$), or to trade the vouchers in resale markets at an endogenous village price q_v. If the household chooses to use the subsidized fertilizer, it incurs a fixed cost C_v^F associated with upgrading the technology. The cost is allowed to vary across villages to account for different specific conditions such as soil quality and whether there is a fertilizer store already set up. Alternatively, the household can trade a quantity $\tilde{f}_i$ vouchers in resale markets at a price q_v. The household can sell its entire subsidized allocation ($\mathscr{D}_i = 0$) or buy any affordable quantity.

When the household chooses the traditional technology, it receives a voucher to redeem a quantity $\bar{f}$ of subsidized fertilizer at the same location as the commercial fertilizer and sells it all in the resale market at an endogenous unit price of q_v. The total available quantity of fertilizer available for production is $F_i = \bar{f} + \tilde{f}_i$.

The commercial and resale markets for fertilizer are active, with the price q_v being the same in both. This price is influenced by the overall quantity of fertilizer available in the village.

The household faces a credit constraint: it cannot borrow against its returns to migration. This constraint implies that the household's returns from both its agricultural activity and its use of resale markets must entirely cover the fixed costs of migration. This setup allows us to see, within a static model, how farmers fund migration through both a medium-term increase in their productivity, consistent with structural change, and through a short-term increase in available cash, consistent with a relaxation of the credit constraint via resale markets. The household maximizes its total surplus by combining its returns to migration and agriculture, subject to a credit constraint. Its optimization problem is:

$$\begin{aligned}
\max_{L_{i,A,T/F}\in[0,L_i];F_i\geq 0;\mathscr{D}_i,\mathscr{M}_i\in[0,1]} & (1-\mathscr{D}_i)\left(paL_{i,A,T}^{\gamma}X_i^{\delta} - L_{i,A,T}\tilde{w}_i\right) \\
& + \mathscr{D}_i\left(pA_iL_{i,A,F}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta} - q_v\tilde{f}_i - L_{i,A,F}\tilde{w}_i - C_v^F\right) \\
& + q_v\bar{f} + L_i\tilde{w}_i - \mathscr{M}_ic_i^M, && (5) \\
\text{s.t. } & L_i = L_{i,A} + (1-\mathscr{D}_i)L_{i,M,T} + \mathscr{D}_iL_{i,M,F}, && (6) \\
& paL_{i,A}^{\gamma}X_i^{\delta} + q_v\bar{f} \geq c_i^M \quad \text{if} \quad \mathscr{M}_{i,T} = 1, && (7) \\
& pA_iL_{i,A}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta} - C_v^F + q_v\tilde{f}_i \geq c_i^M \quad \text{if} \mathscr{M}_{i,F} = 1, && (8)
\end{aligned}$$

[42] This assumption simplifies the model without affecting the estimation results. Introducing the ISP as a percentage of the prices rather than a total transfer does not significantly alter the estimation, as the maximum likelihood estimation relies primarily on variations rather than levels, especially since input prices in the commercial market show minimal variation across locations. In practice, adding prices in the estimation would be equivalent to subtracting a lump sum equal to the out-of-pocket cost of the subsidy (i.e., 50% of the price for all ISP beneficiaries), but this ultimately does not affect the decision at the margin.

where $\mathscr{D}_i$ is the household's decision to upgrade its technology, it is equal to one if the household upgrades its agricultural technology and zero otherwise. $\mathscr{M}i, T$ represents the extensive margin of the individual migration decision (with Li, M, T as the number of migrants) for a household using traditional agricultural methods, while $\mathscr{M}i, F$ refers to the extensive margin of the individual migration decision (with Li, M, F as the number of migrants) for a household adopting upgraded agricultural technology.

The endogenous price of fertilizer in the village q_v^*

Households in a village have access to both the resale market (when the ISP is available) and the commercial fertilizer market. These markets for fertilizer clear and set the price of fertilizer within the village. $\sum_{i=1}^{N} \int_{\zeta_i} \tilde{f}_i dw_i + \bar{F}_v = 0$, where $\bar{F}_v$ is the available commercial fertilizer in the village. This market clearing condition can be re-written as follows:

$$N_1 \bar{f} + \bar{F}_v - \left[\alpha^\alpha p \left(\frac{\beta}{q_v^*}\right)^{1-\alpha}\right]^{\frac{1}{1-\alpha-\beta}} \sum_{i=1}^{N^u} \int_{\zeta_i} X_i \left(\frac{A_i}{\tilde{w}_i}\right)^{\frac{1}{1-\alpha-\beta}} dw_i$$
$$- \left(\frac{p}{q_v^*}\right)^{\frac{1}{1-\beta}} \sum_{j=1}^{N^c} \left[A_j X_j^{1-\alpha-\beta}\right]^{\frac{1}{1-\beta}} = 0 \tag{9}$$

Within the village, N_1 is the number of households that receive the subsidy, while N^u and N^c are respectively the number of upgraders that are unconstrained (interior solution), and constrained to having all their labor in agriculture. The equilibrium price of fertilizer q_v^* has no analytical solution, but can be estimated based on N^u, N^c, and the elasticities of production. Note that when $N^u = 0$, $q_v^{*c} = \frac{p}{N_1 \bar{f} + \bar{F}_v} \cdot \left[\sum_{j=1}^{N^c} \int_{\zeta_i} \left[A_j x_j^{1-\alpha-\beta}\right]^{\frac{1}{1-\beta}} dw_j\right]^{1-\beta}$, and if $N^c = 0$, $q_v^{*u} = \beta \left(\frac{\alpha^\alpha p}{N_1 \bar{f} + \bar{F}_v}\right)^{\frac{1}{1-\alpha}} \cdot \left[\sum_{i=1}^{N^u} \int_{\zeta_i} x_i \left(\frac{A_i}{\tilde{w}_i}\right)^{\frac{1}{1-\alpha-\beta}} dw_i\right]^{\frac{1-\alpha-\beta}{1-\alpha}}$

5.2 The choice to upgrade

Unconstrained households: the interior solution

The household will upgrade to the fertilizer technology if its surplus in that technology is larger than in the traditional agriculture. In both cases, the household has the outside option of migrating. Formally, the household upgrades iff $\pi_{i,T}^{u*} < \pi_{i,F}^{u*}$, which occurs if an unconstrained household's productivity in the upgraded agriculture A_i is above a threshold, such that:

$$\mathscr{D}_i = 1 : A_i \geq \frac{q_v^{*\beta} \tilde{w}_i^{\alpha}}{p X_i^{1-\alpha-\beta}} \left[\frac{\gamma^{\frac{1}{1-\gamma}}(1 - L_i \tilde{w}_i)}{\Psi} \left(\frac{P a X_i^\delta}{\tilde{w}_i^{\gamma}}\right)^{\frac{1}{1-\gamma}} + \frac{C_v^F + c_i^M}{\Psi}\right]^{\frac{1-\alpha-\beta}{1-\gamma}} \tag{10}$$

where $\Psi = \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{1-\alpha}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{1-\beta}{1-\alpha-\beta}}$. And where q_v^*, the optimal price of the fertilizer, is obtained from the market clearing condition on the fertilizer resale market, see Equation 9. There is no closed form solution to q_v^*, and its expression will stem from the estimation of the elasticities of production.

For these unconstrained households, migration levels for households choosing the traditional agriculture and those choosing the upgraded agriculture are respectively:

$$L^{u*}_{i,M,T} = L_i - \left(\frac{\gamma p a X_i^{\delta}}{\tilde{w}_i}\right)^{\frac{1}{1-\gamma}} \tag{11}$$

$$L^{u*}_{i,M,F} = L_i - X_i \left[\left(\frac{\beta}{q_v}\right)^{\beta}\left(\frac{\alpha}{\tilde{w}_i}\right)^{1-\beta} pA_i\right]^{\frac{1}{1-\alpha-\beta}}. \tag{12}$$

Labor constraints bind

When the household is constrained to have all its labor units involved in the agricultural technology ($L_{i,A} = L_i$), it upgrades if its productivity in the upgraded agriculture A_i is above a threshold, such as:

$$\pi^{c*}_{i,F} \geq \pi^{c*}_{i,T} \tag{13}$$

$$A_i \geq \left[\frac{paX^{\delta} + C_v^F}{\beta^{\frac{1}{1-\beta}} - \beta^{\frac{1}{1-\beta}}}\right]^{1-\beta} \frac{q_v^*}{pX_i^{1-\alpha-\beta}} \tag{14}$$

For these constrained households, migration levels are $L^{c*}_{i,M,T} = L^{c*}_{i,M,F} = 0$ regardless of the agricultural technology they choose.

Testing the implications of the model

The model maps to empirical results of the outlined in Section 3 and the mechanisms outlined in Section 4.[43]

Implication 1—There are four groups of households: (i) households that upgrade, and do not have out-migrants; (ii) households that upgrade, and have out-migrants; (iii) households that do not upgrade and do not have out-migrants; (iv) households that do no upgrade, and have out-migrants.[44]

Implication 2—Households delay their migration decision, to use the income from their agricultural upgrade to fund migration.[45]

Implication 3: Migration increases as the resale value of the subsidized fertilizer increases. As the resale value of the vouchers increases, migration becomes comparatively more attractive. This correlation results from the credit constraint being relaxed for more households.

[43]These implications are not Propositions, they can help make sense of the findings. Propositions can be found in the Appendix B

[44]For corresponding propositions, see propositions 1, 2, and 4 in Appendix B.

[45]For corresponding propositions, see Proposition 3 in Appendix B.

Additionally, it also implies that the opportunity cost of the marginal hectare of fertilizer agriculture is higher because it becomes too costly to top-up, and migration becomes relatively more attractive. The correlation between the resale price (which I proxy by using the commercial price) and individual migration at the extensive margin is 0.07 and 0.08.[46] Furthermore, for each additional US$1 of subsidy, there is a 0.2 percentage point increase in the likelihood that a household sends at least one member out and a .1 percentage point increase in the number of people sent out (for regression results, see Table A.12 in the Appendix and Figure A.11).

6 Estimation, in-kind and cash counterfactuals

In this section, I estimate the model of selection presented in Section 5 by Maximum Likelihood; I then use the parameters from the baseline model (ISP with resale) to back out the parameters of the model and estimate the following counterfactual policies: (i) an ISP without resale markets, similar to an in-kind transfer, (ii) a cash-transfer program, with the same pecuniary value as the subsidy for the same households that previously received the ISP, (iii) a smaller cash transfer to all households within treated villages.

6.1 Estimating the model of selection

The benchmark estimation: the ISP and migration

I estimate the baseline ISP parameters in three steps: i) I estimate the production functions for both the traditional (for non-upgraders) and upgraded (for upgraders) agricultural technologies. ii) Using this first step, I compute the counterfactuals of upgrading for non upgraders, and staying in the traditional agriculture for upgraders: which provides the amount of fertilizer non-upgrading households would have used had they upgraded. This step allows me to estimate the output Y_i^F for non-upgraders and thereby back out the productivity in the upgraded agriculture for both upgraders and non-upgraders, iii) I then estimate the joint decision for households to upgrade and migrate. Standard errors are obtained through bootstrapping with 300 repetitions.

Production functions: The optimal levels of migration depend on elasticities and prices. As a first step, I estimate the Cobb-Douglas production functions from Section 5. I do not instrument the inputs of the production function (Olley and Pakes, 1992) because land inputs are fixed, and labor markets are incomplete (Rosenzweig, 1988).

I estimate the production functions for each technology by pooling all four waves of the panel (1999-2000, 2000-2001, 2003-2004, and 2007-2008).

For the fertilizer technology, I estimate the technology among adopting farms (i.e. farms that reported using fertilizer) and compute the counterfactual production for non-adopters. This identification accounts for the inputs of the production function and the village fixed effect,

[46] Figures A.12 and A.11 in the Appendix plot these correlations.

which is the deterministic component of A_i. The residual of $\log(\nu_i)$ is the idiosyncratic part of A_i. The estimation (see Appendix C) shows that the fertilizer technology has an increasing return to scale. While the traditional technology has a constant return to scale.

Fertilizer use, and output: I only observe the total quantity of fertilizer used (F_i) and production of maize in the fertilizer agriculture (Y_i^F) for upgraders, and Y_i^T for non-upgraders. To estimate their corresponding $\widehat{Y_i^T}$ for upgraders and $\widehat{Y_i^F}$ for non-upgraders, I focus on the year 2004, which is the year for which I estimate the joint decision to upgrade and migrate. I estimate $F_{i,2004}$ as such:

$$F_{i,2004} = a_0 + a_1 \text{Production Value}_{2001} + a_2 \text{Fallow land}_{2001} + \text{FE}_v + e_i \tag{15}$$

Once I estimate total quantity of fertilizer used (F_i) among upgraders, I compute $\widehat{F_i}$ for the non-upgraders. Using $\widehat{F_i}$, I compute $\widehat{Y_i^F}$ for non-upgraders, and, thus, back out the household level productivity that stems from upgraded agriculture (A_i). To estimate $\widehat{Y_i^T}$, I use household landholdings, and the total labor units available to the households L_i as inputs.

