Upgrade or Migrate: The Consequences of Input Subsidies on Household Labor Allocation

Binta Zahra Diop*
University of Oxford

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Abstract

Rural development programs often focus on increasing agricultural investment. Yet, many farmers can benefit from investing in a different technology: outmigration. I explore how one common class of policies — input subsidy programs (ISPs) — allows households to sort based on the relative returns of these two technologies. First, I exploit area-by-year variations in the roll-out of a large-scale Zambian ISP and use a difference-in-differences strategy. I show that the ISP fosters specialization by farmers based on their comparative advantage, resulting in increases in both agricultural yields and outmigration. Second, I estimate a structural model that incorporates a positive learning externality related to fertilizer adoption. With this externality, the ISP offers advantages relative to alternative revenue-neutral policy counterfactuals. Compared to an untargeted cash transfer, I find that an ISP that allows for re-selling of fertilizer would increase migration out of agriculture. A more targeted cash transfer, or an ISP without resale markets, would reduce migration. All three counterfactual policies reduce fertilizer use relative to the ISP and hinder the process of specialization.

Keywords: Input Subsidies, Migration, Agricultural Productivity, Sorting, Structural Estimation

JEL Codes: R23, O33, Q12

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*Department of Economics, University of Oxford, bintazahra.diop@economics.ox.ac.uk
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Introduction

In the Global South, rural areas are home to 80% of households who live in extreme poverty.[1] The majority of these households are dependent on farming as a source of income, and cannot afford the investment needed to migrate to areas with better economic prospects, or needed to upgrade their agricultural technology.[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. Economists have historically analyzed these input subsidy programs (ISPs) in terms of their perceived (in)efficiency, especially in relation to alternatives such as cash transfers (Jayne and Rashid, 2013; Jayne et al., 2018; Ricker-Gilbert and Jayne, 2017). Input subsidies are seen as encouraging inefficient use — and potentially overuse — of inputs, relative to the market equilibrium quantities. In the presence of market imperfections, of course, the inefficiency of ISPs is less obvious. First, important learning externalities in the adoption of productive agricultural technologies mean that farmers — who learn from their neighbors' use of a technology — may underinvest in agriculture. Second, low access to credit hampers investments in productive inputs and in outmigration from rural areas.[3] A full analysis of the effect of ISPs needs to consider the ways in which ISPs alter the opportunities that farmers face and the choices they make to either upgrade or migrate.

This paper uses both a natural experiment and structural estimation to explore how ISPs — and by implication a broader class of policies designed to increase agricultural productivity — affect farmers investments in agriculture and migration. I consider an environment in which farmers are not tied to agricultural production. For many rural households, the outmigration of individual family members, or of the entire household, is a realistic alternative to farming. Given this outside option of migration, I ask how an ISP can affect a set of farmers' decisions — specifically their investments in farming and their migration choices. In both my empirical and theoretical frameworks, I consider an environment in which farmers' ability to realize their true comparative advantage is hindered by fixed costs[4], externalities, and an absence of credit markets. I explore this environment in two parts.

First, I focus on a Zambian fertilizer ISP, launched in 2002 to target about 10% of all smallholders. In the early 2000s, the Zambian ISP represented 45% of the country's

[1]From Castaneda et al. (2016), who use a sample of 89 countries from the Global South

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

[3]See Bryan et al. (2014); Angelucci (2015); Cai (2020) for credit constraints, and Conley and Udry (2010); Carter et al. (2021) for the externality.

[4]These fixed costs apply to both adoption of the fertilizer agriculture and of migration

discretionary antipoverty spending and about 20% of its agricultural budgets.[5] Programs similar to Zambia's ISP are currently in place in a dozen African countries — and indeed around the world with a global budget of US$700 billion year globally — making this analysis of relevance well beyond Zambia's borders (Jayne and Rashid, 2013).[6] Using a representative panel of Zambian smallholders between 2000 and 2008 and a difference-in-differences estimation — exploiting variations in the roll-out of the policy over time and across space — I test whether the ISP changed agricultural investment and migration decisions.[7]

I find that the Zambian ISP increased fertilizer adoption, maize yields, inmigration into treated areas, and outmigration from treated areas. More specifically, I find that the externality in adoption is important: all else equal, households in areas with a higher number of fertilizer users have a higher likelihood of using fertilizers as an input. As a result, when the subsidy is introduced, the share of households using fertilizer in treated areas increases by 9 percentage points. Households in treated areas also increased their likelihood of hosting inmigrants by 18 percentage points. The joint increases in fertilizer use and inmigration are consistent with the view that labor and fertilizer are complementary inputs, consistent with previous findings by Beaman et al. (2013) as well as with an old literature dating back to Hayami et al. (1985). These increases in agricultural technology inputs led to a 20% increase in yields. Perhaps surprisingly, the subsidy also increased the share of households outmigrating *en masse* by 8 percentage points. Further, I find that the subsidy increased the share of household with outmigrants by 40 percentage points and double the net outmigration (obtained as the difference between the number outmigrants and immigrants). This increase in outmigration is consistent with farmers sorting into migration and agriculture based on their comparative advantage. The evidence supports a view that some farmers are able to monetize the subsidy to fund migration. The key findings of my empirical analysis are robust to various specifications.[8]

My main results are consistent with two mechanisms, which I validate empirically. First, the simultaneous increases in inmigration and outmigration are a result of an accelera-

[5] The Zambian ISP expanded to reach 85% of households in 2015/16. Furthermore, in 2020, the ISP (which by then was taken out of the budget of the ministry of agriculture) was three times larger than the rest of the country's agriculture budget.

[6] The Zambian ISP is called the Fertilizer Input Support Program also known as the Fertilizer Support Program or FSP operates under the broad strokes of the Maputo and Abuja declarations on Input Subsidy Programs (ISPs) signed by ten countries of the African Union.

[7] In the sample, the mean dollar amount of the input subsidy is $42 (with a median at $48) for those who receive any subsidy. In comparison, in 2010, Zambia started an unconditional cash-transfer program or $12/month paid every two months.

[8] In the main specification, I estimate treatment on the treated, with a difference-in-differences approach, using one cohort of treatment (so not prone to the composition issues highlighted in recent literature). I further check that these estimates hold for a local average treatment effect, based on an IV estimate using political clientelism as an instrument, which I discuss in Appendix A.5

tion in the specialization process. Specialization leads both to an increase in yields for those households that remain in farming and to an increase in migration for others. For the households that remain in agriculture, given poorly functioning labor markets, increasing labor demand is met through increased inmigration. Hence, some households increased both their fertilizer adoption and labor use, intensifying their agricultural activities. Other households, however, divested from agriculture altogether and outmigrated. This specialization channel has similarities to the broad processes of structural transformation driven by productivity improvements (Lewis et al., 1954; Gollin, 2014; Mazur and Tetenyi, 2022), and it clearly accounts for some of the observed patterns in the data, but the analysis suggests that a second channel is also at work. This second channel can be interpreted as a shorter-term relaxation of farmers' credit constraints. Farmers who receive fertilizer through the ISP are typically able to re-sell it to other farmers, at a market prices. These resale markets allows them to monetize the subsidy and to overcome budget constraints and/or credit constraints that prevent them from migrating.

The two channels driving outmigration are observationally distinct. I decompose the changes in outmigration, and find that migration immediately following the program — consistent with a relaxation of the credit constraints — explains about 30% of the total variance in outmigration over the years of the panel; while medium-term migration, consistent with structural transformation mediated by productivity improvements accounts for 45% of the variance. This decomposition shows that despite a strong emphasis on productivity-driven structural change, a substantial part of farmers choices are altered by short-term changes in their liquidity.

In a second part of the paper, I generalize the difference-in-differences estimates with a structural model to compare the current ISP with other alternative policies. The model incorporates key features that correspond to the rural economy of Zambia — and indeed to many rural economies in the Global South. In the model economy, I introduce resale markets that allow farmers to sell subsidized fertilizer to other farmers at a market price, consistent with observed behavior under many input subsidy schemes (World Bank, 2021; Mason and Jayne, 2013). These resale markets are often formally prohibited, but governments typically lack the ability to enforce the prohibition. Another important feature of low-productivity rural economies is that many farmers face binding credit constraints and non-convexities in their agricultural technologies. These features may "trap" farmers in agriculture at the expense of other more profitable activities (Ghatak, 2015; Balboni et al., 2022; Banerjee et al., 2021). Furthermore, farmers' adoption decisions for fertilizer and many new technologies are likely to be suboptimal. A substantial body of literature has documented the importance of externalities and fixed costs, of various kinds, for the adoption of new technologies (Conley and Udry, 2010; Carter et al., 2021; Foster and Rosenzweig, 1995). I choose to model these market imperfections with a simple structure: a cost of adoption that decreases with the number of adopters in a community.[9] As a result, when the level of fertilizer use is low, the level of adoption of the improved technology is sub-optimal.

In the model, both an increase in productivity and a relaxation of liquidity constraints can increase migration. This proposition mimics my reduced-form findings, which are consistent with farmers migrating as they either become more productive over time and need less labor in agriculture to achieve similar levels of income, or by monetizing their ISP voucher in resale markets to relax their credit constraint. These implications of the model derive from the fact that farmers cannot borrow against future migration income, but can use their agriculture surplus to fund migration. In this model, credit constrained farmers farmers who live in areas with high resale prices can use resale markets to generate enough liquidity to fund migration. In contrast, farmers who live in areas with low resale prices, may be better-off funding their migration by first investing in the fertilizer agriculture, and using the realized surplus to migrate.

I estimate the model by maximum likelihood and use these estimates to compare the effects of the current subsidy program when resale markets exist to three revenue-neutral counterfactual policies: a policy that enforces the prohibition of resale markets, and two cash transfer programs (targeted and untargeted). Under the ISP without resale markets, there are fewer households (-15%) that send outmigrants compared to the ISP with resale markets — implying that resale markets are central in the sorting of farmers across migration and adoption. More surprisingly, adoption also decreases substantially (-75%) when resale markets are removed. This drop in adoption is due to the indivisibility of the fertilizer quantity introduced by shutting down resale markets. Recipients cannot sell a portion of their vouchers to other farmers in demand of fertilizer, lowering overall adoption rates. The second counterfactual policy provides cash (*in lieu* of the ISP) to the 8% of households that were the target of the original subsidy. This second counterfactual policy does not address the externality in adoption and thus leads to substantially lower adoption than in the ISP baseline (-99%). The targeted cash-transfer program, however, triggers changes in migration, which are nevertheless smaller (-13%) than the ISP with resale markets. The third counterfactual policy is a cash transfer given to all farmers in treated areas. This untargeted cash-transfer program increases extensive migration by 11% compared to the baseline ISP but has a large negative impact on the adoption of fertilizer by farmers, compared to the current ISP (-99%). Hence, the ISP with resale markets fosters higher level of specialization across migration and fertilizer adoption, compared with the alternatives considered. In an economic environment with substantial market failures and in the presence of externalities, it is not overall straightforward to

[9] These costs are a simplifying assumption that leads to a similar outcome as traditional learning models.

assess the overall welfare implications of these different policies; I thus focus on the positive dimension of the analysis.

This paper contributes to three strands of literature. First, I contribute to a large literature that explores drivers of migration by adding important insights on ways in which farmers can alter their migration decisions through both inmigration and outmigration. Previous studies were for the most part designed to test the presence of either productivity-induced, or liquidity-induced migration, making it infeasible to distinguish between short-term credit drivers of migration (Angelucci, 2015; Gazeaud et al., 2020; Bazzi, 2017; Cai, 2020), from long-term improvements in technology that lower labor demand in agriculture (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 in the reduced-form estimation, decomposing the variance of total outmigration, and then by shutting down different channels in the structural estimation of counterfactuals. I show that although structural change is important in explaining migration, credit constraints are nevertheless binding for many farmers. I further show that both an increase in inmigration and outmigration occur. Inmigration into rural areas has mostly been overlooked in the literature, despite Chamberlin et al. (2020) documenting high incidence of rural-to-rural migration in the context of Zambia. This phenomenon of dual increase in inmigration and outmigration happens via farmers specializing into either migration or in the labor-intensive agricultural technology. In highlighting these dual migration flows, this paper adds to a related literature on how changes in productivity affect the displacement of labor away from rural areas. Imbert et al. (2021) find in China that increased productivity in rural areas decrease outmigration while Bustos et al. (2016), and Bazzi (2017) show that technology improvements in rural Brazil and Indonesia respectively, are labor saving and thus increase outmigration. This latter literature rationalizes the finding that both inmigration and outmigration increases in the Zambian context, with comparative advantages being the main driver.

Second, I contribute to a literature on anti-poverty programs in poor countries. More specifically, I build on a literature on rural markets and model explicitly well-documented market frictions in rural areas. The main market frictions I consider are an externality in adoption (Conley and Udry, 2010; Carter et al., 2021) and poorly functioning credit markets (Ghatak, 2015; Deininger et al., 2007; Cai, 2020; Balboni et al., 2022). Incorporating these frictions, ISPs can affect migration and adoption margins at higher rates than previously found (Jayne et al., 2018; Schmitz et al., 1997). My structural estimates are important in uncovering the intricate ways in which a policy targeted at increasing agricultural productivity can be designed to increase agricultural outputs but also get agents to engage in the activity they are most productive in. More generally, my findings offer a new insights into anti-poverty transfer programs (Banerjee et al., 2021; Bastagli et al., 2016; Haushofer and Shapiro, 2016; Baird et al., 2011). My policy counterfactuals show that unconditional cash transfers may not be as efficient in achieving specific policy objectives (such as increase in agricultural productivity) because they do not address the learning externality in agriculture. By contrast, the ISP with secondary markets can efficiently reallocate transfers by sorting beneficiaries based on their comparative advantage. Despite the previously documented inefficiency of ISPs (Jayne and Rashid, 2013; Xu et al., 2009), I show that only the ISP in conjunction with resale markets leads to efficiency gains and to the levels of specialization we see in the data.