Joint decision to upgrade and to migrate: To estimate the binary decision to upgrade, as well as the number of migrants, I estimate simultaneously Equations 16 using ordinary-least-squares (OLS) separately for villages that receive the subsidy, and villages that do not:

$$\begin{cases} \mathscr{D}_i & = \alpha_0 \log(X_i) + \alpha_1 \log(q_v) + \alpha_2 \log(A_i) + \alpha_3 \log(c_i) + FE_v + \epsilon_i \\ \mathscr{M}_i & = \beta_0 + \beta_1 L_{iM} + \beta_2 Y_{i,T} + \beta_3 \mathscr{D}_i (Y_{i,F} - Y_{i,T}) + \beta_4 q_v + \beta_5 c_i + \mu_i \\ L_{iM} & = \gamma_0 \mathscr{D}_i \log(A_i) + \gamma_1 \log(X_i) + \gamma_2 \log(c_i) + \gamma_3 \log(P_v) + \gamma_3 \log(L_i) \\ & \quad + \gamma_4 \mathbb{1}_{\text{fsp}} \times \log(q_v) + \gamma_5 \log(q_v) + \theta_i \end{cases} \tag{16}$$

The estimation for ISP-recipient villages allows me to estimate the decisions stemming from equations 10, 8, and 12. The estimation for areas outside of ISP-recipient villages provides the parameters when resale markets do not exist.

Each of the parameters used in the estimation is constructed using the description from Table 3. Table 4 summarizes the mean and standard deviations of upgrading ($\mathscr{D}_i$), migrating ($\mathscr{M}_i$), and labor units migrating (L_{iM}) for 10% of the hold-out sample. Overall, the out-of-sample estimates (see Column 3 of Table 4) approximates well the moments of the data (see Column 2 of Table 4). The out-of-sample difference between the estimates and the actual value $\mathscr{M}_i$, L_{iM} are respectively .1% and 5%, while $\mathscr{D}_i$ is at -23%.

Estimating revenue in agriculture: I compute $p \cdot Y_i^T$ and $p \cdot \widehat{Y_i^F}$ for non-upgraders and $p \cdot Y_i^F$ and $p \cdot \widehat{Y_i^T}$ for upgraders.

Table 3: Estimation of the parameters of the model

(1)	(2)	(3)
Par.	Year	Source and Sample
Migration		
w_i	2004	Idiosyncratic shock
m_v	2004	Absorbed in the village fixed effect
c_i	2004	Transportation cost to closest city
j_i	2004	Idiosyncratic shock
Production inputs		
L_i	2004	# HH members (including outmigrants)
F_i	2004	*Upgraders*: Fertilizer used
		Non-upgraders: computed from upgraders
A_i	2004	*Upgraders*: Estimated among upgraders
		Non-upgraders: computed using estimates for upgraders
Elasticities and outputs		
α	2004	Estimated among upgraders
β	2004	Estimated among upgraders
γ	2004	Estimated among non-upgraders
δ	2004	Estimated among non-upgrader
Y_i^T	2004	*Upgraders*: Computing using estimated δ, γ
		Non-upgraders: Using harvest data
Y_i^F	2004	*Upgraders*: Using harvest data
	2004	*Non-upgraders*: Computing using estimated α, β, γ
Number of households		
N_1	2004	# HHs in the village that received ISP
N^u	2004	# HHs with outmigrate in 2004
N^c	2004-8	Total HHs in village minus N^u
Prices and others		
p	2004	Price of maize in 2004
q_v	2004	Computed from Equation 9
C_v^F	2004	Absorbed in the village fixed effect
$\bar{F}_v$	2004	Total fertilizer used in village net of subsidy

Notes: This table summarizes the variables needed to estimate the model. Column (1) lists the parameters of the model. Column (2) lists the years from which the parameter data is taken. Column (3) details the variables used for each parameter.

Table 4: Out-of-sample fit of the model

(1) Variable	(2) Statistics	(3) Estimates	(4) Actual	(5) Difference
$\mathscr{D}_i$	Mean	.762	.617	-.145 (-23.5%)
	SD	.427	.487	
$\mathscr{M}_i$	Mean	.606	.610	.004 (+0.1%)
	SD	.490	.489	
L_{iM}	Mean	1.933	1.851	-.082 (+4.3%)
	SD	1.398	2.238	

Notes: estimates of Joint Equations 16 using maximum likelihood. The estimates presented are from the computation of $\mathscr{D}_i$, $\mathscr{M}_i$, and L_{iM} on a 10% hold-out sample. Column (1) lists all variables of the model estimated. $\mathscr{D}_i$ is one household's decision to upgrade its agricultural technology and start using fertilizer. $\mathscr{M}_i$ is one household's decision to send units of labor to out-migrate. L_{iM} is the optimal number of labor units the household sends to out-migrate. Column (2) shows the statistics displayed (mean, and standard deviation). Column (3) is the fitted estimate from Equation 16 for the 10% out-of-sample households. Column (4) is the actual value of each of the variables (and statistics). Column (5) is the the out-of-sample percentage of error between the estimate and the actual value (i.e. Column (4) - Column (3) and in parenthesis it is $\frac{Column(4)-Column(3)}{Column(3)}$.

6.2 Counterfactual policies: subsidies vs. transfer programs

Using the estimates obtained baseline policy in the model, I estimate the counterfactuals for several popular, rural anti-poverty policies. First, under the model assumptions I explore what would happen with an enforced ban on resale markets and two cash- transfer programs (a targeted and an untargeted one).

ISP without resale: Shutting down the resale markets impacts the reallocation of fertilizer in the local market. Furthermore, farmers with a comparative advantage in migrating cannot generate liquidity to fund migration. This scenario results in substantial efficiency losses, with a decrease in both upgrading (-64.54%) and migration (-4.71%). In this case, the improvement in overall productivity is negative compared to the ISP with resale markets. Indeed, the ISP with resale markets generates a snowball effect because farmers can split their fertilizer transfer across several households.

I test two ways of designing the cash-transfer policy. First, I use the targeting of the ISP, and provide a revenue neutral cash transfer to farming households that had previously received the subsidy. In a second design of the revenue-neutral cash-transfer program, there is no targeting; all farmers living in a treated village receive some amount of cash, but they receive smaller quantities than would be the case in the targeted counterfactual.

Cash transfer programs: The cash-transfer programs have two main feature differences with the baseline ISP with resale. First, the cost of transportation c_i goes down by the amount of the cash transfer. This drop in costs impacts both the decision to upgrade the household's agricultural technology $\mathscr{D}_i$ and its decision to migrate $\mathscr{M}_i$. For households with low transportation costs, the leftover cash is added to the total revenue. Second, the price of fertilizer increases as the total amount of fertilizer available in the village decreases. This is because the central planner no longer provides the subsidized quantity of fertilizer. To estimate the costs of fertilizer, I use Equation 9, and estimate the following:

Equilibrium fertilizer price q_v^*:

$$log(q_v) = \beta_0 + \beta_1(N_{1v}\bar{f} + F_v) + \beta_2 N_{1v} + \beta_3 N_v^u + \beta_4 N_v^c + \epsilon_v,$$

where $N_{1v}\bar{f}$, is the number of households in the village that receive the subsidy. N_v^u is approximated by the number of households that have migrants and N_v^c by the total number of households net of the constrained households.

Targeted cash transfer: The targeted cash-transfer program decreases both migration rates (-5.32%) and the adoption of the fertilizer technology (-70.87%) compared to the baseline of ISP with resale markets. First, the market frictions in technology upgrades are not internalized, and adoption rates plummet compared to the ISP with resale markets. Second, migration also decreases because, unlike the baseline ISP, the cash is fungible, and there is no redistribution of the cash across households. In this case, only the households receiving the subsidy can change their migration decisions. Another aspect of the model is that households that upgrade and generate more profit with the fertilizer technology can fund migration. Because the targeted cash transfer leads to no adoption, there is no spillover effect through prices from the cash-transfer program.[47]

*Untargeted cash transfer:*The untargeted cash-transfer program decreases migration rates (-5.32%) compared to the rates the ensue under the ISP with resale markets; at the same time the untargeted cash-transfer program has strong negative effects on the adoption of the fertilizer technology (-79.87%). This effect is because the market frictions in the fertilizer market remain. [48] Panel A of Table 5 summarizes the counterfactual estimates.

[47]I re-compute the counterfactual but I keep the available fertilizer quantities at the level of the ISP currently in Zambia. I find drops in upgrades rates (-65.33%), in migration rates (-4.48%) but an increase in the total number of migrants (11.01%).

[48]I re-compute the counterfactual but I keep the available fertilizer quantities at the level of the ISP currently in Zambia. I find drops in upgrades rates (-75.43%), in migration rates (-4.48%) but an increase in the total number of migrants (-5.78%).

Table 5: Summary of counterfactual policies

Panel A: Structural estimates for upgrades and migration

	Channels	Upgrade extensive	Migration extensive	Migration intensive
Baseline:				
- ISP + resale	Upgrade: resale, fertilizer prices			
	fertilizer quantities	.664	.663	1.84
	Migration: resale, productivity	(0.015)	(0.016)	(0.044)
Counterfactuals:				
- ISP no resale	Upgrade: fertilizer prices			
	fertilizer quantities	.276	.640	1.83
	Migration: productivity	(0.097)	(0.032)	(0.06)
- Targeted CT	Upgrade: lower transport costs	.227	.636	2.05
	Migration: lower transport costs	(0.448)	(0.04)	(0.53)
- Untargeted CT	Upgrade: lower transport costs	.157	.636	1.74
	Migration: lower transport costs	(0.445)	(0.04)	(0.52)

Panel B: Back-of-the-envelope effects on income

	Input subsidy		Cash transfers	
	Baseline: resale	No resale	Targeted	Untargeted
Mean revenue*	$698	$566	$961	$653
Median revenue*	$315	$253	$344	$257

Notes: This table shows the estimates of the model using Maximum Likelihood. The extensive margins of upgrading and migrating are obtained splitting the probability into a binary variable that equals 1 if the estimated probability is greater or equal to 0.5, and 0 otherwise. Standard errors are in parenthesis and are reported from using the standard deviation over 300 bootstrap replications of the estimation (with replacement). *— Mean and median revenue include include the returns from agriculture as well as the lump sum for the cash transfer.

6.3 Discussion: first best and second-best policies

First-best policy

Considering both the credit constraint and the market frictions in the economy, a first-best policy to minimize distortions and improve the efficiency of the policy would be to identify the two types of farmers—those who would be better off migrating and those who would be better off upgrading—and then lifting the corresponding constraints of farmers in each group. Farmers that have high productivity in the fertilizer-based technology could see their constraints lifted via the ISP, which would address affordability and increase available quantities of fertilizer. Conversely, farmers "trapped" in agriculture—that is, who would be better divesting from agriculture—could receive a cash transfer to address the financial frictions preventing their relocation. Such a policy relies on the central planner's ability to observe farmer types for which elicitation is costly.

Second-best policies

ISP with resale markets (estimated policy in Zambia): Resale markets for fertilizers enhance allocative efficiency by reallocating fertilizer toward farmers in greater need, while generating income for the net sellers. The amount of fertilizer can be split across farmers, creating a snowball effect. However, this policy may introduce distortions (Diamond and Mirrlees, 1971; Mirrlees, 1986). When resale transaction costs are low, this second-best policy approximates the first-best policy in a decentralized manner. The adequacy of the subsidy hinges on the trade-off between a price distortion-induced efficiency loss, increased technology upgrade, and redistribution components.

ISP without resale markets: Without resale markets, the price effect benefits only ISP recipients. Meanwhile, farmers' ability to relax their credit constraint is reduced and farmers can only increase their migration by increasing their productivity in the medium term. Furthermore, unless the planner can elicit types and only provide the subsidy to farmers with the highest returns to upgrading, this policy would introduce a deadweight loss from the inability of farmers to efficiently distribute the subsidized fertilizer. This deadweight loss can be lowered if the cost of eliciting farmer types is low. Alternatively, the central planner could encourage and remove the frictions in resale markets.

Targeted cash transfer: The cash-transfer program given only to the recipients of the ISP in 2004 improves migration outcomes but only in the short run. The channel of increased income from upgrading is reduced for recipients. With this cash-transfer program, the multiplier effect of the subsidy disappears. However, with various estimates of the returns to a cash-transfer program, it may be a better alternative for poverty reduction—but only for the 8% who receive the transfer. Farmers that receive the cash transfer can fund migration, but farmers who do not experience unaltered outcomes. Unlike the ISP with resale markets, the policy's returns do not spill over to the other farmers (i.e. there is no snowball effect). Market frictions remain, and upgrade rates plummet.

*Untargeted cash transfer:*This cash-transfer program is given to all farmers residing in targeted areas. It relaxes the credit constraint for a larger number of households, which can then migrate. However, similar to the targeted cash transfer, upgrade rates are very low as a result of the transfer.