Finally, I add important insights to a booming literature in public economics, documenting the importance of resale markets in rural markets. I find that mechanisms on resale markets lead farmers who have a comparative advantage in activities outside of agriculture to sell their fertilizer to farmer with a comparative advantage in the fertilizer-intensive agriculture, generating income to fund their migration. Previous studies show indeed that these resale markets are important and appear in settings where there are unobserved types, 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 a large in-kind transfer to those with a comparative advantage in the fertilizer-intensive agriculture.

The remainder of the paper proceeds as follows: Section 2 presents the Zambian context, and the data used in the analysis. In Section 3, I present the strategy to causally identify the impact the Zambian FSP had on migration and on the adoption of the new technology. I present the results in Section 4. Section 5 discusses potential mechanisms that generate these results. Section 6 generalizes these finding with a general equilibrium model. I estimate the model in section 7, where I also compare the current ISP with resale markets to policies that may also affect migration decisions in rural areas. I discuss optimal policies in section 8 and finally conclude.

2 The Zambian ISP: context, and data

In this section, I describe relevant institutional details of the the Zambian agricultural system and the data I use in the paper.

2.1 The Zambian ISP: the Fertilizer Support Program (or FSP)

In 2001, The Zambian agricultural sector contributed 16% to the country's GDP (Ritchie and Roser, 2020). At the time, the sector employed about 72% of the Zambian labor force with remarkably low productivity (Ritchie and Roser, 2020). In response to low fertilizer take-up, the Zambian government has designed several programs to increase fertilizer and improved seeds' adoption. Their strategy consisted in addressing both the credit constraints and the resulting high costs of fertilizer.

In the 2002-2003 agricultural season, the government rolled-out the Fertilizer Support program (FSP).[10] The FSP is a cash-only program, giving 50% rebate vouchers on the price of fertilizer inputs (later increased to 60% then 76% starting in 2010-2011) up to a given threshold for farmers with holdings between one and five hectare of land with a focus on maize production (Mason et al., 2013b).[11]

Improving agricultural productivity and reducing poverty are the main goals of the Zambian Fertilizer Support Program (FSP). In Zambia, 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 (see Figure 9 in the Appendix). This phenomenon happened concurrently with large investment in input subsidy programs (Jayne et al., 2018; Chamberlin et al., 2020). Changes in both the subsidy policies along with large migration flows make Zambia a ideal place to understand the potential impacts of ISPs on migration and adoption.

These investments were a substantial financial effort on the part of the Zambian government. Between 2004 and 2011, the FSP alone made-up approximately 30% of Zambia's agricultural spending and 47% of the government's agricultural sector Poverty Reduction Program (Mason et al., 2013a).[12] In the early days of the ISP, Zambia contributed 45% of its annual discretionary antipoverty budget in addition to its agricultural budget (World Bank, 2010), like a dozen African countries that signed the Maputo and Abuja declaration to increase fertilizer-use among farmers. Together African countries invest more than $2Billion in ISPs. This phenomenon is true globally with $700Billion (roughly the GDP of Switzerland) invested in agricultural inputs.

In the Zambian agricultural system, resale of the voucher provided through the ISP is prohibited. There is thus no direct way of observing these resales. In the next this subsection I show indirect measures of these resale markets and discuss their importance.

2.2 Evidence of the existence of resale markets

In what follows, I explore through indirect means, the existence of resale markets for the ISP. The evidence shown in this section is in line with work by Giné et al. (2022) who document active and welfare improving resale markets when ISPs are randomly allocated to farmers in Zambia.

[10]The FISP was later renamed Farmer Input Support program (FISP) and replaced a much smaller Fertilizer Credit Program

[11]The threshold is set to correspond to the advised amount of fertilizer for one hectare of maize: it is 100kg of basal and 100kg of top-dressing

[12]See Table 9 of the Appendix for details on the Zambian agricultural budget.

The agricultural system in Zambia is articulated around cooperatives that allow for collective action within agricultural areas of the country. In the early phases of the program, most farmers in cooperatives were offered vouchers to redeem fertilizer at a subsidized price, for the set amount of fertilizer.[13]

Farmers who need additional supplies of fertilizer could use commercial markets or buy from cooperative farmers for whom the subsidized fertilizer was in excess. As a indication that these markets may exist, World Bank (2010) reports that 12% of the farmers who receive the subsidy do not have farming as their main source of income. Additionally, Mason and Jayne (2013); Xu et al. (2009) document substantial leaks of these subsidies to resale (commercial) markets in Zambia. These subsidies are similar to the in-kind benefits; for which Ravallion (2021) shows that resale markets can improve the allocative efficiency and generates individual gains.

The 12% of cooperative members identified by World Bank (2010), who receive the subsidy and do not farm, can also sell their fertilizers to non-cooperatives members (only cooperative members can receive the subsidy). These resale prices could in theory be lower than the market price, and cooperative recipients could make a profit at any price above the subsidized price. The non-cooperative members are usually poorer households (World Bank, 2010) and would derive a surplus for any price lower than the market price.

Though we do not have direct information on resale markets, there is strong evidence of their existence. Figure 1 shows the distribution of basal fertilizer used on the farm (the same figure for top-dressing fertilizer can be found in Appendix 14). Most farmers plotted on the figure receive bags of 100kg, which is the horizontal dashed line. Any farmers below that line is a potential re-sellers, because they are beneficiaries of the program but report using less than they have received. Mirroring these farmers, any of them reporting to have used more than the 100kg transfer is a potential buyer on resale markets. A few farmers use exactly the amount distributed. Finally a fourth group, that have not received the FSP, report using FSP fertilizer, which implies activity on resale markets.

Furthermore, using data from an randomized control trial (Carter et al., 2021), I find further evidence of existing resale markets. In the sample of farmers used by Carter et al. (2021), 30%[14] of the vouchers intended for the treatment group were redeemed by the control group — further suggesting the existence of resale markets.[15]

Turning to migration for resellers, Figure 2 plots the correlation between the share of

[13]The set amount of fertilizer offered by the government is eight bags of 50 kg of fertilizer (i.e. four basal fertilizer and four top-dressing), which the Government recommends to plant one hectare of maize (World Bank, 2010).

[14]Author's calculations

[15]Carter et al. (2021) takes place in neighboring Mozambique.

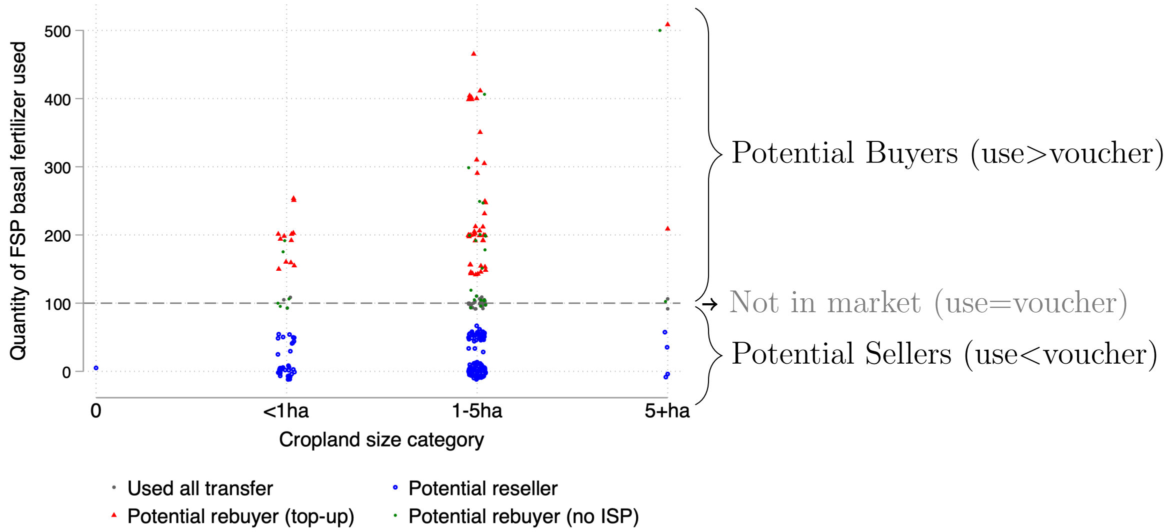


Figure 1: Subsidized basal fertilizer used on farm compared to quantity transferred

Notes: Using self-reported data on basal fertilizer for the year 2004 from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel). For top-dressing fertilizer see Appendix Figure 14. 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.

potential resseller in the SEA and rates of migration. In 2004, SEAs with the most potential resellers are also those with the most households sending outmigrants. This increase tapers off as time goes by (see right-hand side graph in Figure 2). The migrants of 2008 are likely migrating due to increased productivity rather than a relaxation of the credit constraint for migration.

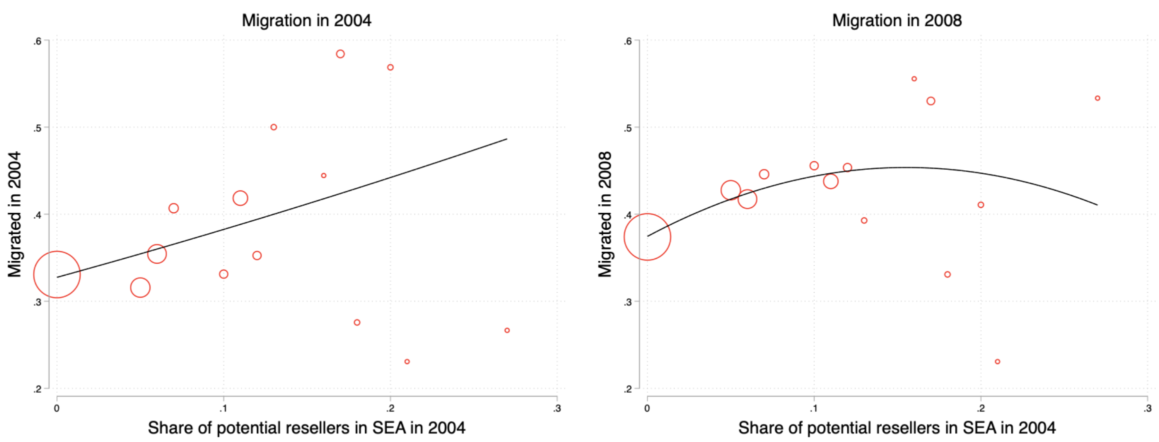


Figure 2: Migration in 2004 and 2008 by share of potential resellers in SEAs

Notes: Using self-reported data from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel).

Resale markets seem to be active, and thus offer the possibility for some farmers to monetize their voucher and fund other activities. In the following section, I discuss the empirical strategy to estimate the extent to which the Zambian ISP altered farmers decisions on a set of agricultural and outmigration outcomes.

Next I present the data I use to conduct the analysis.

2.3 Data

I use a panel of households in rural Zambia from the Zambian Central Statistical Office and the Zambia Food Security Research project at Michigan State University. This panel is made of four waves; the 1999-2000 Post Harvest Survey (PHS) that I use as a baseline to this study. The survey is representative of rural households in Zambia. To that baseline survey, I add the linked first supplemental survey to the 1999/2000 PHS that was conducted in 2001, the Second Supplemental Survey to the 1999/2000 PHS that was conducted in 2004 and the Third Supplemental Survey conducted in 2008. The PHS is a nationwide representative survey of small and medium landholders with three levels of sampling (Xu et al., 2009). Appendix A.2 details the variable construction and the sampling frame.

In the following section, I explore ways in which I can identify the causal link between the Zambian ISP and a set of farmers decisions.

3 A reduced-form empirical strategy

This section describes the difference-in-differences estimation of the causal impact of the ISP on agricultural and migration outcomes.

With the introduction of any class of policies that affects prices of the fertilizer input such as ISP, the household can decide whether to adopt the fertilizer technology or not (binary decision) and this decision impacts its yields. When making its migration decision, the household can alter five margins of migration: it can decide whether to have imigrant or outmigrants at all (extensive margin), it can decide on the number of inmigrants or outmigrants to have (intensive margin). The households also makes a decision on whether to relocate the household entirely. All these margins are summarized in Table 1.

I use a difference-in-differences estimation, to see if the subsidy moved the needle on fertilizer adoption, agricultural productivity. Importantly also elicit the proportion of households whose migration decision is changed as a result of the ISP.

In the remainder of this section, I detail the difference-in-differences estimation strategy I use to obtain the share of households that self-select into adoption or migration. I summarize the outcomes of interest in Table 1.

3.1 Estimation strategy

The source of variation I exploit to identify the causal link of the ISP on migration stems from the staggered roll-out of the policy. This roll-out allows me to construct four different treatment status groups, which then allows me to estimate the policy's impact on adoption, on yields and on migration.[16] The treated group are those standard enumerator areas (SEAs) with at least one household receiving the subsidy in 2004. There are typically only one SEA in a village, with the exception of 7 villages with 2 SEAs each (out of 273) — we can therefore think of these SEAs as villages. There are two potential comparison groups: those SEAs that have no household with the subsidy, and SEAs with at least one household in 2008. A final group of SEAs are those with recipients in 2004 and in 2008.