Optimal policy

If the central planner has a dual objective of moving farmers from a low to a high fertilizer adoption equilibrium while also redistributing income to those facing financial constraints, then resale markets could be an improvement over the no-subsidy alternative. In the Zambian agricultural system, a limited ISP randomly provided to farmers could lead to efficiency gains (Giné et al., 2022) and a rise in both adoption and migration rates. Carter et al. (2021) find that temporary subsidies can lead to long-lasting effects on adoption by moving farmers to a better fertilizer-use equilibrium. Based on their findings, an optimal policy may involve introducing the subsidy with resale markets and phasing out the subsidy once a critical mass of farmers upgrades their agricultural technology and starts using fertilizer. The ISP can then be phased out and replaced by an untargeted cash-transfer program. This optimal policy does not require the central planner to elicit farmers types and saves costly targeting expenses. Instead, the central planner can encourage resale markets and remove frictions that may lower the efficiency of these markets. In neighboring Malawi, Boone et al. (2013) show that combining cash transfers with ISPs can have a multiplicative impact of improving fertilizer adoption, increase farm production and further relax the credit constraint for individuals living in extreme poverty.

Conclusion

I examine the effects of a large-scale Zambian input subsidy program (ISP) on farmers' investment choices by focusing on agricultural upgrading (fertilizer use) and out-migration. Using the staggered rollout of the ISP as a natural experiment, I estimate a difference in differences and find that the ISP significantly increased both upgrade and out-migration rates. Building on these findings, I develop a static choice model to generalize the observed behaviors. The model incorporates key features, including resale markets for the subsidized fertilizer (with endogenous fertilizer prices), a credit constraint (that is relaxed by the ISP). I estimate the model, and compare the current ISP with resale markets to three revenue-neutral, counterfactual policies.

The findings suggest that a subsidy on agricultural inputs can simultaneously address the market frictions affecting both the adoption of fertilizer in agriculture and credit constraints. Alleviating credit constraints allows for the sorting of farmers based on comparative advantage, while the potential allocative inefficiency of subsidies is partially offset by the existence of resale markets.

The empirical part of this paper leverages a unique setting to examine the impact of an input subsidy on a variety of household decisions, also has limitations. First, I do not observe the destination of out-migrants or the origin of in-migrants, which limits the extent to which I can infer the changes in welfare for beneficiary households. I also do not directly observe resale markets, which implies a loss in precision regarding the demand for fertilizer within local areas. A third limitation stems from the frequency of data collection, which occurs every four years and does not allow me to distinguish between seasonal and long-term migration. Future work can explore the dynamic effects of these policies. Although migration decisions are not the sole objective of these policies, this paper is a first step in exploring the indirect impacts that policies might have on migration patterns over time and within countries. The findings can provide information to policymakers when deciding on the allocation of resources.

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A Appendix

A.1 Some context on rural antipoverty programs

A.2 Data and descriptives

First, Census Supervisory Areas (CSAs) were chosen within each district. Second, Standard Enumeration Areas (SEAs) were sampled from each CSA, and finally, households within each SEA were randomly chosen to be interviewed. In addition to the household surveys conducted in 2000, 2001, 2004, and 2008, the 2008 survey includes community-level information gathered from the community headman. This dataset provides information on basic features of communities, rules, constituencies, and distances to main provincial landmarks.

Table A.1: Number of administrative units in the sample

	2000	2001	2004	2008
Provinces	8	8	8	8
Districts	37	37	37	37
Census Supervisory Areas (CSA)	112	112	112	112
Standard Enumeration Areas (SEA)	394	394	394	394
Households	7,859	7,699	6,922	9,347
Communities				1,053

Notes: This table plots the sampling across years for the 1999/2000 Post Harvest Survey and its supplementary surveys.

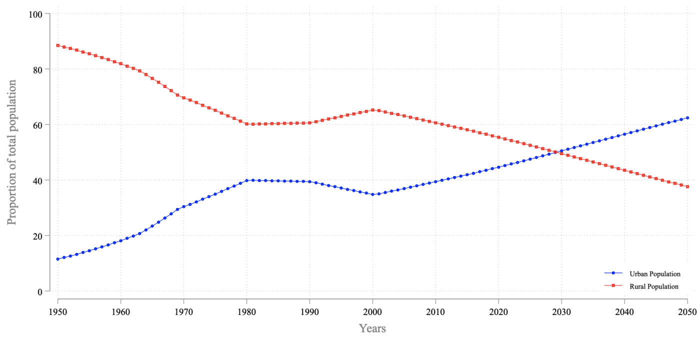


Figure A.1: Rural and Urban Population in Zambia (with projections)

Notes: This figure plots the evolution over time of both the urban and rural populations over the years. Source: United Nations, World Urbanization Prospects: The 2018 Revision.

Table A.2: Household receiving ISP

		2001		2004		2008	
		Total	Percent	Total	% Population	Total	% Population
Total ISP hh		0	0	496	7.17%	525	9.02%
		2001		2004		2008	
		Total	Percent	Total	% ISP subset	Total	% ISP subset
Received ISP	has out-migrant	0	0	226	46.56%	328	62.48%
	no out-migrants	0	0	270	54.44%	197	37.52%
	has in-migrant	0	0	131	26.41%	165	31.43%
	no in-migrants	0	0	365	73.59%	360	68.57%

Notes: This table shows the count and shares of households that receive the ISP among those who have out-migrants, and those who have in-migrants. The sample is all households who received the ISP at any point in the panel (either in 2004 or in 2008). For example: 226 households who had out-migrants in 2004 also received the ISP, and 270 had out-migrants in 2004 and did not receive the ISP. and the rates are contemporaneous. and whether they di Author's calculations using the Supplemental Survey to the 1999/2000 Post Harvest Survey - Zambia Data Documentation, revised June 2010.

Table A.3: Characteristics of households in the panel

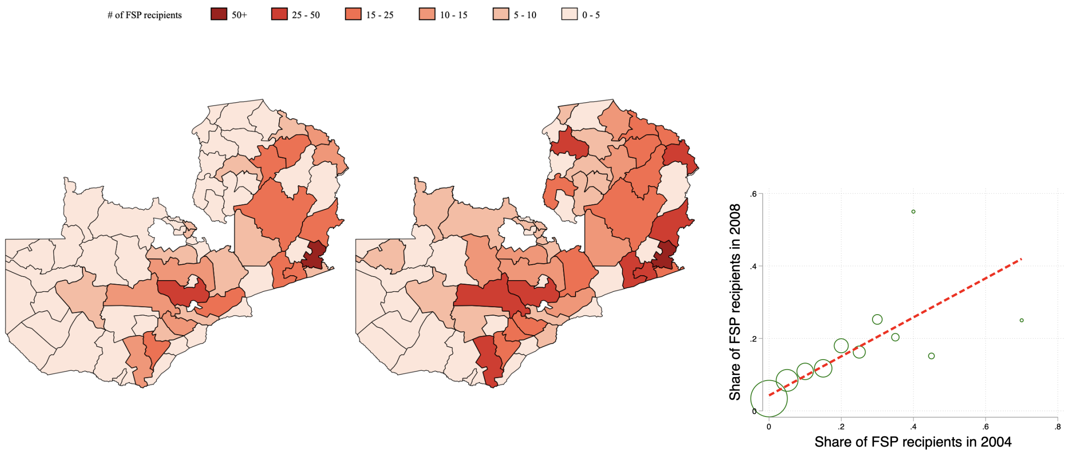
Panel A: Panel Classification of households		
	Frequency	Percent
Household is found in 2001,04,08	4,288	61.9
Household is found in 2001 only	1,273	18.4
Household is found in 2001 & 2004 only	1,070	15.15
Household is found in 2004 & 2008 only	52	0.8
Household is found in 2000 & 2008 only	230	3.3
Household is not found*	9	0.1
Household is found in 2000 only	777	-
Total number of households	7,699	-

* The household was interviewed in 2004 or 2008 but was not the same as the one interviewed in 2001

Panel B: household survey response status			
B.1 Non-migrant households	2001	2004	2008
Completed	6,922	5,419	4,301
Skipped & not interviewed	0	30	0
Currently away from home	0	0	55
Non-contact	337	362	0
Refusal	3	14	22
Dissolved	85	390	366
B.2 Migrant households	2001	2004	2008
Completed after moving to another village	0	0	269
Moved out of village	352	707	810
Total number of households	7,699	6,922	5,823

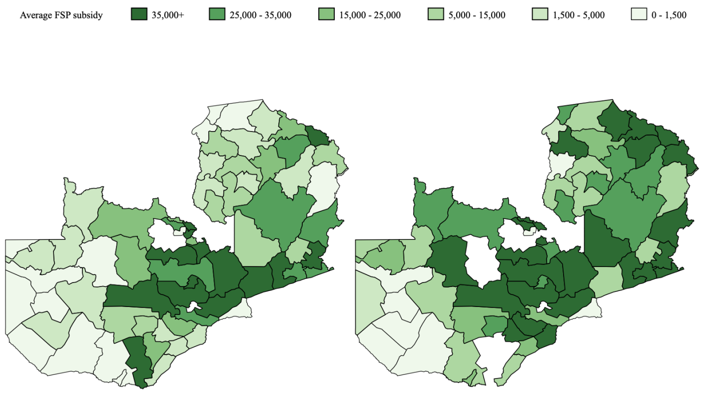
Source: This table details the sample of households. Panel A of A.3 shows when households are found in the panel, and Panel B displays the response statuses of households in the sample for each follow-up year of the panel. In section B.2. of Panel B, are the households I define as migrant households.

Figure A.2: Maps of ISP recipients per districts in 2004 and 2008



2004 | 2008 | Correlation between the share of recipients (in an SEA) in 2004 and 2008

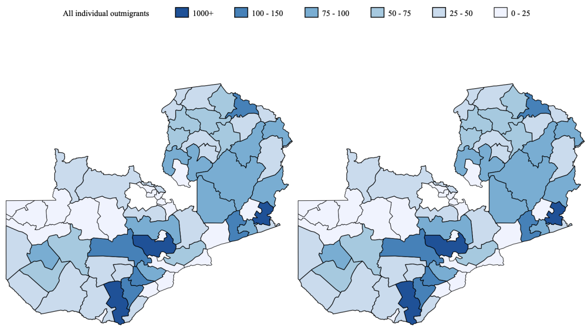
Notes: This figure presents two maps of the distribution of ISP recipients in the country in 2004 and in 2008, and a scatter plot of the correlation receiving the ISP in 2004 (x-axis of the plot on the right) and receiving the ISP in 2008 (y-axis). The sample is all ISP recipients. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.



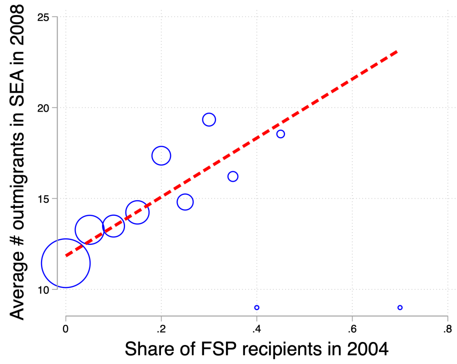
2004 | 2008

Figure A.3: Average amount (ISP) disbursed per household in 2004 and 2008 - by district

Notes: This figure presents two maps of the distribution of ISP amounts across provinces of Zambia in the country in 2004 and in 2008. The ISP amounts are measured by the multiplying the size of the subsidy (50% and 60%) by the price in the province. The sample is all provinces. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.



2004 2008



Average count of out-migrants in SEA in 2008 vs. Share of ISP recipients in 2004

Figure A.4: Maps of the number of individual out-migrants in 2004 and 2008 - Per district
Notes: This figure presents two maps of the distribution of out-migrants in Zambia in the years 2004 and in 2008, and a scatter plot of the correlation between the share of ISP recipients in 2004 (x-axis of the plot on the right) and the number of migrants in 2008 (y-axis). The sample is all villages in the panel. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.

A.2.1 More details on the context of the Zambian ISP

In response to generally low fertilizer take-up, the Zambian government has designed several programs to improve the adoption of fertilizer and improved seeds by addressing both the lack of liquidity and the low profitability of fertilizers. Until 2001, a loan program called the *Fertilizer Credit Program* was in place, allowing farmers to mitigate credit constraints. As a loan program, the *Fertilizer Credit Program* did not meet its repayment goals, achieving a repayment rate of only 30%. In 2001, the *Fertilizer Support program* (FSP) later renamed *Farmer Input Support Program* (FISP) replaced the *Fertilizer Credit Program*. The FSP provided a 50% subsidy to farmers with holdings between one and five hectares of land. This subsidy increased to 60% in the 2006/2007 season and reached 76% in the 2010/2011 season.

The FSP represented a substantial financial effort by the Zambian government. Between 2004 and 2011, the FSP alone accounted for 38% of Zambia's agricultural spending and 47% of the government's agricultural sector Poverty Reduction Program (Mason et al., 2013b).

Table A.4: Public budget: Agricultural Sector, 2004/05, Zambia

Program	Percent
Fertilizer Support program	38%
Personal Emolument	21%
Food reserve agency maize marketing	13%
Food Security Pack (PAM) & Emergency Drought Recovery Project	12%
Operational funds	11%
Irrigation development	3%
Irrigation development	3%
Infrastructure	2%

Notes: This table details the proportion of the agricultural budget allocated to the most expansive eight investment of the Zambian government in agriculture for the agricultural season 2004-2005. Source: World bank Fertilizer toolkit

Improving agricultural productivity is the main goal of this policy. However, such large investments could have substantial indirect impact on migrations to urban poles. The share of the population living in rural areas has been shrinking rapidly while the share of the population living in urban areas has been rising. This phenomenon happened concurrently with large investment in input subsidies.[49]

A.2.2 Timeline of agricultural programs

Zambia has a long history of fertilizer subsidy programs. In the wake of global structural adjustments initiated by the International Monetary Fund (IMF) and the World Bank, Zambia relied heavily on fertilizer subsidy programs to support its agricultural sector. With both a debt relief through the Heavily Indebted Poor Countries program and a transition from conditionality to direct budget support by the World Bank, the country was able to launch the *Fertilizer Support Program* (FSP) and scale up its subsidy agenda increasing from an average of roughly 40,000 metric tons of fertilizer delivered per year to about 65,000 metric tons per year (Minde et al., 2008). The FSP was a cash-only program, unlike previous credit programs; it subsidized fertilizer purchases at a at a 50% rate, focusing on maize production. In 2006 the program was extended to 84,000 metric tons per year and the subsidy was raised to 60% (Mason et al., 2013). In conjunction with the FSP and on a much smaller scale, the Food Security Pack or Program Against Malnutrition (PAM), an agricultural input grant targeting vulnerable households with holdings under 1 hectare was put in place. According to Mason et al. (2013), this program has very low political inference.

According the program guidelines, first a cooperative or farmer was chosen and then subsidized inputs were given to farmers. Selection criteria apply to both components and include wealth, financial capacity at the cooperative level, field size and financing capacity criteria.

[49] See Figure A.1 showing the evolution and previsions of urban and rural populations in Zambia.

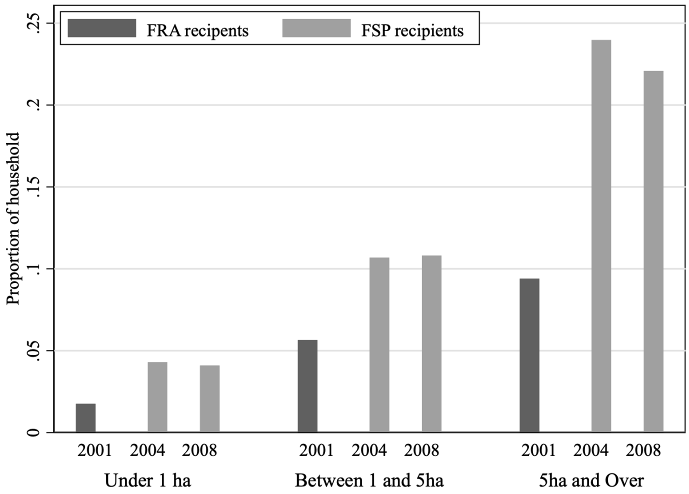
Farmer organizations as well as cooperatives are channels through which FSP inputs are distributed. Farmers are required to be members of a cooperative or an organization, and each organization proposes eligible farmers to benefit from the subsidy.
Below is a short presentation of the ex-ante eligibility rules on each layer.

Cooperative or farmer group eligibility rules (partially quoted from World Bank, 2010)
1. Written by-laws to manage their funds and have appropriate accountability mechanisms;
2. Have an executive committee structure and should operate a bank account;
3. Demonstrate the need and ability to use the inputs well;
4. Should be registered by the Registrar of Cooperative Societies and Registrar of Societies;
5. Should have no outstanding loans from the past seasons;
6. Should be located in an agricultural area and should be engaged in agricultural activities;
7. Should demonstrate knowledge in cooperative and agribusiness 'management.

Farmer selection criteria (partially quoted from World Bank, 2010)
1. Be a small scale farmer and involved in farming within the cooperative coverage area;
2. Has the capacity to grow 1-5 hectares of maize;
3. Have the capacity to pay 40% of the cost of inputs;
4. Should not concurrently benefit from the Food Security Pack;
5. Should not be a defaulter from FRA and/or any other agricultural credit program.

These selection criteria do not fully apply. Figure A.5 shows the distribution of FSP beneficiaries over the years and across land holdings. I use Mason et al. (2013b) definition of land holdings as the sum of cultivated and fallow land. With this definition of landholdings, a striking inadequacy to FSP guidelines arises: a high proportion of the sample's "over five hectares landholders" receive a subsidy, when they should not be eligible. Similarly, a few farmers with landholdings under one hectare receive the subsidy; this proportion is however substantially than that of medium landholders. This limited discrepancy is likely due to the existence of the PAM program for farmers with landholdings under one hectare.

Figure A.5: Proportion of FRA and FSP recipients across effective field size



Notes: This figure illustrates the proportion of households owning less than 1 hectare, 1-5 hectares, and more than 5 hectares of land who received either the input subsidy program (targeted at landowners with 1-5 hectares) or the FRA program (targeted at those with less than 1 hectare). The majority of households fall into the less than 1 hectare or 1-5 hectare categories, with only a small proportion in the 5+ hectare group, reflecting the panel's sampling strategy.

A.3 More on the reduced-form estimation

A.3.1 Source of variation

The post-harvest panel starts in 2000 (the baseline year) and follows-up with households in 2001, 2004, and 2008. The 2004 surveys constitute the first round of data after the introduction of the subsidy policy. Given this data structure, I observe four village groups: i) areas that never received the ISP subsidy, ii) areas that received the ISP subsidy in 2004, iii) areas that received the ISP subsidy in 2008 and finally iv) areas that received the subsidy in both 2004 and 2008.

Table A.5: Baseline characteristics of households in villages receiving the ISP at different times 2004, 2008

	(1)	(2)	(3)	(4)	(5)	(6)
	Cohorts				t-tests	
Variable in 2001	2004	2008	No ISP	Overall	p-value	
Average in villages	T	C1	C2		T-C1	T-C2
HH size	6.325	5.893	5.683	6.065	0	0
Men headed HH	.801	.777	.742	.779	.066	0
HH outmigrated	.044	.045	.049	.046	.995	.434
# of migrants in HH	.138	.151	.134	.139	.419	.815
Net income$^{\times}$	12.666	9.706	8.642	10.993	0	0
Wealth Index	.141	-.115	-.196	0	0	0
HH head education*	5.654	5.354	4.807	5.354	.03	0
Landholding size	3.215	2.908	2.521	2.958	.005	0
N	4,137	1,213	2,340	7,690		
Control in 2004		Yes	Yes			
Control in 2008		No	Yes			

Notes: This table shows average values for the cohort of villages that received the ISP in the 2004 (early treated), in 2008 (late treated), and villages that never receive the subsidy in the period of the study. The 't-test' column shows individual p-values for tests of covariates. The analysis focuses on the 2004 as a treatment group and I show results for that cohort. In line with Callaway and Sant'Anna (2021), the row 'Control in 2004' shows which cohorts make up the control group for the estimation of the short term effects for the 2004 treatment cohort, while 'Control in 2008' shows which cohorts make up the control group for the estimation of the medium term effects. $^{\times}$: income measured in 100K ZK. *: The household's head education is measured in years.

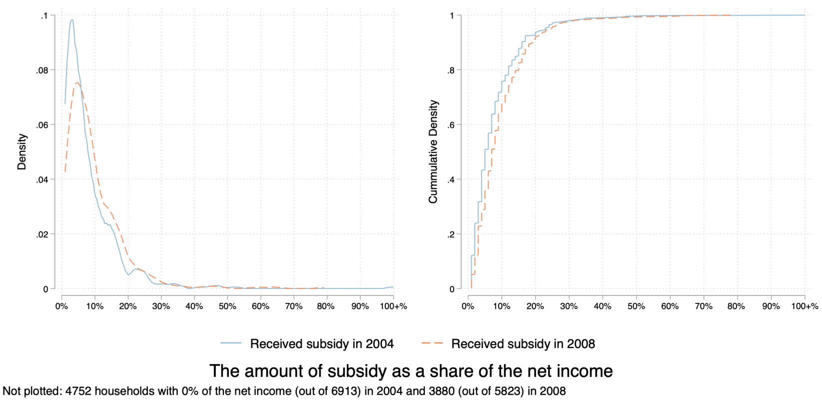


Figure A.7: Total amount of the subsidy over the net income of the household

Notes: This figure plots the density and cumulative distribution of the share of the income that the ISP transfer represent for households that receive the subsidy for each of the two treatment groups (i.e. those who received the subsidy early, in 2004; and those who received the subsidy late, in 2008). The variable plotted is $\frac{\text{Amount of Subsidy}}{\text{Subsidy + Total other income}}$.

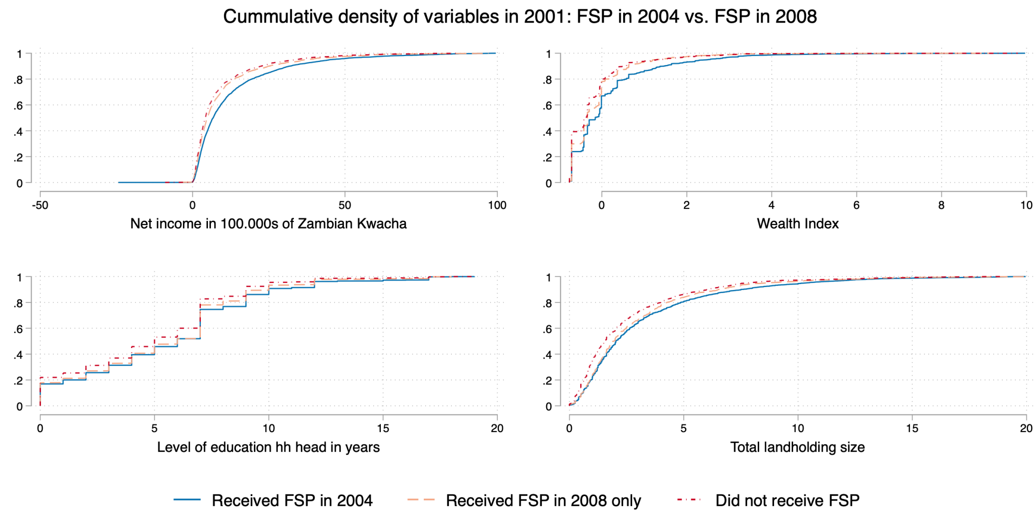


Figure A.6: Baseline characteristics between households in areas that received the subsidy in 2004, 2008 and in areas that did not receive the subsidy

Notes: This figure plots the cumulative distribution in 2001 of the net income, the wealth, the level of education of the household head, and the total landholding size for each of the two treatment groups (i.e. those who received the subsidy early, in 2004; and those who received the subsidy late, in 2008).

Table A.6: Count of villages per treatment years

(1) Years Receiving ISP	(2) Number of villages	(3) % of total villages	(4) Treatment status
2003, 2004, 2007, and 2008	133	33.76%	ISP 2004
Never	115	29.19%	No ISP
2007, and 2008	45	11.42%	ISP 2008
2003, and 2004	28	7.11%	ISP 2004
2004, 2007, and 2008	17	4.31%	ISP 2004
2004, only	16	4.06%	ISP 2004
2008, only	10	2.54%	ISP 2008
2003, 2007, and 2008	7	1.78%	ISP 2008
2003, 2004, and 2008	7	1.78%	ISP 2004
2003, 2004, and 2007	5	1.27%	ISP 2004
2003, only	3	0.76%	No ISP
2007, only	3	0.76%	No ISP
2004, and 2007	3	0.76%	ISP 2004
2004, and 2008	2	0.51%	ISP 2004

Notes: This table shows the count of villages, for each combination of treatment years, ranked by the count of villages in each category. Column (1) shows the combinations of panel years in which at least one household in the village is treated. Column (2) shows the number of villages in each of those treatment combinations, Colum (3) the share of the total villages that is in this treatment combination, and Column (4) the treatment status used in the analysis. The analysis does not account for recall years (2003, and 2007) to measure treatment to avoid conflation of treatment and resale. The treatment years 2003, 2004, 2007, and 2008 correspond to the agricultural seasons 2002/2003, 2003/2004, 2006/2007, and 2007/2008. The agricultural years 2002/2003, and 2006/2007 are based on farmer recall from the panel years 2003/2004, and 2007/2008 respectively. Most villages are treated in one year and get treated in subsequent years. Only a handful of villages get treated in years that are not adjacent.