Using farmers in SEAs that receive the subsidy in 2004 as a treatment group allows the estimation of the impact of the subsidy against a pure control group. This design implies that treated SEAs are home to households that do not receive the subsidy. Hence, my estimates of the impact of the FSP on migration are a lower bound of the true effect.

Over the period of the study, districts[17] that see growth in the number of households using fertilizer and households with outmigrants between 2004 and 2008 tend to be the ones that have the most FSP recipients.[18]. To investigate further this correlation, I make use of the fact that some SEAs received the subsidy in 2004, some in 2008 and some never receive the subsidy (Figure 16 of the appendix plots the 2004 and 2008 comparison groups). A natural strategy is to use a difference-in-differences estimation. Using the the variation in whether the SEA received the FSP. The empirical model is the following:

$$Y_{h,t} = \alpha \mathbb{1}_{\{FSP\}} + \beta \mathbb{1}_{\text{Post}} + \gamma \mathbb{1}_{\{\text{Post*FSP}\}} + \eta X_h^0 + \epsilon_{h,t}, \tag{1}$$

where $Y_{h,t}$ is alternatively the adoption, the yields or one of the five margins of migration in Table 1. $\mathbb{1}_{\text{Post*FSP}}$ is equal to one if the household is from an SEA that received the program after 2004 and X_h^0 is a vector of households characteristics at baseline including the size and wealth of the household. I cluster the standard errors at the SEA level, which is both the unit of sampling and of treatment. To account for the gap in adoption

[16]For more on the variation in treatment, see Appendix A.3.1

[17]In the dataset, SEAs are the smallest unit of sampling, then census supervisory areas (CSA), then districts, then provinces.

[18]More on the correlation between FSP and migration in figures 17 and 18 of the appendix that show the average volume of subsidized fertilizer received by households, and the number of outmigrants (individual migrants) respectively.

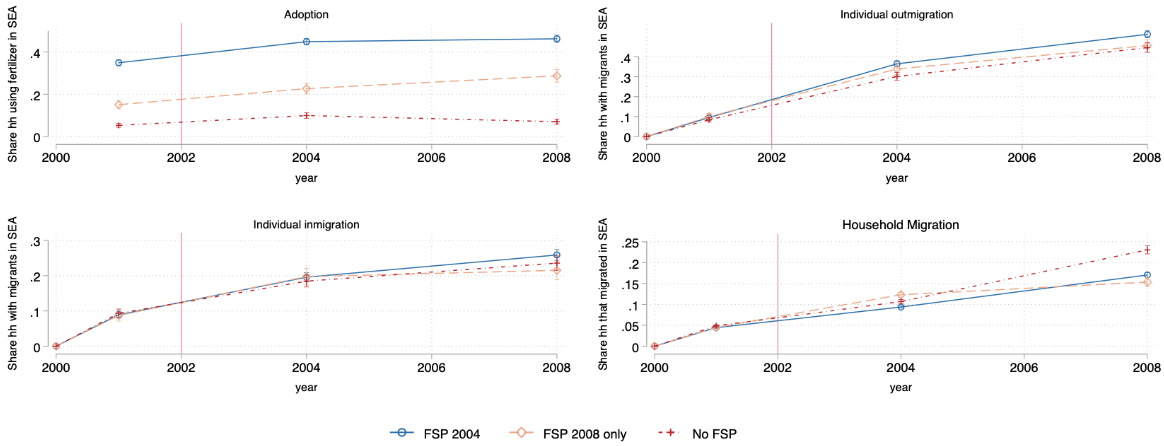


Figure 3: Extensive adoption, outmigration and migration rates per treatment group

rates between treated and control groups at baseline (see Figure 3), I add adoption in 2001 in the estimation of the effect of the ISP on the adoption of fertilizer.

There are three groups of SEAs with different treatment status. Which means there are two potential control groups. In the following subsection, I detail the potential alternatives and give a rational for my choice of the control group.

3.2 Comparison groups

I consider three SEA groups: i) SEAs that did not receive the subsidy (Control 2), ii) SEAs that received the subsidy in 2004, and iii) SEAs that appear to have received the subsidy in 2008 only — i.e. at the time of the study they have not received the subsidy (Control 1). Figure 3 plots the change in the average proportion of households that adopt the fertilizer technology, and that change their migration decision in SEAs.

I focus on the group of SEAs that receive the subsidy in 2004 as the treated group. The preferred comparison group is the group of SEAs that received the FSP in 2008. This choice is justified by the fact that households who receive the subsidy in 2008 are agricultural households and have had a delayed rolled-out purely due to logistics, and perhaps political reasons independent from their propensity to migrate or their productivity in the fertilizer-intensive technology. I show in Table 2 that households in the SEAs that received the subsidy in 2004 bear most resemblance to households who receive the subsidy in 2008, compared to those who never receive the subsidy (see column 5 and 6; p-values of the t-tests comparing the treatment group to the 2008-FSP group and the no-FSP group). However, the treatment group is on average richer and has larger households than the 2008-FSP group as shown by the significant p-values on column (6). Households being richer also translates in households having more years of education. This difference in the number of years of education though significant, is small in, with only .3 years of education difference between the treatment group and Control 1 ($p - value = .03$). To account for these imbalances, I control for wealth at baseline, and household size in all my econometric specifications. Furthermore, I run falsification tests by restricting the sample to only 2004 as a post treatment year. I find that prior to the subsidy, migration follow a similar trend, albeit with a limited number of years to check for trends. The results are robust to the restriction of the sample as well. Unfortunately, I am not able to check for parallel trends due to the limited number of time periods.

Selection into household outmigration may affect individual migration. It is however likely that those changes will be small in comparison to gains made by having a comparison group similar in terms of rural activities — household migration is indeed much smaller in magnitude than individual outmigration. Here, there is a trade-off between the bias that would be introduced between a) using households that are never receiving the FSP (as these households are likely very different households) and b) the bias introduced by choosing SEAs receiving the FSP in 2008 (because the opportunity cost of one household migrating changes when the prospect of receiving the subsidy in 2008 increases). I present the resulta using areas that did not receive the ISP as a control in the robustness checks.

Table 1: Outcomes for the difference-in-differences

Outcomes	**Extensive** Share of HH with...	**Intensive** Number of...	**Treated** FSPyear	**Control**
Agriculture				
Adoption	any fertilizer	-	2004	2008/No FSP
Inmigration	1+ inmigrants	inmigrants/HH	2004	2008
Outmigration				
Household	migration *en masse*	-	2004	2008
Individual	1+ outmigrants	outmigrants/HH	2004	2008

Notes: These variables are measures of both agricultural activity and outmigration decisions. Adoption is adoption of the fertilizer agricuture, yields are total kg/ha for a household, and inmigration represent the number of individuals who inmigrate into the households. These inmigrants increase the available labor in the household in the absence of fully functioning labor markets. The outmigration outcomes are made up of two variables: the household outmigrating as a whole (*en masse*) and the household sending its individual outmigrants out.

Table 2: Baseline characteristics between households in areas that received the subsidy in 2004, 2008 and in areas that did not receive the subsidy

Variable in 2001 At the SEA level	Treated FSP2004	Control 1 FSP2008	Control 2 No FSP	Overall	t-tests'p-value T-C1	 T-C2
Average HH size	6.325	5.893	5.683	6.065	0	0
Average men headed HH	.801	.777	.742	.779	.066	0
Share HH w/ relationship to head-person	.326	.319	.436	.358	.648	0
Share of HH that outmigrated	.044	.045	.049	.046	.995	.434
Average # of migrants in HH	.138	.151	.134	.139	.419	.815
Average net income in 100K ZK*	12.666	9.706	8.642	10.993	0	0
Wealth Index	.141	-.115	-.196	0	0	0
HH head education (years)	5.654	5.354	4.807	5.354	.03	0
Total landholding size	3.215	2.908	2.521	2.958	.005	0
N	4,137	1,213	2,340	7,690		

Notes: The 'ttest' column shows individual p-values for tests of covariates.
*ZK: Zambian Kwacha

In the following section, I present the results of the estimation and check for the robustness of these estimates to different specifications.

4 Reduced-form impacts of Zambia's input subsidy program

In this section I show resulting change in the adoption of fertilizer and in migration decisions induced by the ISP. First I show the causal impacts of the FSP on agricultural outcomes. Then I show the ISP's impact on households outmigration decisions, I then decompose the impacts across short-term and medium term changes.

4.1 Agricultural intensification

Prior to looking at migration outcomes, I show that the subsidy program designed to move the needle on the adoption of fertilizer indeed improved agricultural outcomes. Table 3 shows the difference-in-differences results on agricultural inputs such as fertilizer adoption, inmigration (labor in farms), and maize yields in SEAs that receive the subsidy in 2004 against those that receive the subsidy in 2008. Column (1) shoes the results on fertilizer adoption against 2008 recipients.

Table 3: Difference-in-differences on the adoption of the fertilizer technology

	(1)	(2)	(3)	(4)	(5)
	Adoption	Yields	Individual inmigration		
	Extensive Marginal	Output kg/ha	Extensive Marginal	Intensive Marginal	Intensive Compound
PostxFSP	0.094***	149.4**	0.072***	-1.14***	0.95***
	(0.013)	(68)	(0.008)	(0.04)	(0.083)
FSP	-0.0077	238.8***	-0.008	0.05	0.01
	(0.015)	(76.4)	(0.007)	(0.04)	(0.08)
Post	0.09***	27.2	0.07***	-1.12***	0.89***
	(0.019)	(50.5)	(0.012)	(0.048)	(0.05)
Observations	10,920	10,792	13,889	15,483	11,612
Controls	Yes	Yes	Yes	Yes	Yes
Adoption in 2001	Yes	-	-	-	-
# Households	3871	3869	13889	3871	3871
# SEA	273	273	273	273	273
Comparison	2008	2008	2008	2008	2008

Notes: standard errors clustered at the SEA level in parentheses. I control for adoption in 2001 in column (1) to account for the gap in adoption (treated areas have higher adoption rates at baseline than control areas). Controlling for household size in 2004, wealth index in 2004. The "2008" control group correspond to households that have received the ISP in 2008. The outcome is the whether the household in an SEA that received the FSP adopted the fertilizer technology. *** p<0.01, ** p<0.05, * p<0.1

We see that adoption in SEAs that received the subsidy increases by 9 percentage points from an estimated counterfactual of .25%. Column (2) of Table 3 shows the impacts of the subsidy on yields. It shows in an increase of 149kg/ha from a estimated counterfactual of 730kg/ha — a 20% increase from expected yields stemming from the subsidy. Mazur and Tetenyi (2022) find similar increase in yields — i.e. an increase of 26% — as a result of the introduction of an fertilizer ISP in 10 African countries.

When labor markets are not fully functioning as implied by the analysis in Appendix , one margin to increase labor supply, is to increase the household size by hosting inmigrants. Beaman et al. (2013) show that fertilizer and labor are complements in agriculture; with thin labor markets, we expect inmigration to increase when fertilizer increases. Column (3) show that the FSP increases the propensity for a household to host an inmigrant (extensive margin) by a statistically meaningful 18 percentage points (from an estimated counterfactual of 17%); however, we see in column (4) that the intensive margins of migration (the number of inmigrants) decreases by almost three folds (-2.9x for the marginal measure) as a result of the subsidy. The sign is reversed in Column (5) when we account for inmigration aggregated over the years 2001, 2004, 2008 (compounded, with an increase of 50% increase against the estimated counterfactual). These columns summarize an ambiguous change in the number inmigrants.

The externality in the adoption of fertilizer

An important rational for the proliferation of ISPs in African countries, and beyond, is the existence of an externality in adoption. I test the existence of this externality leveraging the difference-in-differences setting. I split the treated SEAs among those that have more than the median of adopters and those below the median of adopters. I then estimate a triple difference of the following form:

$$\begin{aligned}\text{Adopt}_{h,t} = \quad & \alpha\mathbb{1}_{\{FSP\}} + \beta\mathbb{1}_{\text{Post}} + \gamma_1\mathbb{1}_{\{\text{Post*FSP}\}} + \gamma_2\mathbb{1}_{\{\text{Post*HighAdopt}\}} \\ & + \gamma_3\mathbb{1}_{\{\text{FSP*HighAdopt}\}} + \gamma\mathbb{1}_{\{\text{Post*FSP*HighAdopt}\}} + \eta X_h^0 + \phi\mathbb{1}_{\{h,FSP\}} + \epsilon_h \end{aligned} \tag{2}$$

I control for baseline household size, wealth, and importantly baseline fertilizer adoption, and whether or not the household received the ISP ($\mathbb{1}_{\{h,FSP\}}$). This latter control ensures that the change in adoption estimated by this triple difference comes from the change in the share of adopters (excluding household i) rather than its status as an ISP recipient.

I find that being in an area with a relatively high number of adopters (more than 17% of adopters in the area) changes a household probability of adopting 45 percentage points (see regression in Table 17 of Appendix A.4).

In the following subsection, I explore the causal impact of the ISP on an important margin: outmigration. Outmigration in the context of agricultural households can be considered as divestment from agriculture. And so understanding this decision margin for farmers who receive the FSP is very important.