Table A.7: Descriptive statistics: Check of the randomness of attrition

Panel A: 2001 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.45	7347	6.06	352	6.43	7699	3.81
	Gender of hh head	0.78	7347	0.77	352	0.78	7699	0.10
	Age of the hh Head	43.74	7347	40.85	352	43.61	7699	14.08
	Wealth: plough/harrow/oxcart	0.02	7347	-0.25	352	0.01	7699	23.54
	hh head is relative to headman	0.30	6922	.	.	.	.	.
Data from 2001	Dwelling has concrete walls	0.24	6922	.	.	.	.	.
	Dwelling has traditional doors	0.63	6922	.	.	.	.	.
	Dwelling has traditional floor	0.83	6922	.	.	.	.	.
	hh head is single	0.03	6912	.	.	.	.	.
	hh head is monogamous	0.68	6912	.	.	.	.	.
	hh head is polygamous	0.10	6912	.	.	.	.	.
	hh head is divorced	0.06	6912	.	.	.	.	.
	hh head is widowed	0.11	6912	.	.	.	.	.
	hh head is separated	0.01	6912	.	.	.	.	.
	hh head went over primary	0.22	6912	.	.	.	.	.
	Crop land: purchased	0.03	7347	.	.	.	.	.
	Crop land: inherited	0.26	7347	.	.	.	.	.
	Crop land: allocated	0.48	7347	.	.	.	.	.
	Crop land: rented or borrowed	0.04	7347	.	.	.	.	.
	Crop land: walked in	0.11	7347	.	.	.	.	.

Panel B: 2004 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.51	6215	6.12	707	6.47	6922	7.43
	Gender of hh head	0.78	6215	0.78	707	0.78	6922	0.01
	Age of the hh Head	44.22	6215	40.71	707	43.86	6922	39.08
	Wealth: plough/harrow/oxcart	0.05	6215	-0.16	707	0.03	6922	25.09
	hh head is relative to headman	0.31	6215	0.21	707	0.30	6922	30.18
Data from 2001	Dwelling has concrete walls	0.24	6215	0.25	707	0.24	6922	1.21
	Dwelling has traditional doors	0.63	6215	0.65	707	0.63	6922	0.68
	Dwelling has traditional floor	0.83	6215	0.78	707	0.83	6922	10.35
	hh head is single	0.03	6207	0.05	705	0.03	6912	7.74
	hh head is monogamous	0.68	6207	0.71	705	0.68	6912	3.68
	hh head is polygamous	0.10	6207	0.07	705	0.10	6912	7.50
	hh head is divorced	0.07	6207	0.06	705	0.06	6912	0.50
	hh head is widowed	0.11	6207	0.10	705	0.11	6912	1.94
	hh head is separated	0.01	6207	0.02	705	0.01	6912	0.71
	hh head went over primary	0.22	6207	0.30	705	0.22	6912	24.22
	Crop land: purchased	0.03	6215	0.03	707	0.03	6922	1.51
	Crop land: inherited	0.29	6215	0.20	707	0.28	6922	23.75
	Crop land: allocated	0.50	6215	0.51	707	0.50	6922	0.26
	Crop land: rented or borrowed	0.04	6215	0.08	707	0.04	6922	30.51
	Crop land: walked in	0.12	6215	0.11	707	0.12	6922	0.18

Panel C: 2008 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.69	4744	6.09	1079	6.58	5823	22.97
	Gender of hh head	0.79	4744	0.79	1079	0.79	5823	0.15
	Age of the hh Head	44.66	4744	41.95	1079	44.16	5823	32.30
	Wealth: plough/harrow/oxcart	0.10	4744	-0.14	1079	0.06	5823	46.18
	hh head is relative to headman	0.32	4744	0.26	1079	0.31	5823	14.41
Data from 2001	Dwelling has concrete walls	0.23	4744	0.28	1079	0.24	5823	13.29
	Dwelling has traditional door	0.65	4744	0.53	1079	0.63	5823	59.14
	Dwelling has traditional floor	0.84	4744	0.81	1079	0.83	5823	5.77
	hh head is single	0.03	4738	0.03	1078	0.03	5816	0.66
	hh head is monogamous	0.68	4738	0.70	1078	0.69	5816	1.76
	hh head is polygamous	0.11	4738	0.09	1078	0.11	5816	2.24
	hh head is divorced	0.06	4738	0.08	1078	0.06	5816	4.10
	hh head is widowed	0.11	4738	0.09	1078	0.11	5816	3.23
	hh head is separated	0.01	4738	0.01	1078	0.01	5816	3.94
	hh head went over primary	0.21	4738	0.26	1078	0.22	5816	16.59
	Crop land: purchased	0.01	8268	0.03	1079	0.02	9347	9.67
	Crop land: inherited	0.17	8268	0.27	1079	0.18	9347	60.43
	Crop land: allocated	0.29	8268	0.48	1079	0.32	9347	156.43
	Crop land: rented or borrowed	0.02	8268	0.06	1079	0.02	9347	88.92
	Crop land: walked in	0.06	8268	0.13	1079	0.07	9347	67.43

Notes: This table presents descriptive statistics for households in the study sample, comparing households that migrated in the specified years to those that did not migrate. It allows for a comparison of the characteristics of the migrant households (those who migrated entirely), and those who stayed behind. It provides means and counts for key household characteristics, as well as an overall population mean. The final column displays F-statistics testing for differences between the means of the migrating and non-migrating households. Panel A provides statistics for households that migrated in 2001. Panel B provides statistics for households that migrated in 2004 (excluding those who migrated in 2001). Panel C provides statistics for households that migrated in 2008 (excluding those that migrated in 2001 or 2004).

Table A.8: Quantity and revenue per hectare (ha) in 2001 for ISP recipients in 2004, by migration status in 2008

Panel A: Household migrated in 2008

2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Migrated	Stayed	Diff.	P-value	Migrated	Stayed	Diff.	P-value
Total land holdings	9.53	5.28	81%	0			.	
Adults in the household	4.16	4.39	-5%	.033			.	
Kg of maize	1085	1021	6%	0			.	
GV of maize	245032	227986	7%	0			.	
GV of all	348680	346478	1%	.112			.	
GV of cash crops	17804	30761	-42%	.635			.	
GV of other staples	63352	60578	5%	.792			.	
GV of high value food	22492	27153	-17%	.889			.	

Panel B: Household with 1+ in-migrant in 2008

2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Inmig.	No inmig.	Diff.	P-value	Inmig.	No inmig.	Diff.	P-value
Total land holdings	5.68	6.07	-7%	0	5.8	5.17	12%	.041
Adults in the household	4.76	3.94	21%	0	6.66	5.21	28%	0
Kg of maize	1033	1028	0%	0	966	878	10%	0
GV of maize	219829	241390	-9%	.004	715023	616373	16%	0
GV of all	341323	352501	-3%	.11	1085416	936524	16%	0
GV of cash crops	38171	19307	98%	0	127045	115201	10%	.001
GV of other staples	58693	63343	-7%	.284	155017	97158	60%	.052
GV of high value food	24630	28461	-13%	.748	87596	105605	-17%	.461

Panel C: Household with 1+ out-migrant in 2008

2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Outmig.	No outmig.	Difference	P-value	Outmig.	No out-migrants	Difference	P-value
Total land holdings	5.56	6.28	-12%	0	5.59	5.37	4%	.041
Adults in the household	4.9	3.64	35%	0	6.79	4.42	54%	0
Kg of maize	1078	966	12%	0	1039	708	47%	0
GV of maize	224586	238055	-6%	.001	753906	508279	48%	0
GV of all	349180	343600	2%	.055	1109458	841663	32%	0
GV of cash crops	36798	18515	99%	0	153395	59489	158%	0
GV of other staples	65806	54527	21%	.416	110925	165616	-33%	.001
GV of high value food	21991	32504	-32%	.998	91030	104578	-13%	.599

Notes: This table reports land holdings, the household size, the quantity and gross value (GV) of maize, and other crops per hectare in 2001 and 2008 for ISP recipients in 2004, categorized by household migration status in 2008. The outcomes are presented separately for households that migrated entirely, those with at least one in-migrant, and those with at least one out-migrant. The differences in means (Diff.) are calculated between households that migrated versus stayed (Panel A), households with in-migrants versus those without (Panel B), and households with out-migrants versus those without (Panel C). P-values indicate the statistical significance of these differences. ”GV” represents the gross value of crops per hectare, including maize, cash crops, other staples, and high-value food crops. All differences are expressed as percentages where applicable.

A.4 Comparing households with different labor allocation choices

Table A.9: Characteristics of households across upgrading decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Upgrade occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
	Household characteristics							
HH size	5.73	5.48	6.59	6.30	6.73	6.38	7.78	7.30
Share upgraders	.18	0	.46	0	.46	1	.72	1
Share with in-migrant	0	.01	0	.01	0	.05	0	.05
Share with out-migrant	.07	.36	.10	.40	.10	.56	.11	.62
Number Out-migrants	.12	.94	.12	1.25	.11	1.22	.18	1.42
Education out-migrants	.40	0	.46	0	.41	0	.75	0
	Household's head characteristics							
HHH education	5.07	4.51	6.57	5.69	5.71	5.90	6.65	6.71
Share woman	.20	.20	.17	.15	.14	.15	.14	.18
	Farming characteristics							
Total landholding	2.39	1.83	2.86	2.20	3.40	2.89	4.69	4.28
Share of maize	.56	.52	.56	.55	.55	.55	.57	.60
Fertilizer per ha maize	60	33	138	114	110	229	192	297
Fertilizer per ha total	27	12	62	54	51	107	103	163
Maize Yields	1622	1321	1962	1524	1878	1953	2190	2324
	Financial characteristics							
Remittances received	21349	97548	34631	133835	28419	155842	34867	325285
Remittances sent	13986	61467	20722	143945	23642	228724	34946	326411
Wealth index 2001	-.10	-.17	.28	.28	.18	.18	.76	.76
N	2473	1567	624	624	407	407	633	633

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to upgrade their agricultural technology. I show this mean for three different decision points: Columns (1) and (2) are those who never upgraded, Columns (3) and (4) are those who upgraded in 2004, and did not upgrade subsequently, Columns (5) and (6) are the households who only upgraded in 2008 and finally Columns (7) and (8) are those who upgraded both in 2004 and 2008. This table shows that upgraders are on average richer than non-upgraders. If further shows that those who upgraded in both 2004 and 2008 and substantially richer than other households. And that at baseline the households with most labor (larger household sizes), and land had high yields and were upgraders.

Table A.10: Characteristics of households across outmigration decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Outmigration occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
	Household characteristics							
HH size	5.09	6.17	7.03	6.13	6.26	6.05	9.05	6.48
Number Out-migrants	.07	0	.23	0	.09	1.96	.25	2.25
Share upgraders	.25	.23	.37	.23	.37	.37	.47	.50
Share with in-migrant	0	.01	0	.01	0	.02	0	.07
Share with out-migrant	.05	0	.18	0	.07	1	.17	1
Education out-migrants	.28	0	.91	0	.23	0	.93	0
	Household's head characteristics							
Share woman	.15	.10	.21	.17	.20	.25	.18	.25
HHH education	5.86	5.55	5.69	5.25	5.28	5.19	5.5	5.80
	Farming characteristics							
Total landholding	2.38	2.13	3	2.33	3.26	2.72	4.11	3.39
Share of maize	.56	.52	.56	.56	.55	.55	.57	.58
Fertilizer total	46	56	50	72	44	66	58	93
Fertilizer maize	99	121	110	164	97	147	123	181
Maize Yields	1702	1624	1871	1808	1867	1722	1996	1824
	Financial characteristics							
Remittances received	23105	101743	35749	181735	19933	140002	35662	274593
Remittances sent	17706	88786	17446	201084	17140	138898	30326	268956
Wealth index 2001	-.05	-.05	.15	.15	.11	.11	.55	.55
N	2080	1174	610	610	812	812	635	635

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to have out-migrants. I show this mean for three different decision points: Columns (1) and (2) are those who never sent out-migrants, Columns (3) and (4) are those who sent out-migrants in 2004, and did not send out-migrants subsequently, Columns (5) and (6) are the households who only sent out-migrants in 2008 and finally Columns (7) and (8) are those who sent out-migrants both in 2004 and 2008. This table shows that households that sent out-migrants are on average richer than those he did not. If further shows that those who sent out-migrants in both 2004 and 2008 and substantially richer than other households. And that at baseline the households with most labor (larger household sizes), tend to send more out-migrants. Finally, households with out-migrants both send and receive more remittances.

Table A.11: Characteristics of households across inmigration decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Inmigration occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
			Household characteristics					
HH size	6.57	6.23	5.94	.	7.11	6.80	7	6.36
Share upgraders	.37	.40	.34	0	.40	.51	.38	.38
Share with in-migrant	0	0	0	0	0	1	0	0
Share with out-migrant	.09	.52	.10	0	.20	.67	.09	.80
Number Out-migrants	.12	1.08	.14	.	.33	1.70	.10	2.05
Education out-migrants	.43	0	.51	.	1.38	0	.50	0
			Household's head characteristics					
HHH education	5.46	5.44	6.11	.	5.01	5.15	5.21	5.25
Share woman	.17	.20	.20	0	.33	.41	.25	.34
			Farming characteristics					
Total landholding	3.17	2.58	2.54	.	3.88	4.32	3.27	2.97
Share of maize	.55	.56	.57	.	.60	.58	.56	.55
Fertilizer per ha maize	105	142	99		99	201	107	180
Fertilizer per ha total	47	69	48		53	93	51	77
Maize Yields	1843	1716	1755		1626	1945	1931	1737
			Financial characteristics					
Remittances received	23137	159927	34464		30086	227614	34895	238670
Remittances sent	17644	155509	22567		23722	173409	26658	231895
Wealth index 2001	.14	.14	.12	.12	.5	.5	.27	.27
N	2212	2212	508	508	83	83	188	188

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to host in-migrants. I show this mean for three different decision points: Columns (1) and (2) are those who never host in-migrants, Columns (3) and (4) are those who host in-migrants in 2004, and did not host in-migrants subsequently, Columns (5) and (6) are the households who only host in-migrants in 2008 and finally Columns (7) and (8) are those who host in-migrants both in 2004 and 2008. This table shows that households that host in-migrants are on average similar in wealth to those who did not. If further shows that at baseline the households with most labor (larger household sizes), tend to host more in-migrants. These estimates should be interpreted carefully as the in-migration variable is a proxy of true in-migration.

A.5 Mechanisms

A.5.1 More details on resale markets

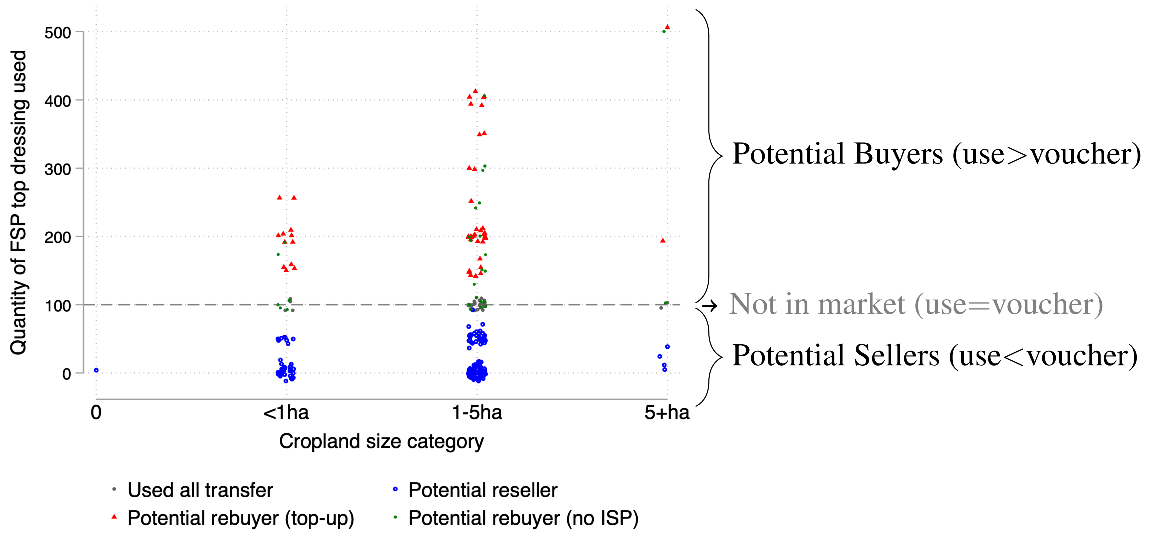
Figure A.9 plots the self-reported source of fertilizer used in farms. Panel 1 shows the source of fertilizer used in 2004 for households that did not migrate in 2008, and Panel 2 shows the sub-sample of households that migrated in 2008. Each graph plots fertilizer used by farmers owning farms of different sizes against the amount of fertilizer used from each source.[50]

[50] In the sample of Zambian small holders, only 20% report receiving the subsidized fertilizer on time for the 2003-2004 agricultural season. This implies that a large amount of fertilizer used in a given season is from left

On the far left two graphs, I plot the fertilizer used on the farm, stemming from the fertilizer subsidy program. The red-dashed line is the 100kg voucher received by all farmers. Any farmer group using more than this amount has likely obtained their vouchers from other farmers (or through other unknown means), and any farmers using less than the red-dashed line have potentially sold their voucher to another farmer. The far-right panel plots the distribution of farm sizes in the sample. Most farms in the sample (1-5 hectares) use exactly the amount provided via the voucher subsidy and supplement with commercial markets. However, some farmers — with very large farms — use more subsidized fertilizer than officially received, and farmers with small farms use less than they have received. This implies a redistribution — across farmers, based on farm sizes and needs.

overs from the previous season. This further implies that to use the fertilizer at the appropriate time in the planting season, most farmers need use left-over fertilizer (of lower quality), commercial or resale markets. Another implication of this delay is that migration becomes in this case more attractive than agriculture because of the lost revenue in agriculture.

Panel A: Top-dressing fertilizer



Panel B: Basal fertilizer

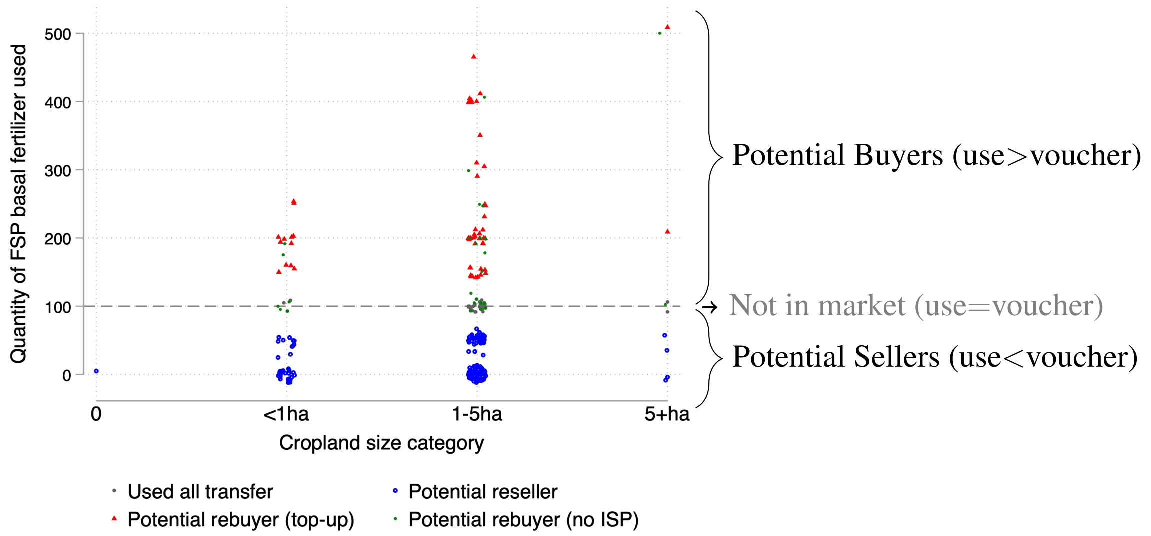


Figure A.8: Subsidized fertilizer used on farm compared to quantity transferred

Notes: This figure shows the distribution of fertilizer used, against the (official) ISP fertilizer quantity for top-dressing fertilizer (top row) and basal fertilizer (bottom row). Using self-reported data on top-dressing fertilizer for the year 2004 from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel). The horizontal line is 100kg (the amount received by farmers). Each dot represents the quantity of fertilizer used by one household with a random small perturbation to get a clearer representation of the number of households. The potential resellers are those who report to have used less than the 100kg received, and the potential re-buyers are those who report using more than 100kg.

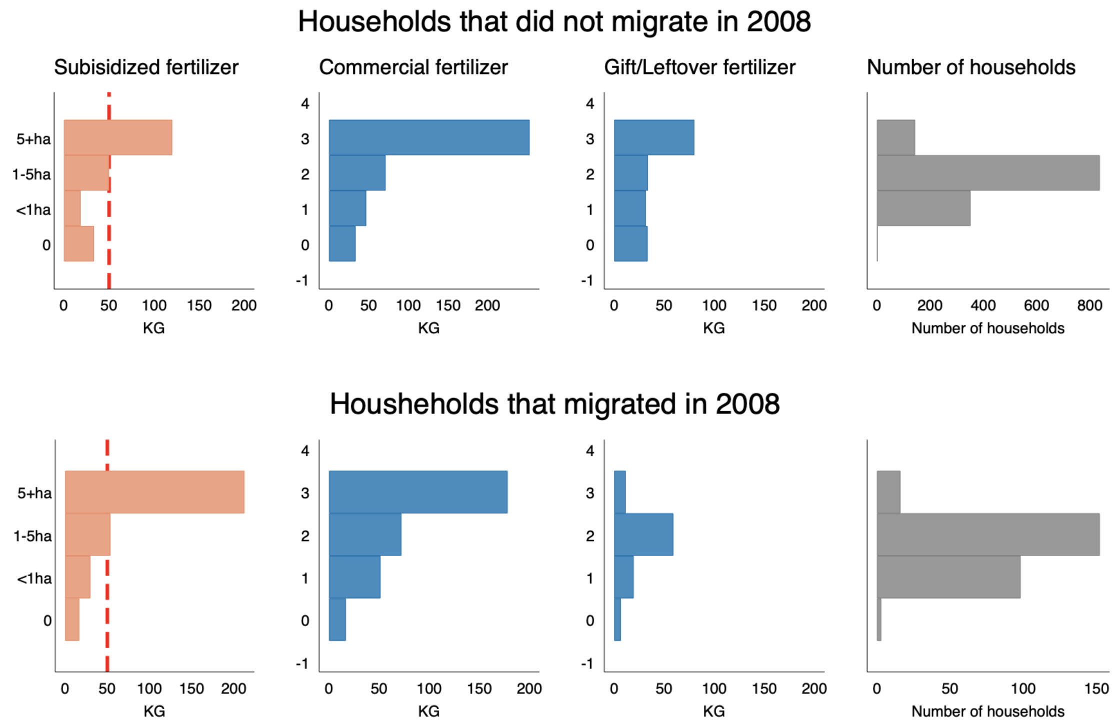


Figure A.9: Source of fertilizer used on the farm in 2004

Notes: This figure illustrates the sources of fertilizer used in 2004 by households that did not migrate (top row) and those that migrated in 2008 (bottom row), if they used any fertilizer at all. The first column represents ISP fertilizer use, the second column shows commercial fertilizer use, the third column reflects fertilizer obtained as a gift or leftover from previous seasons (low quality), and the fourth column depicts the distribution of farm sizes. The majority of farms are between 1 and 5 hectares. The figure highlights that farmers who migrated tended to use marginally more fertilizer from the subsidy program in 2004 compared to their non-migrant counterparts. It also shows that fertilizer use varies across different farm sizes, with smaller farms using lower quantities of fertilizer, often well below the allocated amount (indicated by the dashed vertical line), suggesting the potential for resale. The data is self-reported from the 1999-2000 post-harvest survey and its supplemental panel surveys.

A.6 SUTVA test for difference and difference

A first issue with the estimation of the difference-in-differences is the possibility that the stable unit treatment value assumption (SUTVA) does not hold. In the Zambian ISP setting that would imply two things: a) the spillover effects could occur across treatment units, i.e. farmers in treated areas selling to farmers in control areas, and thus relaxing credit constraints for farmers in the treated areas, while increasing access to fertilizer in control areas. With these spillovers, migration is overestimated — as the control group increases its demand and thus puts pressure on fertilizer prices — and upgrading is underestimated as the control group would adopt because of the ISP; b) the roll-out of the subsidy should also affect the network of fertilizer suppliers, thus making it easier for farmers in control groups to adopt fertilizer due to the ISP.

Both channels — through trade across treatment status and through the network of suppliers

— could bias the results presented in the paper. There are however limitations in the panel that hamper my ability to check for the existence of these sources of the SUTVA violation.

The sampling of villages[51] is such that villages are unlikely bordering each other. However, to check for the importance of spillovers in our sample, I look at the variations in the price of commercial fertilizer across high and low treatment density areas. If spillovers are important, the expectation is that high treatment density areas to have more variations in prices (both a potential increase in prices if demand effects dominate or decrease in prices if supply network effects dominate). The results are presented in Figure A.10.

Prices have not significantly changed in for control households located in areas with a high concentration of ISP recipients in 2004. Albeit representing a large portion of farmers in Zambia, the 1 to 5 hectare holders do not have as much market power as would larger farms, and in 2004, at the onset of the ISP the effect of the subsidy may not have been as important on national prices as they would have been in the later years of the ISP.