4.2 Divestment from agriculture: outmigration

After finding that indeed the fertilizer ISP increased agricultural inputs (labor via inmigration and fertilizer use) and yields, I explore a second set of outcomes, that can inform us on whether these subsidies affect a set of decision beyond that of the stated target of the policies. I explore are outcomes related to outmigration and other off-farm activities. Table 4 shows that both for household migration and for individual migration increases across-the-board as a result of the FSP. Table 4 shows the difference-in-differences estimates for outmigration.

Columns (1) of Table 4 reports the estimates for household migration (*en masse*). As a result of the FSP, household outmigration (extensive margin) increased by about 8 percentage points — from an estimated counterfactual of about 12%.[19] Because the treatment is at the SEA level, these estimates are attenuated (biased towards zero) by households in the treated SEA that did not receive any subsidy — suggesting an even larger impact of the subsidy on household migration. This estimate is large but rather than highlighting a massive outflow of households, it shows that household migration rates are quite small at baseline.

Column (2) of Table 4 displays the estimates for the extensive margin of individual outmigration, column (3) the intensive margin of migration but measured each year (marginal), and finally column (4) looks at the measure of indivudual outmigration aggregated across the years 2001, 2004, and 2008 (compounded). At the extensive margin, there is a significant increase of about 40 percentage points (from an estimated counterfactual of 33%) on the propensity for a household to have at least one outmigrant as result of the subsidy. This result is coupled with an increase in the intensity with households in SEAs receiving the subsidy having between 1.98 (compounded) to 2.38 (marginal) times more outmigrants than SEAs that received the subsidy in 2008.

Column (5) and (6) of Table 4 show the estimates of intensive outmigration net of inmigration. It show that even acounting for inmigration, households in areas that receive the FSP tend to be net senders of outmigrants (compared to the control group made-up of those who receive the FSP in 2008).

In sum, the FSP has intensified the flows of both household and individual outmigration. This finding suggests frictions in the credit markets, which makes migration and relocation costs too high to allow for an optimal level of migration. When the subsidy is introduced, a plausible interpretation is that that voucher resale markets allow households with a low comparative advantage in the fertilizer agriculture to fund their outmigration. These households with a high comparative advantage in migration resell their subsidized fertilizer to households with a high comparative advantage in the fertilizer agriculture who in turn will host migrants. As fertilizer becomes more accessible, some households host inmigrants and double down in the agricultural technology.

[19] These 10% are obtained by adding up the estimate of the constant and the one for post and the SEA = 0.108 + 0.109 + 0

Table 4: Difference-in-differences outmigration

	(1)	(2)	(3)	(4)	(5)	(6)
	HH outmig	Individual outmigration			Net outmigration	
	Extensive Marginal	Extensive Marginal	Intensive Marginal	Intensive Compound	Intensive Marginal	Intensive Compound
PostxFSP	0.079***	0.395***	0.720***	1.138***	1.862***	0.967***
	(0.006)	(0.011)	(0.026)	(0.043)	(0.045)	(0.0473)
FSP	-0.001	-0.016**	-0.046***	-0.091***	-0.097**	-0.0639*
	(0.001)	(0.007)	(0.017)	(0.031)	(0.045)	(0.0387)
Post	0.109***	0.37***	0.65***	1.071***	1.765***	0.905***
	(0.00893)	(0.014)	(0.036)	(0.058)	(0.07)	(0.0617)
Observations	18,288	14,879	15,483	11,612	15,483	10,920
Controls	Yes	Yes	Yes	Yes	Yes	Yes
# Households	4,572	3,871	3,871	3,871	3,871	3,871
# SEA	331	273	273	273	273	273
Comparison	2008	2008	2008	2008	2008	2008

Notes: standard errors clustered at the SEA level in parentheses. Controlling for hh-size in 2004, wealth index in 2004. The outcome is the number of individual outmigrants who left the household or the number of inmigrant hosted by the household in the period. Netmigration is, at the household level, the difference between the number of outmigrants and the number of inmigrants. *** p<0.01, ** p<0.05, * p<0.1

These results are robust to different specifications, that I detail in the next subsection.

4.3 Robustness checks

In this subsection, I detail the different falsification tests I run to ensure the stability of estimates. More specifically I i) explore alternatives comparison groups, ii) I alter the regression to rid the possibility of forbidden comparisons, and finally, iii) I detail an alternative estimation using a political economy instrumental variable estimation.

Alternative comparison groups

Given that the 2004 recipient SEAs make-up the treatment group, the 2008 FSP-recipient could be considered a naive comparison group as those SEAs would likely be similar households in terms of rural activity but for administrative reasons received the FSP in 2008 and not in 2004. In this ideal case, I would compare the rate of household migration in 2008, for SEAs that received the FSP in 2004 against those who received the FSP in 2008. However, one can argue that SEAs that received the subsidy in 2008 only saw differential household migration patterns due to the increase in the opportunity cost of migration in 2008 and not in other years, due to the new 2008 subsidy. If this differential migration is true, SEAs receiving the FSP in 2008 may have been on a different trajectory with respect to household migration compared to other SEAs. This change in composition is likely not occurring for SEAs that did not receive the subsidy at all, and thus may be a preferred comparison group. Figure 3 (bottom right graph for household migration) shows that indeed for household migration that may be true: there is a stark change in the slopes of household outmigration between 2004 and 2008 for the group receiving the FSP in 2008. In the appendix A.5, I present the results using the group of SEAs that never received the subsidy as a comparison group, and results are similar in magnitude and in sign. Given the importance of household migration with regards to the much larger share of households remaining but with individual outmigrants, the bias stemming from the opportunity cost of migrating is likely smaller than the bias stemming from using *No FSP* as a comparison group.

I also use the *No FSP* group as a comparison group for the other estimates of the reduced-form analysis and find results of similar magnitude.

"Forbidden" comparisons

One can argue that including the 2008 year in the panel is a "forbidden" comparison, as it compares treated households to households treated in 2008 (Goodman-Bacon, 2021). In this setting, it is clear that the estimate is an underestimate because the paper identifies two sources of migration, first the relaxation of the credit constraint, which occurs immediately after receiving the subsidy, and labor released due to increased productivity, occurring in the medium run. In this setting, I am accounting for the short run migration on the part of the treated group, but in turn underestimating the medium term effect of the subsidy on migration: that is because some households that have received the ISP in 2008 may have responded with short term migration in 2008 already. To alleviate this issue, I exclude the year 2008 from the estimation, and present the result in Appendix A.5. The results are consistent with the main results of the paper, but become less precise, albeit significant.

In this empirical analysis, I estimate the impact of the subsidy for one cohort (2004) and against one cohort who either received the subsidy at a later period, or did not receive the subsidy at all. I do not pool treatment cohorts, and look at a static treatment. For that reason, there is no staggering of treatment, intertemporal treatment, and thus I do not need to correct the estimates of my paper (Callaway and Sant'Anna, 2021; De Chaisemartin and d'Haultfoeuille, 2020; Jakiela, 2021; Goodman-Bacon, 2021; De Chaisemartin and D'Haultfoeuille, 2022). I further pool all households within an SEA in the treatment group, whether or not the individual household received the subsidy (SEA is treated if the number of recipient households is positive), which limits selection into treatment, which may invalidate the estimation of a difference-in-differences (Rios-Avila et al., 2022).

Alternative estimations using the political economy of the subsidy

As a robustness-check to the difference-in-differences estimation, I estimate an instrumental variable, using the political clientelism and the choice of location of fertilizer providers (see Section A.5 of the appendix). I use political clientelism findings by Mason et al. (2013b) and Mason et al. (2017) in an instrumental variable design. I exploit the variations in the distribution of subsidies at the constituency level created by political clientelism to measure the impact of the policy on migrations.[20] I identify a Local Average Treatment Effect (LATE) on those who benefited from the subsidy due to presidential elections outcomes in their constituency.

I find that the results are qualitatively the same, though measuring a local average treatment effect of the farmers who receive the subsidy because they happen to be in the constituency won by the incumbent president.

These indirect impacts of the subsidy on migration found in this section may be considered "unexpected" by some. In the following subsection, I explore plausible mechanisms supported by correlational evidence that may explain this impact on migration decisions of treated households.

5 Mechanisms

In Zambia, I find that ISPs led to an increase in migration decisions. These changes in migration decisions for farmers are a composite of short-term migration consistent with the relaxation in credit constraints, and long-term migration consistent with structural change mediated by productivity changes. In subsection 5.1 I measure the weight of each short and long term migration.

Furthermore, I find both an increase in inmigration and outmigration. These results can be puzzling, but are rationalized by the specialization of farmers in activities for which they have a comparative advantage. In subsection 5.2, I explore this specialization process as a driver of these dual results.

5.1 Credit constraints vs. productivity drivers of migration

In the medium run some households may at first adopt the fertilizer, increase their productivity and thus free-up some labor that can then migrate as their increased productivity allows them to let go of labor on the land. This medium-run mechanism does not have to include resale markets and are in line with the structural transformation literature.

[20] The constituencies in Zambia are larger than the SEA, so these political economy results should not invalidate out cross-SEA measures of migration found with the difference-in-differences estimation.

I distinguish such households by comparing causal rates of migration for households responding to the ISP by migrating immediately after receiving the subsidy in 2004 and those that change their migration decision in 2008, four years after the implementation of the subsidy program. Households responding on the year they are given the subsidy have not yet seen their productivity increase, and so the channel is consistent with a relaxation of the credit constraint. Similarly those who migrate in the following years are likely migrating because the household free-up labor by becoming more productive.

Extensive Migration: First I explore the weight of each short-term and medium-term extensive migration decisions for households. The difference-in-differences treatment-on-the-treated estimator is a weighted average of the immediate impacts in 2004, and medium-term impacts in 2008. To identify the importance of short-term impacts, which are consistent with the relaxation of the credit constraint, relative to medium term impacts consistent with changes in productivity, I show the point estimate for each of these effects. I estimate the following model, for the extensive margins of interest:

$$Y_{h,t} = \quad \alpha \mathbb{1}_{\{FSP\}} + \beta \mathbb{1}_{\text{Post}} + \gamma_1 \mathbb{1}_{\{\text{FSP*Year=2004}\}} + \gamma_2 \mathbb{1}_{\{\text{FSP*Year=2008}\}} + \eta X_h^0 + \epsilon_{h,t} \tag{3}$$

Where γ_1 is the short-term effect, and γ_2 the medium to long-term effect. Because the farmers control group in 3 receive the treatment in 2008, γ_2 is net of short term migration (because farmers who would have made the decision to migrate immediately upon receiving their vouchers have left in 2008).

Intensive Migration: For intensive margins of migration (i.e. the number of migrants per households), the total number of migrants in the household at the end of the panel is the sum of all migrants across the three time periods (i.e. 2001, 2004, 2008).

$$m_h = m_{h,2001} + m_{h,2004} + m_{h,2008} \tag{4}$$

Where $m_{h,2001}$ is the number of migrants for a household h in the year 2001.

To measure the importance of each year and thus allow me to distinguish short-term and medium-term migration, I decompose the variance of the compounded migration measure at the end of the panel (i.e. in 2008). Equation 4 allows a simple decomposition of the variance of migration measured at the end period. The total migration measure can be summarized as such:

$$\begin{aligned}\text{Var}[m_h] = \quad & \text{Var}[m_{h,2001}] + \text{Var}[m_{h,2004}] + \text{Var}[m_{h,2008}] \\ & + 2 \cdot \text{Cov}[m_{h,2001}, m_{h,2004}] + 2 \cdot \text{Cov}[m_{h,2004}, m_{h,2008}] \\ & + 2 \cdot \text{Cov}[m_{h,2001}, m_{h,2008}] + \nu \end{aligned} \tag{5}$$

Table 5 shows the results for both Equation 3 in Panel 1 and Equation 5 in Panel 2. The weight for the short-term effects is largest for outmigration (see column 1 of Table 5), accounting for about 60% of the total migration response. For inmigration (Column 2) and adoption (Column 3), the weight is equally balanced across short-term and medium-term effects.

In Panel 2, I show the rate for each component of the variance decomposition in Equation 5. Though outmigration in 2008 accounts for most of the intensive outmigration, short-term outmigration immediately following the subsidy program accounts for a substantive 30% of the variance of the total number of outmigrants in the household.

In Panel 2, Column (2), the pattern for inmigration is inverted compared to that of outmigration, with most of the variance captured by earlier years of the panel. Most of the inmigration variance is captured between 2001 and 2004, both together accounting for about 75% of the variance; consistent with increased productivity. When the subsidy is introduced, a candidate explanation is: productivity increases, decreasing the need for labor and thus decreasing inmigration even for those with a comparative advantage in agriculture.

Table 5: Immediate vs. medium term effects

Panel 1: Channels for extensive migration

	(1)	(2)	(3)
	Extensive margins		
	outmigration	inmigration	adoption
Difference-in-Differences TOT	0.395***	0.180***	0.262***
	(0.0107)	(0.00993)	(0.0286)
Channels			
Short-term effect	0.349***	0.162***	0.256***
(*Post*× *FSP*× *Year 2004*)	(0.0122)	(0.0296)	(0.0290)
Long-term effect	0.459***	0.202***	0.268***
(*Post*× *FSP*× *Year 2008*)	(0.0131)	(0.0114)	(0.0296)
Weight short-term	58.18%	55%	50%
Observations	22,039	22,039	14,254
# Households	6,619	6,619	5,833
# SEA	332	332	332

Panel 2: Variance decomposition of intensive migration by 2008

	(1)	(2)	(3)
	Intensive margins		
	outmigration	inmigration	
Variance Decomposition			
Migration in 2001	04.70%	55.48%	-
Migration in 2004	30.03%	17.13%	-
Migration in 2008	46.10%	09.43%	-
Sorting: intensive 2001-04	05.29%	07.44%	-
Sorting: intensive 2004-08	11.69%	01.95%	-
Sorting: intensive 2001-08	01.69%	08.04%	-
Residual variance	00.90%	00.54%	-
# Households	3,227	3,227	-

Notes: TOT stands for teratment-on-the-treated estimates. Standard errors clustered at the SEA level in parentheses. Controlling for hh-size in 2004, wealth index in 2004. Outcomes are extensive measures of migrations at the household level: whether the household migrated entirely, has 1+ outmigrant, or has 1+ inmigrant. *** p<0.01, ** p<0.05, * p<0.1

In the remainder of the section, I explore specialization as a driver of the impacts of the subsidy on both outmigration and adoption. First with correlational evidence from the year the subsidy was disbursed, and then using a triple difference estimation.

5.2 Farmers specialization across agriculture and migration

In this section, I present correlational evidence that specialization of households across farming and other off-farm activities based on comparative advantage may be a mechanism leading to the increase in both agricultural and migration outcomes. Following the subsidy in 2004, I can distinguish four groups of farming households: those that respond on the outmigration margin, those on inmigration margin, those on both margins simultaneously, and those for which there are no changes in migration decisions.

Crop choices and migration decisions: To understand which mechanisms may have led to both an increase in agricultural outputs and in outmigration, I split the 2004 sample into the four groups of farming households. I then run the following regression to obtain the correlation between sources of income and migration choices limiting the sample to the 2004 sample that are in treated SEAs:

$$Y_h = \alpha + \beta_1 \mathbb{1}_{\{h,nomigrant\}} + \beta_2 \mathbb{1}_{\{h,inmigrant\}} + \beta_3 \mathbb{1}_{\{h,both\}} + \theta_{vil} + \epsilon_h$$

Where Y_h is alternatively the gross value of the household output of cash crops and of staple crops, or the off-farm and in-farm income. The outmigrant group is the reference category. Figure 4 shows the estimated coefficient (these estimates are not causal). On the left panel of Figure 4 we see the breakdown changes in the value of the harvest of cash crops and staple crops. On the right panel, we see coefficients for total, in-farm, and off-farm net incomes. Households with at least one outmigrant are the reference point (i.e. 0 line). There are coefficient for each other type of household: households with only inmigrants, households with both inmigrants and outmigrants, and households with no changes in their migration decisions.

On almost all measures, outmigrant households are similar to inmigrant households. When it comes to staple crops however, inmigrant households perform statistically better than outmigrant household, implying — given the increase in inmigrant — a larger allocation of inputs to agriculture.

We also notice that households with both inmigrants and outmigrants outperform outmigrant households on staple crops, and off farm income. A candidate explanation for this observation is that these households optimize on their choice of outmigrants and inmigrants, within the household based on their comparative advantage, and thus can maximize each individual member's output across the board.

Heterogeneity in income source by migration group: The empirical analysis suggests a degree of divestment away from agriculture for households that have a comparative

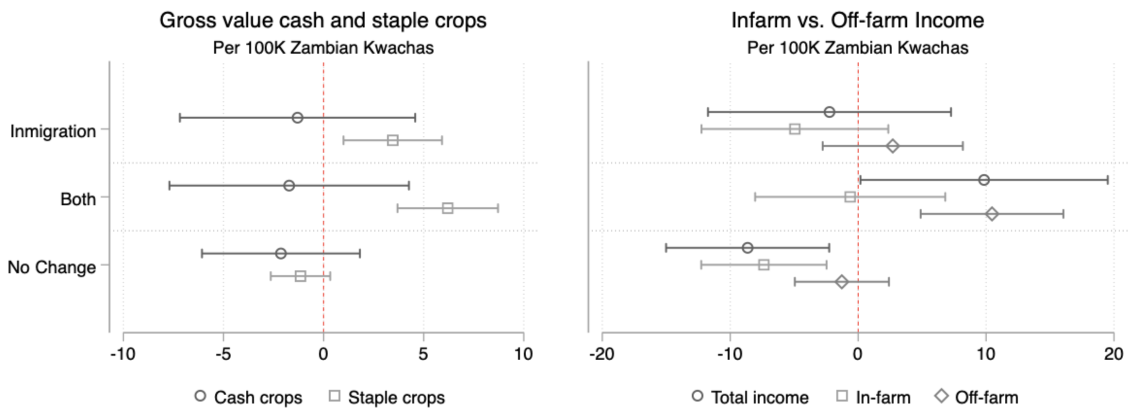


Figure 4: Specialization in agriculture across migration status
Notes: Households with at least one outmigrant are the reference point (i.e. 0 line). There are coefficient for each other type of household: households with only inmigrants, households with both inmigrants and outmigrants, and households with no changes in their migration decisions. The left panel reports coefficient for gross value of cash and staple crop harvests, and the right panel total, infarm, and off-farm net incomes.

advantage outside of agriculture. One way to see whether we do see that households who send outmigrants divest from agriculture is to look at the source of income of the household and see whether it changes as the subsidy is introduced. If specialization actually occurs, we should expect heterogeneous responses for households with a comparative advantage in migrating, who send individuals out and those with a comparative advantage in the agricultural technology who host inmigrants.

In order to explore whether this heterogeneity is observed, I use a triple difference estimation across households who receive the subsidy and host outmigrants and those who receive the subsidy and send outmigrants. These estimates are correlations and would not highlight causal links. More formally I estimate the following equation:

$$\begin{aligned}\text{Income Source}_{h,2008} = \quad & \alpha \mathbb{1}_{\{FSP\}} + \beta \mathbb{1}_{\text{Post}} + \gamma_1 \mathbb{1}_{\{\text{Post*FSP}\}} + \gamma_2 \mathbb{1}_{\{\text{Post*in/out}\}} \\ & + \gamma_3 \mathbb{1}_{\{\text{FSP*in/out}\}} + \gamma \mathbb{1}_{\{\text{Post*FSP*in/out}\}} + \eta X_h^0 + \epsilon_{h,2008} \qquad (6)\end{aligned}$$

Table 6 shows the heterogeneity measures across income sources for households with extensive individual outmigration (row 1), households with extensive individual inmigration (row 2) and finally households with both extensive individual inmigration and outmigration (row 3). The outcomes of these estimations are net in-farm income, net out-farm income, and business incomes. It shows that all three types of households seem have higher infarm income compared to the reference group (the one with no inmigrants or outmigrants), households with both inmigrants and outmigrants are the ones with the highest net-infarm income among.

Table 6: Heterogeneity in the source of income across household types

	(1)	(2)	(3)	(4)
	Net in-farm	Net off-farm	Business income	N (household)
Outmigration group	2,426,644***	947,714**	593,315**	9,777
	(500,982)	(271,099)	(236,244)	
Inmigration group	2,922,621***	1,457,295***	802,221***	9,777
	(978,345)	(314,715)	(244,806)	
Both inmigrants & outmigrants	3,068,624***	1,628,374***	539,493**	7,081
	(556,568)	(361,454)	(215,158)	

Notes: standard errors clustered at the SEA level in parentheses. Controlling for hh-size in 2004, wealth index in 2004. Comparing household with 1+ outmigrant/1+ inmigrant/ both 1+ outmigrant and 1+ inmigrant vs. household with no in or outmigrants. *** p<0.01, ** p<0.05, * p<0.1

In sum, households seem to specialize in their comparative advantage. With both hosts-households (with inmigrants) and sending-households (with outmigrants) having the same income, but getting them from difference sources.

In the next section, I generalize the findings from the reduced-form estimation using a structural model of self-selection into fertilizer use and migration. I then estimate the model and compare the ISP baseline with other popular rural policy and see how these policies deferentially affect migration and technology adoption.

6 A structural model of sorting via resale markets

In this section, I explore the mechanisms through which a subsidy on fertilizer inputs can affect migration. I present two environments, one without the subsidy, and one with the subsidy. In this model, households make a joint decision across i) adopting the fertilizer technology and ii) sending some of its members out for migration.

I develop a static Roy model of selection across the fertilizer and the traditional technologies with migration as an outside option. Farmers' decision to adopt the fertilizer technology is affected by a positive externality and households might not adopt the fertilizer even in cases where it would be profitable to do so. Farmers' migration decision on the other hand, is affected by their inability to borrow against their migration income. Farmers are heterogeneous on several dimensions, they have varying endowments in labor, land, and farming productivities. I explicitly model resale markets which allow farmers to relax their credit constraint, when they choose to sell their subsidized fertilizer voucher. As a result of these resale markets farmers can sort across migration, adoption, and traditional agriculture based on their comparative advantage.

6.1 The setup

The household makes the joint decision to adopt the fertilizer technology and to migrate. The household (indexed i) maximizes its surplus across all its options, similar to Suri (2011). Figure 5 summarizes the two joint-decisions considered in the model. The decision to use or not the fertilizer and the decision on how many migrants to send under two environments: one with the subsidy and one without the subsidy. In the remainder of the section, I model the decisions of a single household across these environments.

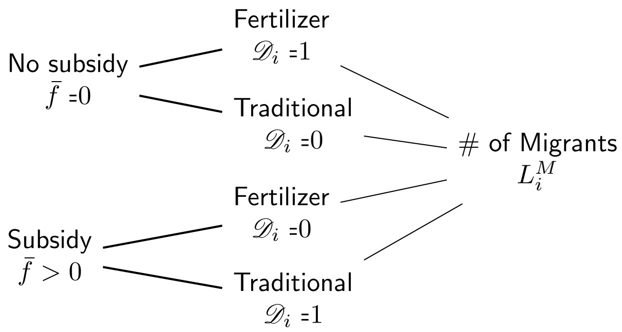


Figure 5: Household i Set of Choices in the Static Model

Notes: In this model the households makes two joint-decisions. The decision to use or not the fertilizer ($\mathscr{D}_i$) and the decision on how many migrants to send. This decision is made under two environments: one with the subsidy and one without the subsidy.

The household has L_i units of labor. It decides on units of labor $L_{i,A}$, $L_{i,M}$ to allocate to agriculture, and to migration respectively. $L_{i,A} \in [0, L_i]$, and $L_{i,M} \in [0, L_i]$, such that the household can divide an individual members' 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 across two technologies: i) the traditional technology which uses labor and land as inputs, and ii) a fertilizer technology that requires fertilizer as an additional input. The two agricultural technologies produce a homogeneous output. For the traditional technology, land holdings are not binding, and do not enter the production function. However, in the fertilizer technology, landholdings X_i enter the production function explicitly.

Migration: the surplus generated by the labor allocated to migration is $\pi^M = (L_i - L_{i,A}) \cdot (w - m_i(\theta_{vil}, \zeta_i)) - c$, where c is the fixed cost of migration which can be interpreted as the initial cost the first migrant leaving the household has to incur to find a dwelling at their destination, w is the individual exogenous wage at destination. The wage is assumed to be same for all migrants, however, $m_i(\theta_v, \zeta_i)$ the marginal cost of migration varies by household. It is a measure of how costly it is for a household to migrate. m_i is made up of two components, one known to the household that is function of the village they live in, θ_v, and one that is a migration idiosyncratic shock ζ_i, and unknown to the household when it makes its decision. ζ_i is normally distributed.

6.2 Traditional agriculture

The production function for the traditional technology is $Y^T = a \cdot L_{i,A}^{\gamma}$, the surplus stemming from the traditional technology alone is $\pi^T = p \cdot a \cdot L_{i,A}^{\gamma}$, where γ is the output elasticity of labor in the traditional agriculture. The household faces a credit constraint, meaning that it cannot borrow against its returns to migration. This constraint implies that its returns to agriculture must entirely cover its fixed cost of migration.

In the model, I make the simplifying assumption that the fertilizer is subsidized at 100%, and so the household receives a bag of a quantity $\bar{f}$ for free. 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 production; or trade the vouchers in resale markets at a price q. When the household chooses the traditional technology, it receives a quantity $\bar{f}$ of subsidized fertilizer, and sells all of it in the resale market (i.e. $\tilde{f} = -\bar{f}$) at a unit price of q.

The household maximizes its total surplus combining its returns to migration and agriculture, subject to a credit constraint, and has the following optimization problem:

$$\max_{L_{i,A}} \quad \pi^{T,M} = \left\{p \cdot Y^T + q \cdot \bar{f} + \pi^M\right\}, \tag{7}$$

$$\text{s.t. } L_i = L_{i,A} + L_{i,M}, \tag{8}$$

$$L_i \neq L_{i,A} \iff p \cdot Y^T \geq c - q \cdot \bar{f}, \tag{9}$$

The first order conditions are thus $\frac{\partial \pi^{T,M}}{\partial L_{i,A}} = \gamma \cdot p \cdot a {L_{i,A}^*}^{\gamma-1} - (w - m_i(\theta_{vil}, \zeta_i)) = 0$.