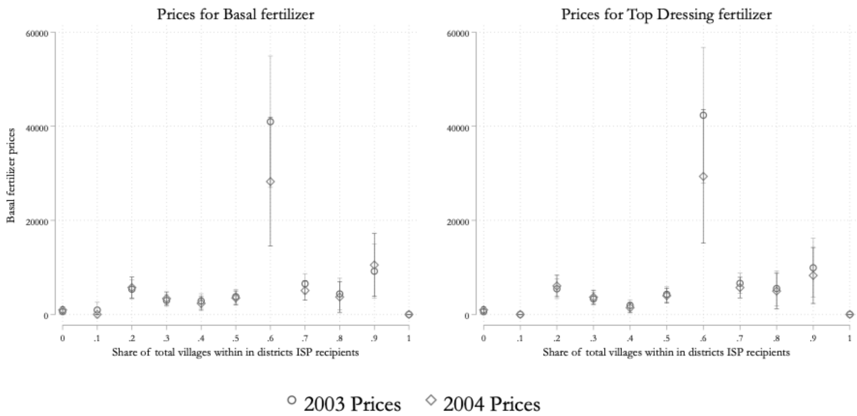


Figure A.10: Sutva test: change in fertilizer prices for non ISP recipients, depending on concentration of ISP villages in districts

Notes: This figure shows the relationship between fertilizer prices and the share of villages within districts that are ISP recipients, for both Basal (left panel) and Top Dressing fertilizer (right panel). Circles denote 2003 prices, while diamonds represent 2004 prices. The vertical lines indicate 95 percent confidence intervals. The figure examines potential spillover effects from the ISP rollout, which could arise if fertilizer from treated areas was sold in control areas or if the ISP altered the network of fertilizer suppliers. Prices have not significantly changed for control households located in areas with a high concentration of ISP recipients in 2004, suggesting that spillovers did not have a substantial effect on commercial fertilizer prices during this period.

[51] These villages correspond to Standard Enumeration Areas (SEA) and are the least aggregated and include typically one village (see Table A.1 of the Appendix).

Table A.12: Impact of the Volume of Subsidy on Migration Decisions of Individuals

	(1) Indiv - Rate Out	(2) Indiv - Count Out
Extra dollar subsidy	0.00257***	0.0105***
	(0.000360)	(0.00152)
Square extra dollar subsidy	-1.71 $\cdot 10^{-06}$***	-3.10 $\cdot 10^{-6}$*
	(3.77 $\cdot 10^{-7}$)	(1.84 $\cdot 10^{-06}$)
Total in-kind and cash remittances	0.000193**	0.000394
	(7.98e-05)	(0.000254)
Constant	0.0930***	0.301***
	(0.000663)	(0.00276)
Observations	31,078	31,078
R-squared	0.008	0.020
Number of hhcode	11,166	11,166
Household and year FE	yes	yes

Notes: This table presents the impact of the volume of subsidy on migration decisions of individuals. Column (1) reports the results for the individual rate of out-migration (Indiv - Rate Out), and column (2) reports the results for the individual count of out-migrants (Indiv - Count Out). The coefficients for the extra dollar subsidy and its squared term indicate a nonlinear effect on migration decisions, with positive but diminishing returns. The total in-kind and cash remittances variable shows a positive effect on migration in column (1), though the effect is not statistically significant in column (2). All regressions include household and year fixed effects. Standard errors are robust and are reported in parentheses. p<0.01, p<0.05, and p $<$ 0.1 denote statistical significance at the 1

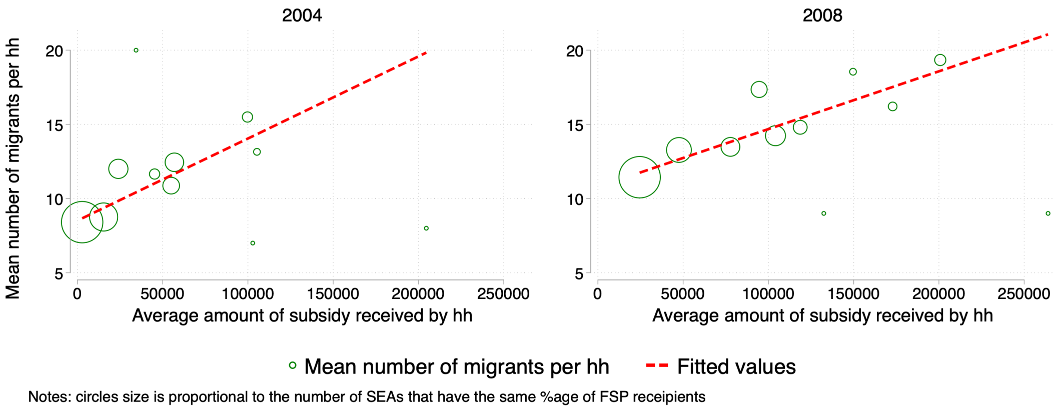


Figure A.11: Impact of the Volume of Subsidy on Migration Decisions of Individuals

Notes: This figure plots the correlation between the computed amount of the transfer through he ISP, and the number of migrants per household in 2004 (left) and in 2008 (right). It shows that (a) there is a positive correlation between the amount received and the number of migrants, consistent with the fact that farmers who receive larger transfers, generate more income to fund migration, and (b) that the correlation is stronger for those who received the ISP in 2004.

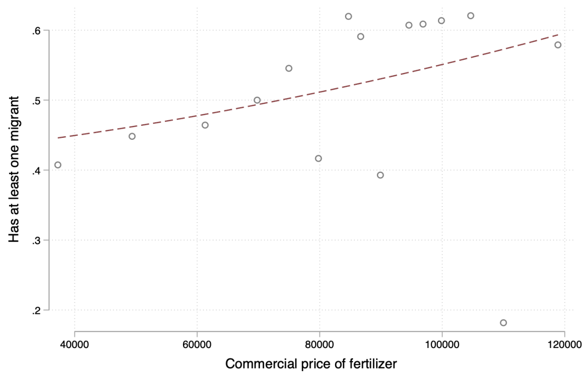


Figure A.12: Commercial price of fertilizer vs. extensive individual migration

Notes: This figure shows the correlation between the commercial price of fertilizer, and the likelihood of sending migrants out of the village.

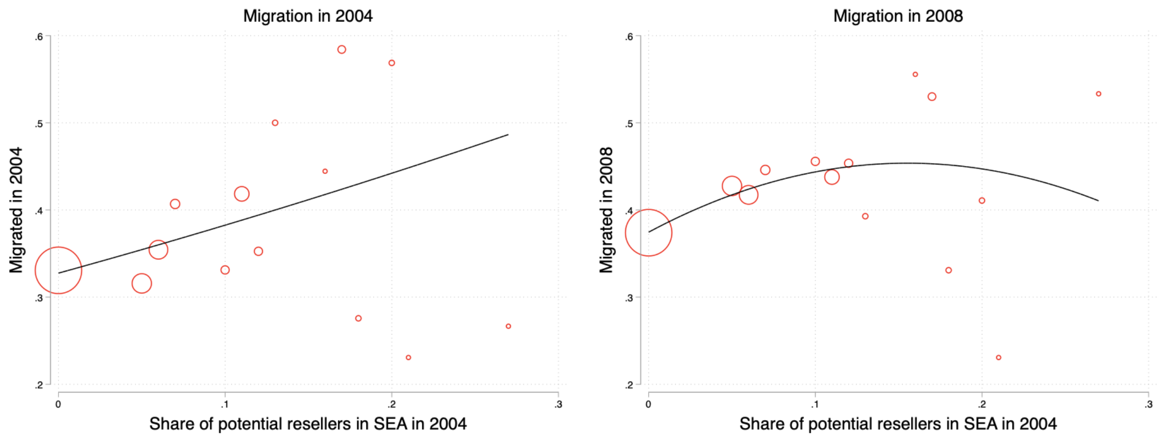


Figure A.13: Migration in 2004 and 2008 by share of potential resellers in a villages

Notes: This figure shows plots on the left the correlation between migration and the share of farmers who use less fertilizer than they (should have) received —these are potential resellers. The left panel plots this correlation for 2004 migration, and the right panel for migration that occurred in 2008, with respect to the share in 2008. This figure allows us to understand the correlation between potential sales with short term (left) and long term (right) migration. The underlying data are self-reported data from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel). In 2004, villages with the most potential resellers are also those with the most households sending out-migrants. This increase tapers off as time goes by (see right-hand side graph in Figure A.13). The migrants of 2008 are likely migrating due to increased productivity rather than a relaxation of the credit constraint for migration.

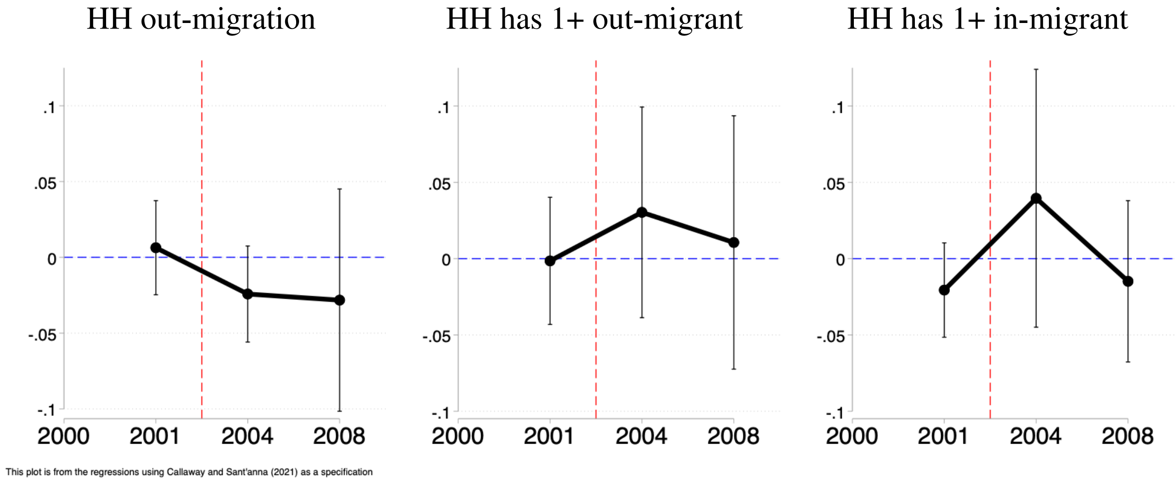


Figure A.14: Effects shutting down persistent short term migration

Notes: This figure shows the treatment effects from limiting the sample to villages that were treated only in 2004 and were not treated again in the 2006-2007 or 2007-2008 periods. It shows that the long term effects are not due to a succession of short term effects. The x-axis represents years from 2000 to 2008, while the y-axis indicates the estimated treatment effects on the outcome of interest. The red dashed vertical line marks the year of treatment, 2004, while the blue dashed horizontal line represents zero treatment effect. Each plot corresponds to a different margin of migration (from left to right): (i) en-masse migration, (ii) sending out-migrants, and (iii) hosting in-migrants. The figure highlights that treatment effects persist through 2008, even though the villages were treated only once. Error bars represent 95 percent confidence intervals.