The optimal labor allocated to migration under the traditional agriculture is the following:

$$L_{i,M}^* = \begin{cases} 0 & \text{if } p \cdot Y^T < c - q \cdot \bar{f} \\ L_i - \left[\frac{\gamma \cdot p \cdot a}{w - m_i}\right]^{\frac{1}{1-\gamma}} & \text{otherwise.} \end{cases} \tag{10}$$

When the subsidy is introduced, the household receives a lump sum amount from the sale of the subsidized fertilizer $\bar{f} > 0$, independent of its labor allocation decision. In both environments (with and without the subsidy), the optimal interior solution for labor units allocated to migration under the traditional agriculture is the same. However, the credit constraint is shifted by farming households' ability to re-sell their voucher for the subsidized fertilizer. This shift reflects a relaxation of the credit constraint that farming households face.

6.3 Fertilizer agriculture

The production function for the fertilizer-intensive technology is $Y^F = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta}$, the profit function stemming from selling the production is $\pi_i^F = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i)$, where A_i is the household's idiosyncratic productivity, X_i the landholdings of the household, F_i the total amount of fertilizer used on the farm such that $F_i = \tilde{f}_i + \bar{f}$, the quantity received via the subsidy and the quantity traded in markets. The household purchases an amount $\tilde{f}$ of fertilizer at a price q. Without the subsidy (i.e. $\bar{f} = 0$), the total amount of fertilizer available for the farmer is $\tilde{f} + \bar{f} = \tilde{f}$.

The household is a price taker in the fertilizer market, and q is the manufacturing price of fertilizer, and the village faces a fixed cost T_v of adopting the fertilizer that must be split across all adopting households in the village. The learning externalities in agricultural technology adoption (Conley and Udry, 2010; Carter et al., 2021; Foster and Rosenzweig, 1995) enter the household's problem via the cost of adoption at the household level $T_{area} \cdot (1 - \frac{\sum_{j \neq i} \mathscr{D}_j}{N})$ (where j indexes all households of the village and N is the total number of farmers in the village). In other words, the fixed cost of using fertilizer depends on the share of households in the village that adopts the fertilizer-augmented technology. Here, one can think of this fixed costs as the cost of getting a vendor to set-up shop in a village, or the cost of renting out a truck to transport the fertilizer to the village. This cost is fixed but is shared among all the users in the village.

With the subsidy, i.e. $\bar{f} > 0$, the household can either choose to use the subsidized fertilizer in their production; or trade the vouchers in resale markets at a price q. With the subsidy, the village level cost of transportation is no longer an issue for the household because the planner internalizes the externality. The household can trade a quantity $\tilde{f}_i$ in resale markets (either selling or buying). The household can sell its entire subsidized allocation, or it can buy any affordable amount; with $\tilde{f}_i \in [-\bar{f}; \infty)$. The total available quantity of fertilizer available for production is $F_i = \tilde{f}_i + \bar{f}$.

The household maximizes its surplus under the credit constraint, and its optimization problem is the following without the subsidy:

$$\max_{L_{i,A}, F_i} \pi^{F,M} = p \cdot Y^F - q \cdot (\tilde{f}_i) - (1 - r_{\bar{f}}) \cdot T_{area} \left(1 - \frac{\sum_{j \neq i} \mathscr{D}_j}{N}\right) + \pi^M, \tag{11}$$

$$\text{s.t. } L_i = L_{i,A} + L_{i,M}, \tag{12}$$

$$L_i \neq L_{i,A} \iff p \cdot Y^F - (1 - r_{\bar{f}}) \cdot T_{area} \left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right) \geq c + q \cdot (F_i), \tag{13}$$

where $r_{\bar{f}}$ is the subsidy rate for the bag of fertilizer received. Here we make the simplifying assumption that the when the susbidy is available, the household receives a bag for free, i.e. $r_{\bar{f}} = 1$. The first order conditions are the following:

$$\frac{\partial \pi_i^{F,M}}{\partial L_{i,A}^*} = \alpha p \cdot Y^F - (w - m_i(\theta_{vil}, \zeta_i)) = 0, \tag{14}$$

$$\frac{\partial \pi_i^{F,M}}{\partial F_i^*} = \beta P \cdot A_i \cdot {L_{i,A}^*}^{\alpha} {F_i^*}^{\beta-1} X_i^{1-\alpha-\beta} - q = 0, \tag{15}$$

.

The household allocates labor across migration ($L_{i,M} = L_i - L_{i,A}$) and agriculture ($L_{i,A}$) such that the marginal return across the two activities is the same. The household uses a fertilizer amount such that its return in the agricultural sector are equal to the price of fertilizer in resale markets.

Without the subsidy (i.e. $f = 0$), and when the household chooses the fertilizer agriculture, the household optimal level of migration is :

$$L_{i,M}^* = \begin{cases} 0 \text{ if } p \cdot Y^F - T_{area} \left(1 - \frac{\sum_{j=1}^N \mathscr{D}_j}{N}\right) < c + q \cdot (F_i) \\ L_i - \left[\left(\frac{p \cdot A_i \cdot \alpha}{w - m_i}\right)^{(1-\alpha)\cdot(1-\beta)} \cdot \left(\frac{\beta}{q}\right)^{\beta} \right]^{\frac{1}{1-\alpha-\beta}} \cdot X_i \text{ otherwise.} \end{cases}$$

(16)

With this lower cost of fertilizer use, the quantity of fertilizer used increases, leading to higher prices in resale markets. This higher price in resale markets means that households that were credit constrained and thus could not migrate, see their credit constraints in turn relaxed more and so we should see more migration. *With the subsidy, i.e. $\bar{f} > 0$:* resale markets exist and they clear. These resale markets thus endogenize the resale prices q. This market clearing condition means that $L_{i,M}^*$ is known after accounting for the decision to adopt.

6.4 Choice to adopt the fertilizer technology

The household will adopt fertilizer if its surplus in the fertilizer agriculture is larger than in the traditional agriculture. In both cases, the household has the outside option of migrating. Formally: $\mathscr{D}_i = 1$ iff $\pi_i^{FM*} \geq \pi_i^{TM*}$.

Without the subsidy, i.e. $\bar{f} = 0$: the household adopts the fertilizer agriculture if :

$$A_i \geq \left[\frac{(p \cdot a \cdot \gamma)^{\frac{\gamma}{1-\gamma}} \cdot (p \cdot a - w + m)}{\left(\frac{1}{Z}\right)^{\alpha} (B)^{\frac{\beta}{\omega}} \cdot X_i - q \left(\Psi \cdot (B)^{1-\alpha}\right)^{\frac{1}{\omega}} \cdot X_i - \frac{\alpha}{Z} \left(\Psi \frac{(B)^{\beta}}{Z}\right)^{\frac{1}{\omega}} - (1 - r_{\bar{f}}) \cdot T_{area} \left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right)} \right]^{1-\alpha-\beta}, \tag{17}$$

where $Z = \frac{\alpha}{w-m_i}$, $B = \frac{\beta}{q}$, and $\omega = 1 - \alpha - \beta$ and $\Psi = P \cdot A_i \left(\frac{\alpha}{w-m_i}\right)^{\alpha}$ A household adopts the fertilizer-intensive agriculture if and only if its idiosyncratic productivity, A_i, is above a given threshold. Note that adoption is thus increasing in the number of households that adopt the fertilizer in the village $\left(\frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right)$. It is also decreasing in the returns to migration.

In the setting without the subsidy, only the most productive farmers choose to adopt, and the outside option of migration is attractive to both traditional and fertilizer-intensive farmers.

With the subsidy, i.e. $\bar{f} > 0$*:* the market clearing condition is such that $\sum_{j=0}^{N} \tilde{f}_j = 0$. At equilibrium, the resale prices q^*, the total fertilizer used F^*, and labor share migrating $L_{i,M}$ are the following:

$$q^* = \beta \left[\left(\frac{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)}{N \bar{f}} \right)^{1-\alpha-\beta} \cdot P \cdot \left(\frac{\alpha}{w - m_i} \right)^{\alpha} \right]^{\frac{1}{1-\alpha}}, \tag{18}$$

$$F_i^* = A_i^{1-\alpha-\beta} \cdot \left(\frac{N \bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)} \right) \cdot X_i, \tag{19}$$

$$L_{i,M}^* = L_i - A_i^{1-\alpha-\beta} \cdot \left[p \cdot \left(\frac{\alpha}{w - m_i} \right) \cdot \left(\frac{N \bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)} \right)^{\beta} \right]^{\frac{1}{1-\alpha}} \cdot X_i. \tag{20}$$

Adoption of the fertilizer agriculture happens when:

$$A_i \geq \left[\frac{(p \cdot a \cdot \gamma)^{\frac{\gamma}{1-\gamma}} \cdot (p \cdot a - w + m)}{\left(P (Z)^{\alpha} (Q)^{\beta}\right)^{\frac{1}{1-\alpha}} X_i^{\alpha+\beta} - \beta \left[\left(\frac{1}{Q}\right)^{1-\alpha-\beta} \cdot P \cdot (Z)^{\alpha} \right]^{\frac{1}{1-\alpha}} (Q) X - \left[Z P (Q)^{\beta} \right]^{\frac{\alpha}{1-\alpha}} X \cdot (w - m_i(\theta_{vil}, \zeta_i))^{\frac{1}{1-\gamma}}} \right]^{1-\alpha-\beta},$$

where $Z = \frac{\alpha}{w-m}$ and $Q = \frac{N \bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)}$. Only the most productive farmers choose to adopt. Here, the price of the fertilizer has been endogenized. Furthermore, the threshold is lower in comparison to the environment without subsidies because the fixed cost of adoption $T_{area} \cdot \left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_i}{N}\right)$ is eliminated as the subsidy is introduced. Here, the number of households that adopt the fertilizer-intensive technology in the village $\left(\frac{\sum_{j=1}^{N}\mathscr{D}_j}{N}\right)$ is present as an argument of the decision via the resale markets.

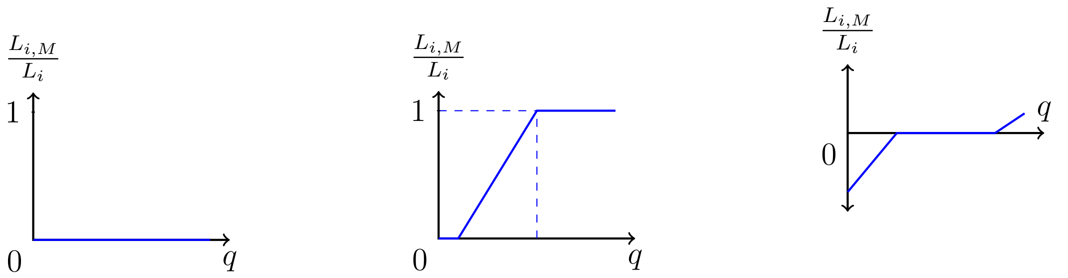
With the subsidy, changes in adoption rates as a result of the subsidy are ambiguous. On the one hand because as more households adopts, prices in resale markets soar, making purchasing fertilizer more expansive. On the second hand, because when adoption increases in the village, the opportunity cost of adopting increases putting pressure on the household to divest from the fertilizer agriculture altogether.

6.5 Comparative statics

I compare migration decisions of households with varying A_i (i.e. comparative advantages). In Figure 27, I plot migration responses to resale prices for three households with different comparative advantages.

For the household A of Figure 27, we see that households that have a comparative advantage in the non-fertilizer or traditional agriculture technology do not migrate. These households would generate income by selling fertilizers on resale markets, but as we saw earlier, their decision to migrate does not depend on q. The households' migration decision is thus left unchanged by the subsidy under this framework.

For household C of Figure 28, the household has a comparative advantage in the fertilizer technology. In this setting, with very low q, the household stays and hosts inmigrants (the only margin to increase the labor supply within the household under imperfect labor markets) to help with the production. This feature stems from the complementarity between labor and fertilizers for the household (Beaman et al., 2013). The household decision is a corner solution where all its labor is allocated to the fertilizer technology. As q gets smaller, the household budget constraint is relaxed and it can hire labor absent members of the household. In this analysis, I assume that households do not hire labor except by hosting in-migrants. This assumption corresponds to the observation that small rural farms tend to rely heavily on family labor (Rosenzweig, 1988). As q increases however, migration becomes more attractive and the household start allocating members to migration. We thus see that for high values of q the household either engages in traditional agriculture or migrates depending on its productivities.



HH A: Low A_i low $w - m_i$ HH B: Low A_i, high $w - m_i$ HH C: High A_i low $w - m_i$

Figure 6: Comparative statics with different comparative advantages

6.6 Testing the implications of the model with descriptive statistics

In what follows, I test three important implications of the model using the Zambian post-harvest survey.

Implication 1: to have an impact on migration, the subsidy must be large enough to relax credit constraints.

A central mechanism through which the subsidy may change migration patterns is via the relaxation of the credit constraint. The relaxation of the credit constraint may only mechanism to explain the increase in migration if the income a household generates via the resale market is substantial in comparison to its net disposable income. I compare the subsidy amount to the disposable income. The subsidy amounted 50% of the price of fertilizer in 2004 and 60% in 2008.

The subsidy represents more than 10% of net yearly income for 10% to 30% of the sample (depending on whether we look at the 100kg threshold or the amount of fertilizer used on the farm respectively). Which is a substantial amount.[21]

Implication 2: migration increases as the resale value of the subsidized fertilizer increases

Another implication of the model is that as the resale value of the vouchers increases, migration should be comparatively more attractive. This correlation is a result of the credit constraint being relaxed for more households. Additionally, it also implies that

[21]Figure 21 in the appendix plots the distribution of $\frac{\text{Subsidy amount}}{\text{Subsidy amount + Disposable Income}}$ for households that received the subsidy in 2004 and households that received the subsidy in 2008. It shows that for most households, the amount of the subsidy exceeds 10% of the disposable income — which is a large amount.

the opportunity cost of the marginal hectare of fertilizer agriculture is higher because it becomes too costly to top-up, and thus relatively, migration becomes more attractive.

The correlation between resale price (which I proxy using the commercial price) with individual migration at the extensive margin is a 0.07 and 0.08 at the intensive margins.[22] Furthermore, an additional $1 of subsidy, there is a increase of .2 percentage point in the likelihood that a household sends at least one member out and an increase of .1 percentage point in the number of people sent out (for regression results, see Table 23 in the Appendix and Figure 24).

Implication 3: for relatively high levels of fertilizer access, households sort based on their endowments in labor, land and returns to fertilizer use and migration (comparative advantage).

This implication is shown in the empirical estimation of Section 3, where I show that while some households choose to increase their supply of migrants, others adopt the new technology and invest in agriculture.

In Appendix A.9, I develop an alternative model which accounts for a more complex set of option for the farmers, and further accounting for the central planner problem. This alternative model does away with some of the restrictive assumptions of the model and leads to similar predictions when solved using simulated data.

In the next section, I present the structural estimation strategy, the results of the structural estimation, and compare the baseline ISP policy in the presence of resale markets with cash transfer policies and in-kind transfers.

7 Structural estimations and counterfactuals

7.1 The benchmark estimation: ISP and migration

Elasticities of production

The optimal levels of migration depends entirely on elasticities and prices. Here, I estimate the Cobb-Douglas production function from Section 6.

Identification: I identify the different production function by estimating the fertilizer technology among adopting farms (i.e. farms that report to use fertilizer on their farms)

This accounts for all the inputs of the production function and the village fixed effect

[22]Figures 23 and 24 in the appendix plot these correlations

which is the predictable component of A_i. The residual of this equation is $\log(\nu_i)$, the idiosyncratic portion of A_i.

Fertilizer Technology: $\log(Y_{maize,i}) = \log(A_i) + \alpha \log(L_{i,A}) + \beta \log(F_i) + \nu \log(X_i) + \theta_{vil}$					
Sample: FSP + Adoption	α	ν	β	$\alpha + \nu + \beta$	P-value $H_0 : \alpha + \nu + \beta = 1$
Estimates	.109	.449	.483	1.041	.42
Standard Errors	(.047)	(.036)	(.033)		

Traditional Technology: $\log(Y_{maize,i}) = \gamma \log(L_{i,A}) + \mu \log(X_i) + \theta_{vil}$					
Sample: FSP + No adoption	γ	μ		$\gamma + \mu$	P-value $H_0 : \gamma + \mu + \beta = 1$
Estimates	.166	.572		.738	0
Standard Errors	(.034)	(.030)			

The estimation shows that the fertilizer technology has constant return to scale while the traditional technology is decreasing returns to scale. This implies that on average, the optimal size of traditional farms should be smaller relative to fertilizer-intensive farms.

The externality of adoption: In the model the externality is a linear function of the number of farmers who are at any time using the fertilizer.

Identification: To estimate this cost T_{area}, while abstracting for general endogeneity of adoption within an area I estimate the Equation 21 among areas that did not receive the subsidy. Using areas that receive the subsidy would risk underestimating the importance of the externality. That is because the central planner puts in place this subsidy exactly to get rid of this externality T_{area}. To address endogeneity issues in each village, I use the lagged share of adopters to instrument the current share of adopters. I estimate the effects with the following model:

$$\mathscr{D}_i = \mathbb{1}_{year=2004} + \theta_{province} + T_v \cdot (\theta_{vil} \times Share\widehat{Adopters}_{SEA,t}) + \iota_{i,t} \tag{21}$$

Aggregating over all these estimates of T_v gives an average of $T = 1.463$ with standard errors of .2; showing that indeed probability of adoption for one household strongly depends on the share of households around them using fertilizer, but more importantly that this parity is greater than 1. Figure 7 plots the distribution of the estimates for T_v: it shows that there is indeed an persistent externality across villages. The dashed blue line represents the estimate equal to -1. Any estimate above that line represents areas in

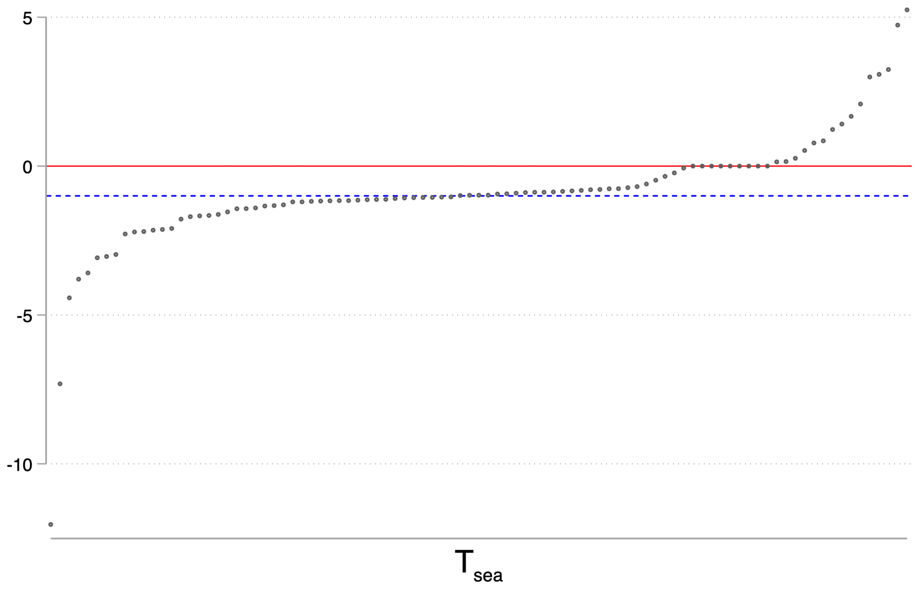


Figure 7: Estimates of T_v

Notes: Estimates of T_v stem from Equation 21. It is a measure of how sensitive adoption is to changes in the village level adoption rate in the absence of the subsidy.

which there is a strong externality as defined in the model —i.e. a great propensity that a household adopt as the number of adopters increase around them.

I extrapolate the distribution T_v in areas that have received the subsidy based on the estimates harvested from 21.

The joint-decision Across Adoption and Migration

The household makes its decision on adoption of fertilizer and migration simultaneously. Section 6 shows that the adoption of the fertilizer-intensive technology is a based on whether household' productivity exceeds a threshold. When there is a subsidy, this threshold is a function of the ratio of the price of the output, the ratio of adopters to beneficiaries of the ISTP, the exogenous migration wage and the household's landholdings. Remember from the solutions of the model in section 6 that $\mathscr{D}_i = 1$ [23] $\iff A_i = \upsilon_i + \theta_{vil} \geq f(P_v, w_v, q_v, X_i, Q_v)$. Because υ_i is normally distributed, $Pr(\mathscr{D}_i = 1) = \Phi(\beta_1 P_v + \beta_2 w_v + \beta_3 q_v + \beta_4 X_i + \beta_4 Q_v + \sum \eta_v \theta_{vil})$, where $\Phi(\cdot)$ is the cumulative distribution function of the normal distribution. This assumption allows me to estimate the technology adoption decision with a logistic regression. Without the subsidy, I can write $\mathscr{D}_i = 1 \iff A_i = \upsilon_i + \theta_{vil} \geq f(P_v, w_v, q_v, X_i, Q_v, T_v)$.

[23] Where P is the price of the output, w is the wage at destination, q is the resale price of the fertilizer, X the household's landholdings and $Q = \frac{N\bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)}$.

The choice of the number of migrants is censored at 0. Households do not send outmigrants when their optimal L_i^M is negative. In that case, we also cannot infer the wage at destination. In order to estimate the choice of the number of migrants, I choose the model of selection from Heckman (1979).

Formally, I write the two decisions as follows, first when the subsidy is available:

$$\begin{cases} Pr(\mathscr{D}_i = 1) = \Phi(\beta_1 P_v + \beta_2 w_v + \beta_3 q_v + \beta_4 X_i + \beta_4 Q_v + \beta_5 T_v + \sum \eta_v \theta_{vil} + \epsilon_1) \text{ if } \bar{f} > 0, \\ L_i^M = \begin{cases} 0 & \text{if } (w - m_i(\theta_{vil}, \zeta_i))^* \leq \bar{w}_i, \\ L_i^{*M} & \text{Otherwise,} \end{cases} \end{cases}$$

and when the subsidy is not available:

$$\begin{cases} Pr(\mathscr{D}_i = 1) = \Phi(\beta_1 P_v + \beta_2 w_v + \beta_3 q_v + \beta_4 X_i + \beta_4 Q_v + \sum \eta_v \times T_v + \epsilon_1) \text{ if } \bar{f} = 0, \\ L_i^M = \begin{cases} 0 & \text{if } (w - m_i(\theta_{vil}, \zeta_i))^* \leq \bar{w}_i, \\ L_i^{*M} & \text{Otherwise .} \end{cases} \end{cases}$$

We do not observe L_i^{*M}, but we can infer it from the estimated elastiticies. More specifically, in the case with susbidy, $\widehat{L_{i,M}^*} = L_i - \widehat{A_i}^{1-\widehat{\alpha}-\widehat{\beta}} \cdot \left[p \cdot \left(\frac{\widehat{\alpha}}{\widehat{w - m_i}} \right) \cdot \left(\frac{N\bar{f}}{\sum_{j=0}^{N} \widehat{\mathscr{D}_j}(A_j X_j)} \right)^{\beta} \right]^{\frac{1}{1-\widehat{\alpha}}} \cdot X_i + \epsilon_3$, and without subsidy, $\widehat{L_{i,M}^*} = L_i - \left[\left(\frac{p \cdot \widehat{A_i} \cdot \widehat{\alpha}}{\widehat{w - m_i}} \right)^{(1-\widehat{\alpha}) \cdot (1-\beta)} \cdot \left(\frac{\widehat{\beta}}{q} \right)^{\widehat{\beta}} \right]^{\frac{1}{1-\widehat{\alpha}-\widehat{\beta}}} \cdot X_i + \epsilon_3'$. The decisions to migrate and to adopt the fertilizer is allowed to be correlated. In practice, this correlation in decisions implies that the error terms in the decision to migrate and to adopt the ferilizer are jointly distributed. Note that the choice of migration is also subject to selection, with only households with a comparative advantage in migration migrating. We thus have: $\begin{pmatrix} \epsilon_1' \\ \epsilon_2' \\ \epsilon_3' \end{pmatrix} \sim \mathcal{N} \left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{\mathbf{1}}'^{\mathbf{2}}, \sigma_{1,2}', \sigma_{1,3}' \\ \sigma_{1,2}', \sigma_{\mathbf{2}}'^{\mathbf{2}}, \sigma_{2,3}' \\ \sigma_{3,2}', \sigma_{3,2}', \sigma_{\mathbf{3}}'^{\mathbf{2}} \end{pmatrix} \right)$, and $\begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \end{pmatrix} \sim \mathcal{N} \left(\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{\mathbf{1}}^{\mathbf{2}}, \sigma_{1,2}, \sigma_{1,3} \\ \sigma_{1,2}, \sigma_{\mathbf{2}}^{\mathbf{2}}, \sigma_{2,3} \\ \sigma_{3,2}, \sigma_{3,2}, \sigma_{\mathbf{3}}^{\mathbf{2}} \end{pmatrix} \right)$, where ϵ_2, and ϵ_2' are the error terms of the equations of selection into migration in the case with subsidy and without subsidy respectively. This selection leads to a threshold of participation into migration that is stochastic, leading to the following full set of simultaneous equations:

$$\begin{cases} Pr(\mathscr{D}_i = 1) = \Phi(.) \text{ if } \bar{f} = 0 \text{ or } \bar{f} > 0 & \text{(adoption of technology),} \\ \begin{cases} Pr(\mathscr{M}_i = 1) = \Phi(.), & \text{(heckit selection),} \\ L_i^M = f(.) + \epsilon_3 & \text{(heckit outcome).} \end{cases} \end{cases}$$

where $f(.)$ is a linear function of the variables in the the expression of $\widehat{L^*_{i,M}}$.

Estimation: I retrieve the parameters of the model using maximum likelihood estimation. I write the likelihood function as follows:

$$L = \prod_{i=1}^{n} \overbrace{\left\{ \Pr[\mathscr{D}_i = 1] \times \overbrace{\{\Pr[w_i{}^* \leq \bar{w}_i]\}^{1-\mathscr{M}_i} \left\{ f\left(L_i^M | w_i{}^* > \bar{w}_i\right) \times (1 - \Pr[w_i{}^* \leq \bar{w}_i]) \right\}^{\mathscr{M}_i}}^{\text{Migration decision (2steps)}} \right\}^{\mathscr{D}_i} \cdot}^{\text{Adoption}}$$
$$\underbrace{\left\{ (1 - \Pr[\mathscr{D}_i = 1]) \times \underbrace{\{\Pr[w_i{}^* \leq \bar{w}_i]\}^{1-\mathscr{M}_i} \left\{ f\left(L_i^M | w_i{}^* > \bar{w}_i\right) \times (1 - \Pr[w_i{}^* \leq \bar{w}_i]) \right\}^{\mathscr{M}_i}}_{\text{Migration decision (2steps)}} \right\}^{1-\mathscr{D}_i},}_{\text{No adoption}} \tag{22}$$

where $w_i^* = (w - m_i(\theta_{vil}, \zeta_i))^*$.