B A model of selection

B.1 Solutions for traditional agriculture

Unconstrained households: the interior solution

When the household's labor units in agriculture, or credit constraints are not binding, the household's set of choices is in the interior solution, leading to the following first order conditions:

$$\frac{\partial \pi^{u*}_{i,T}}{L_{i,A}} = paL_{i,A}^{\gamma-1}X_i^{\delta} - \tilde{w}_i = 0; \tag{B.1}$$

Which leads to the household to choose the below levels of migration, and leading to the profits $\pi^{u*}_{i,T}$

$$\text{Unconstrained migration } L^{u*}_{i,M} = L_i - \left(\frac{\gamma paX_i^{\delta}}{\tilde{w}_i}\right)^{\frac{1}{1-\gamma}} \tag{B.2}$$

$$\text{Unconstrained profit} \quad \pi^{u*}_{i,T} = \gamma^{\frac{\gamma}{1-\gamma}}(1-\gamma\tilde{w}_i)\left(\frac{paX_i^{\delta}}{\tilde{w}_i{}^{\gamma}}\right)^{\frac{1}{1-\gamma}} + \tilde{w}_iL_i + q_v\bar{f} - c_i^M \tag{B.3}$$

Labor constraints bind

If the household that has an optimal labor demand that is larger than its endowment of labor units ($L^*_{i,A} > L_i$), or a household for which the credit constraint binds (i.e. $PY_i + q_v\bar{f} >$

c_i^M) meaning that the household would want to migrate but cannot afford to), its constrained migration units of labor, and profits are the following:

$$\text{Constrained migration } L_{i,M}^{c*} = 0 \tag{B.4}$$

$$\text{Constrained profit} \quad \pi_{i,T}^{c*} = paL_i^{\gamma} X_i^{\delta} + q_v \bar{f} \tag{B.5}$$

B.2 Solutions for upgraded agriculture

Unconstrained households: the interior solution

When the household's labor units in agriculture, or credit constraints are not binding, the household's set of choices is in the interior solution. The household optimizes over its labor units and its fertilizer use, leading to the following first order conditions:

$$\frac{\partial \pi_{i,T}^{u*}}{L_{i,A}} = \alpha p A_i L_{i,A}^{\alpha-1} F_i^{\beta} X_i^{1-\alpha-\beta} - \tilde{w}_i = 0; \tag{B.6}$$

$$\frac{\partial \pi_{i,T}^{u*}}{F_i} = \beta p A_i L_{i,A}^{\alpha} F_i^{\beta-1} X_i^{1-\alpha-\beta} - q_v = 0; \tag{B.7}$$

These FOCs, lead to the optimal unconstrained solutions over migration, fertilizer use, the resulting profits to be:

$$\text{Unconstrained migration } L_{i,M}^{u*} = L_i - X_i \left[\left(\frac{\beta}{q_v}\right)^{\beta} \left(\frac{\alpha}{\tilde{w}_i}\right)^{1-\beta} pA_i \right]^{\frac{1}{1-\alpha-\beta}}, \tag{B.8}$$

$$\text{Unconstrained fertilizer } F_i^{u*} = X_i \left[\left(\frac{\beta}{q_v}\right)^{1-\alpha} \left(\frac{\alpha}{\tilde{w}_i}\right)^{\alpha} pA_i \right]^{\frac{1}{1-\alpha-\beta}}, \tag{B.9}$$

$$\text{Unconstrained profit} \quad \pi_{i,F}^{u*} = X_i \left[pA_i \frac{1}{q_v^{\beta} \tilde{w}^{\alpha}} \right]^{\frac{1}{1-\alpha-\beta}} \Psi + q_v \bar{f} + L_i \cdot \tilde{w}_i - C_v^F - c_i^M, \tag{B.10}$$

where $\Psi = \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{1-\alpha}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{1-\beta}{1-\alpha-\beta}}$.

Labor constraints bind

If the household has an optimal labor demand that is larger than its endowment of labor units ($L_{i,A}^* > L_i$), or has a binding credit constraint (i.e. $PY_i + q_v \bar{f} > c_i^M$ meaning that the household would want to migrate but cannot afford to), its constrained migration units of labor, and profits are the following:

$$\text{Constrained migration } L_{i,M}^{c*} = 0 \tag{B.11}$$

$$\text{Constrained fertilizer} \quad F_i^{c*} = \left[\frac{pA_iX_i^{1-\alpha-\beta}}{q_v}\right]^{\frac{1}{1-\beta}} \tag{B.12}$$

$$\text{Profit} \quad \pi_{i,F}^{c*} = \left(\beta^{\frac{1}{1-\beta}} - \beta^{\frac{1}{1-\beta}}\right)\left[\frac{pA_iX_i^{1-\alpha-\beta}}{q_v}\right]^{\frac{1}{1-\beta}} + q_v\bar{f} - C_v^F \tag{B.13}$$

Proposition 1 *There exist at most two cut-offs in X_i that determine whether the household has any migrants. For X_i lower than a cuttoff X_i^L, the household is not productive enough and thus cannot afford to migrate (the credit constraint is binding). Similarly for X_i higher than X_i^H, the household is very productive in agriculture, and no household member migrates. For values of X_i between X_i^L and X_i^H the number of migrating labor units is an inverted U-shape.*

Proof of Proposition 1.

$$\frac{\partial \pi_{i,T}^{u*}}{X_i} =$$

■

Proposition 2 *For the unconstrained household, there exist at most two cut-offs in $\tilde{w}_i$ that lead to different migration decisions. For $\tilde{w}_i$ lower than $\tilde{w_i^L}$, the household specializes in agriculture, and for $\tilde{w}_i$ higher than $\tilde{w_i^H}$, the entire household migrates. For values of $\tilde{w}_i$ between $\tilde{w_i^L}$ and $\tilde{w_i^H}$ the number of migrating labor units is increasing.*

Proof of Proposition 2. an interior solution requires that $L_{i,M} > 0$, or equivalently, $L_{i,A} < L_i$. Taking the derivative of ex-post returns with respect to $\tilde{w}_i$:

$$\frac{\partial \pi_{i,T}^{u*}}{\tilde{w}_i} = \frac{\gamma^{\frac{\gamma}{1-\gamma}}(1-\tilde{w}_i)}{(\gamma-1)\tilde{w}_i}\left(\frac{paX_i^{\delta}}{\tilde{w}_i}\right)^{\frac{1}{1-\gamma}} + L_i;$$

For a given endowment of land and labor units, if $\tilde{w}_i$ is under a threshold $\tilde{w_i^L}$, $1-\tilde{w}_i$ is positive, making $\frac{\gamma^{\frac{\gamma}{1-\gamma}}(1-\gamma\tilde{w}_i)}{(\gamma-1)\tilde{w}_i}$. Above $\tilde{w_i^L}$, the household returns to migration are large enough to send increasing number of labor units, until all its units migrate, which is reached when $\tilde{w}_i > \tilde{w_i^H}$ ■

Proposition 3 *When the subsidy is introduced and for migration costs that sufficiently low, resale markets make the number of households who can afford to migrate larger, thus increasing migration rates within a village.*
For some households with very low migration costs, the entire households can migrate, funding migration entirely with the proceed from the resale of the subsidized fertilizer.

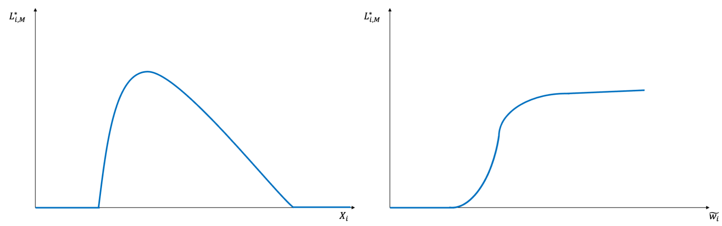


Figure B.1: Comparative statics

Notes: This figure plots the number of labor units within households migrating as a function of landholding X_i on the left panel, and as a function of the returns to migration $\tilde{w}_i$ on the right panel.

Proof of Proposition 3. Without the subsidy $q\bar{f} = 0$. Equation 7 shows for households with a binding credit constraint, i.e. $paL_{i,A}^{\gamma}X_i^{\delta} + q\bar{f} < c_i^M$, migration does not occur. Note that:

$$\forall \bar{f} > 0; q > 0 : paL_{i,A}^{\gamma}X_i^{\delta} + q\bar{f} > paL_{i,A}^{\gamma}X_i^{\delta} \tag{B.14}$$

$$\Rightarrow \sum_{i=1}^{N_v} 1_{\{paL_{i,A}^{\gamma}X_i^{\delta}+q\bar{f}>c_i^M\}} \geq \sum_{i=1}^{N_v} 1_{\{paL_{i,A}^{\gamma}X_i^{\delta}>c_i^M\}} \tag{B.15}$$

Which implies that when households can trade their fertilizer in resale markets, they end up with more disposable income. Some households for which the credit constraint binds prior to the subsidy see their constraints relaxed, and they can afford to migrate. ■

Proposition 4 *If q^* is sufficiently low, a household that has high returns to migration want to put all their labor into migrating but need to fund it by using some in agriculture for profits. Said more precisely, their unconstrained labor choice would cause profit to fall below the amount required by credit constraint. Therefore, they set their labor to exactly cover the cost of migrating, making some households' optimal choice to both upgrade & migrate. This household's upgrading decision may lead to the household overusing fertilizer, such that $F_i > F_i^*$.*

Proof of Proposition 4. The credit constraint is of the form $pY_i + q\bar{f} \geq c_i^M$ where $Y_i = a \cdot L_{i,A}^{\gamma}X_i^{\delta}$ for non-upgraders, and $Y_i = A_i \cdot L_{i,A}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta}$ for upgraders. For households with A_i large enough, the household upgrades (see Equation 10).

Households who have high returns to migration ($\tilde{w}_i$), and whose optimal interior choice is binded by the credit constraint will increase their agricultural production just enough to cover the migration cost.

For non-upgraders, this means that $paL_{i,A}^{\gamma}X_i^{\delta} + q\bar{f} = c_i^M$, which implies $L_{i,A} = \frac{c_i^M - q\bar{f}}{X_i^{\delta}}^{\frac{1}{\gamma}}$.

For upgraders, this means that $pA_i \cdot L_{i,A}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta} + q\bar{f} = c_i^M$. For the extreme where $q = 0$, we have $L_{i,A} = \left(\frac{\tilde{w}}{\alpha}\right)^{\frac{1}{\alpha}}$ and $F_i = \left(\frac{c_i^M\alpha}{\tilde{w}pA_iX_i^{1-\alpha-\beta}}\right)^{\frac{1}{\beta}}$

Both solutions deviate from the optimal solutions, and for high enough costs of migration, and returns to migration, there may be some over-investment in the upgraded agriculture, due to this shadow cost of the constraint.

■

C Structural estimation

Table C.1: Estimation of the production functions for agricultural technoloties

Panel (A) Fertilizer: $\log(Y_{maize,i}) = \log(A_i) + \alpha\log(L_{i,A}) + \beta\log(F_i) + \nu\log(X_i) + \theta_{vil}$					
Sample: ISP + Adoption	α	ν	β	$\alpha+\nu+\beta$	P-value $H_0: \alpha+\nu+\beta=1$
Estimates	.116	.736	.306	1.158	.00
Standard Errors	(.037)	(.037)	(.029)		

Panel (B) Traditional: $\log(Y_{maize,i}) = \gamma\log(L_{i,A}) + \mu\log(X_i) + \theta_{vil}$					
Sample: ISP + No adoption	γ	μ		$\gamma+\mu$	P-value $H_0: \gamma+\mu+\beta=1$
Estimates	.133	.828		.961	0.26
Standard Errors	(.030)	(.028)			

Notes: This table shows the estimates for the Cobb Douglas equations on Panel A for the Fertilizer technology and Panel B for the Traditional technology. Standard errors are clustered at the village level.

Table C.2: Estimation of simultaneous Equations 16

	(1)	(2)	(3)	(4)	(5)	(6)
	Villages **with** subsidy			Villages **without** subsidy		
Variables	$\mathscr{D}_i$	$\mathscr{M}_i$	$L_{i,M}$	$\mathscr{D}_i$	$\mathscr{M}_i$	$L_{i,M}$
$\log(X_i)$	0.123***		0.123***	0.144***		0.136**
	(0.0116)		(0.0442)	(0.0208)		(0.0658)
$\log(q_v)$	0.827*		0.299	0.297		0.0673
	(0.431)		(0.184)	(0.683)		(0.230)
$\log(c_i)$	-0.0224		-0.178***	-0.0155		0.0187
	(0.0284)		(0.0453)	(0.0816)		(0.0637)
L_{iM}		0.161***			0.183***	
		(0.00433)			(0.00734)	
Y_T		-1.54e-08**			-2.45e-08**	
		(7.23e-09)			(9.70e-09)	
$(Y_F - Y_T) \times 1_{\mathscr{D}_i=0}$		-4.55e-09			-2.20e-08*	
		(1.04e-08)			(1.28e-08)	
$(Y_F - Y_T) \times 1_{\mathscr{D}_i=1}$		-1.79e-09			-1.49e-09	
		(1.93e-09)			(5.32e-09)	
q_v		7.98e-05*			6.01e-05	
		(4.08e-05)			(4.73e-05)	
c_i		-3.67e-07			7.82e-07	
		(6.74e-07)			(7.17e-07)	
$\log(A_i) \times 1_{\mathscr{D}_i=0}$			-1.121***			-0.759
			(0.418)			(0.476)
$\log(A_i) \times 1_{\mathscr{D}_i=1}$			0.0514			0.0398
			(0.0839)			(0.166)
$\log(P_v)$			-0.568***			-0.536*
			(0.216)			(0.284)
$\log(L_i)$.			2.447***			2.308***
			(0.0735)			(0.110)
$1_{FSP} \times \log(q_v)$			-0.0137			
			(0.0132)			
Constant	-5.028*	0.323***		-1.719	0.284***	
	(2.991)	(0.0535)		(5.328)	(0.0664)	
Village FE	Yes	No	No	Yes	No	No
Observations	1,495	1,495	1,495	580	580	580
R-squared	0.402	0.288	0.664	0.470	0.352	0.659

Notes: The table presents estimates of a system of simultaneous Equations 16 for villages that received the subsidy (columns 1-3) and those that did not (columns 4-6). The dependent variables are the binary decision to upgrade infrastructure ($\mathscr{D}i$), the decision to migrate ($\mathscr{M}i$), and the number of labor units migrating (L_{iM}). Standard errors are obtained with 300 bootstrap of all three steps of the estimation, i.e. the production function, the imputation of fertilizer and traditional production for farmers who did not respectively upgrade, and upgraded, and finally this joint decision.