Table 24 in the Appendix A.7, presents the result of this maximum likelihood simultaneous estimation.

Goodness of fit

To check for goodness of fit, Table 7 where I summarize the in-sample prediction of the model. columns (1)-(2) reports the moments for each parameter fitted in the model for the actual data (column 1) and for the maximum likelihood estimations. Column (3) shows the difference between the actual and the prediction of the maximum likelihood estimation.

The model seem to perform relatively well in matching the cross sectional moments. The differences are relatively small for the binary decision to migrate ($\mathscr{D}_i$) and for the binary decision to migrate ($\mathscr{M}_i$). The difference for the intensive migration variable is large, but it is expected as here I am measuring L_{iM} in terms of number of migrants. The difference in number of migrants predicted by the model is under one household member which in magnitude is still relatively small.

Table 7: Goodness of fit for the structural estimation

In-sample performance

Averages

	Actual	Prediction	Difference
$\mathscr{D}_i$	.3270548	.3231824	.0038724
L_{iM}	1.813601	2.73248	-.9188788
$\mathscr{M}_i$	.6978963	.7108344	-.0129381

Standard Deviations

	Actual	Prediction	Difference
$\mathscr{D}_i$	.4691949	.4677559	.001439
L_{iM}	1.963202	1.046767	.9164356
$\mathscr{M}_i$	.4592261	.4534315	.0057947

Correlation

	Actual	Prediction	Difference
$corr(\mathscr{D}_i, \mathscr{M}_i)$	0.0942	.2018	

Notes: column (1) is the actual observation of the parameters for the year 2004, column (2) is the prediction using the maximum likelihood estimated of the simultaneous equations, using 2004 data, column (3) is the difference between actual and predicted outcomes.

7.2 Estimation of counterfactual policies

Using the estimates obtained from the model, I estimate the counterfactuals from several popular rural antipoverty policies. First, I explore, under the model assumptions, what would happen with a cash-transfer program, a binding restriction on resale markets and finally a subsidy on the cost of the externality.

Impacts of a cash-transfer programs (targeted and untargeted)

The cash-transfer program has two main feature difference with the baseline ISP model. First, the externality $T_{area}\left(1 - \frac{N}{\sum_{j=0}^{N} \mathscr{D}_j(A_j X_j)}\right)$ remains after the policy is introduced. Second the cash-transfer program does not foster resale markets.

I will test two ways of designing the cash-transfer policy, a first I will use the targeting of the ISP, and provide a revenue neutral cash-transfer to farming households who had previously received the subsidy. In a second design of the revenue neutral cash-transfer program, there is no targeting and all farmers living in a treated SEA receive some amount for cash.

Targeted cash-transfer: I find that the targeted cash-transfer program increases decreases both migration rates (-13%) and the adoption of the fertilizer technology (-99%). First, the externality in adoption is not internalized and adoption rates plummet compared to the ISP. Second migration also decreases because unlike the ISP, the cash is fungible and there is no redistribution of the cash across households. In that case, only the households receiving the subsidy can change their migration decisions. Another channel of the model is that households that adopt the fertilizer agriculture and generate more profit in the fertilizer agriculture can fund migration. Because the targeted cash-transfer leads to no adoption, there is no spillover (in the model) of the cash-transfer program. Figure 8 plots the prediction on fertilizer adoption and on extensive migration.

Untargeted cash-transfer: I find that the cash-transfer program increases migration rates substantially (+11%) but has strong negative effects on the adoption of the fertilizer technology (-99%). That is because the externality in adoption is not internalized. Figure 8 plots the prediction on fertilizer adoption and on extensive migration.

Impacts of shutting-down the resale markets (ISP without resale)

Shutting down the resale markets will impact the reallocation of fertilizer in the market. Furthermore, farmers with a comparative advantage in migrating but who are credit constrained are not able to generate liquidity to fund migration. This policy effectively has the mirror effect of the cash-transfer program. There are substantial efficiency losses with a drop in both adoption (-75%) and in migration (-15%). In that case the improvement in overall productivity is negative compared to the ISP with resale markets.

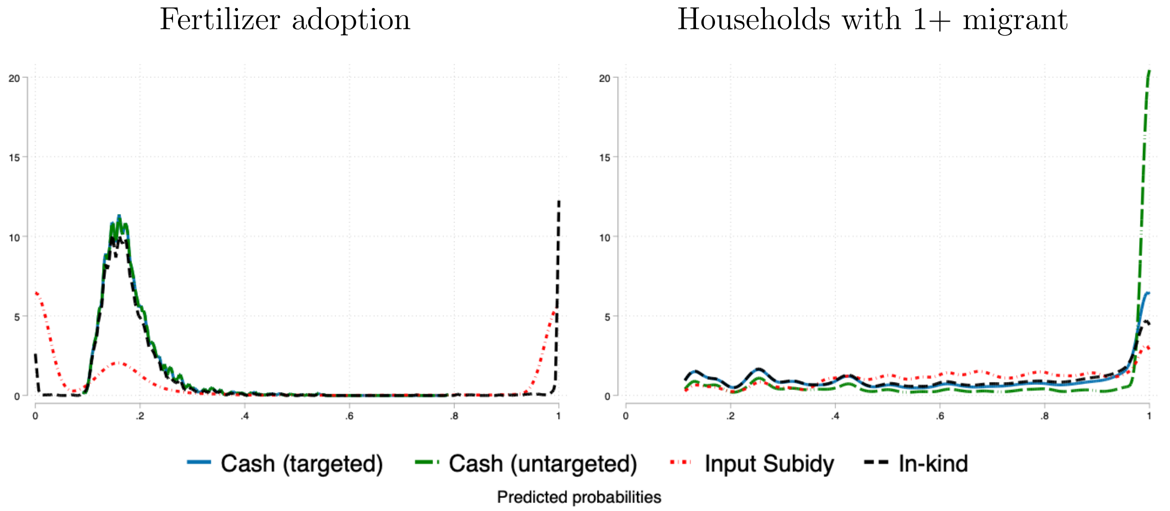


Figure 8: Distribution of probabilities for a household to adopt the fertilizer agriculture and for it to send out one outmigrant

Table 8 summarizes the findings of the counterfactual estimations.

Table 8: Summary of counterfactual policies

Policy	Channels		Share of total population	
	Adoption	Migration	Adoption	Migration
Baseline:				
- ISP + Resale	No externality, Resale	Resale, Productivity	32%	71%
Policy	Channels		Change from Baseline	
	Adoption	Migration	Adoption	Migration
Counterfactuals:				
- ISP no Resale	No externality, Resale	Productivity	-75%	-15%
- Targeted CT	Large externality	More liquidity for some	-99%	-13%
- Untargeted CT	Large externality	More liquidity for all	-99%	+11%

Based on the results of the reduced-form and the structural estimations, in the following section I discuss the optimal policy design in the presence of market friction such as an externality and credit constraints.

8 Optimal policy design and discussion of results

In this section, I discuss the optimal policy in light of my empirical and theoretical findings.

An important feature of low-productivity agriculture-intensive economies is that many farmers face binding credit constraints and non-convexities in their agricultural technologies. Both these features lead to farmers being "trapped" in agriculture, although they could earn higher returns in other activities such as migration (Ghatak, 2015). In this paper, farmers with a comparative advantage in agriculture face an additional barrier: the learning externality in the adoption of the fertilizer technology (Conley and Udry, 2010; Carter et al., 2021). This learning externality implies that as more neighboring farmers use fertilizers, a farmer corrects upward her previously downward biased expected profits which reduces the probability of adopting a more efficient technology for some farmers. As a result, when fertilizer use is low in a village, fertilizer adoption is sub-optimal, as farmers have systematically low expectations of returns for the technology.

In this paper, I model ways households respond to a fertilizer ISP with resale markets. I predict that households sort across rural production technologies and migration based on their comparative advantage. Households with a comparative advantage in the fertilizer technology would double-down in agriculture, increasing both its use of fertilizer and labor inputs (i.e. adopt fertilizer and host inmigrants). Alternatively, households with a comparative advantage in other activities that require outmigration would have stayed in the agricultural sector, not because they would be most productive, but because they cannot afford to relocate due to imperfect credit markets. When the subsidy is introduced, these households with a comparative advantage in other activities can relax their credit constraint in two ways. A first way is to relax their credit constraint by selling their subsidized fertilizer voucher to pay for outmigration. Another channel is through an increase in productivity that allows farmers to use the surplus from agriculture to fund migration.

8.1 First-best policy

In light of both the credit constraint, and the positive learning externality in the economy, a first-best policy could be to identify the two types — those with the comparative advantage in migrating and those with a comparative advantage in the fertilizer technology — and lift the corresponding constraints. On the one hand, farmers with a high productivity in the fertilizer agriculture could see their constraints lifted via an input subsidy — addressing both the affordability and internalizing the learning externality by increasing the use of fertilizer across the board. On the other hand, farmers "trapped" in agriculture — who would be better off in another activity but are credit constrained — could receive a cash transfer to address the financial frictions preventing their relocation. This first best policy relies on governments' ability to observe the farmers' types for which elicitation is costly.

8.2 Second-best policies

ISP with resale markets (currently in Zambia): When resale markets for fertilizers exist, they improve allocative efficiency by moving the fertilizer from farmers who need it less to those who need it most while generating income to fund migration and other activities for the former group. Such a policy would certainly introduce distortions (Diamond and Mirrlees, 1971; Mirrlees, 1986), potentially making farmers substitute labor for cheaper fertilizer; and therefore increase levels of unemployment in the economy. That is a concern if fertilizer inputs and labor are substitutes. Beaman et al. (2013) have shown in similar contexts that labor and fertilizers are complements, implying that if anything, an increase in the use of fertilizer should lead to a decrease in unemployment. Carter et al. (2021) and Conley and Udry (2010) have shown the importance of network and neighbors' fertilizer adoption on one farmer's likelihood to adopt fertilizers. Additionally, when transaction costs are low, this second-best policy approximates the first-best policy in a decentralized fashion. The adequacy of a subsidy thus depends on the trade-off between the loss of efficiency induced by the distortion in prices, the increased adoption of an improved technology, and the redistribution component of the subsidy.

ISP without resale markets: Without resale markets, the learning externality is addressed, but farmers ability to relax their credit constraint is reduced. Furthermore, unless the planner can elicit types and only provide the subsidy to farmers with a comparative advantage in the improved agricultural technology, there is a deadweight loss stemming from the impossibility of farmers to efficiently distribute the subsidized fertilizer. As found in the counterfactual analysis (see Section 7), the ISP with resale markets dominates. For this policy to reach the levels of adoption reached by the ISP with resale markets, it would require the central planner to elicit farmers comparative advantages and target households with the highest productivity in the fertilizer agriculture with the ISPs. Instead, the central planner can encourage resale markets, and remove the frictions on those markets.

Targeted cash transfer programs: The cash-transfer program given to only the recipients of the subsidy in in Zambia in 2004 improves migration outcomes, but only for the 8% (those who receive the transfer). Farmers that receives the cash transfer can fund migration with the transfer, however farmers that do not receive the subsidy have unaltered outcomes. Unlike for the ISP with resale markets, the returns of the policy is not felt by other farmers. Furthermore, the learning externality is not internalized, and adoption plummets. The cash transfer progam addresses farmers credit constraints but fails to address the learning externality and the availability of the improved technology.

Untargeted cash transfer programs: This cash transfer program is given to the 50% of the population that resides in targeted areas. As a result it relaxes the credit constraint for a larger number of households who can then migrate. However, just like for the targeted cash transfer program, adoption is very low, close to zero as a result of the transfer.

8.3 Optimal policy

If the central planner has a dual objective of moving farmers from a low to a high equilibrium of fertilizer adoption while also redistributing income to those who face financial constraints, then resale markets could be an improvement from the no-subsidy alternative. In the setting of 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 require introducing the subsidy, with resale markets and then, following Carter et al. (2021) phase out the subsidy once a critical mass of farmers adopt the subsidy. The ISP can then be phased out and replaced by an untargeted cash transfer program. This optimal policy does not require that the central planner elicit farmers' comparative advantage, and so the planner does not need to invest in costly targeting. Instead, the central planner can encourage resale markets, and remove the frictions that may lower the efficiency of these resale markets.

In neighboring Malawi, there is evidence that combining cash-transfers to fertilizer programs can have a multiplicative impact of improving fertilizer adoption, increasing farm production, improving soil quality in the long run but also further relaxing the credit constraint of the ultra poor (Boone et al., 2013).

Conclusion

In this paper, I find that a subsidy on agricultural inputs can simultaneously address the learning externality affecting the adoption of fertilizer in agriculture and credit constraints. Alleviating credit constraints makes it possible for farmers to sort by comparative advantage. Farmers with a comparative advantage in migrating can do so, while farmers with a comparative advantage in farming can reach the optimal level of input use. The potential allocative inefficiency of subsidies is offset by the existence of resale markets, which allow the reallocation of fertilizer from farmers who need it the least to those who need it most. Resale markets also generate income to fund migration for households with a comparative advantage in migrating.

I find an increase in both inmigration and outmigration as a result of an acceleration in the specialization process with a simultaneous increase of yields for some farmers and migration for others. With poorly functioning labor markets, increasing labor supply within the household implies increasing inmigration rates. Hence, some households increased both their fertilizer adoption and labor supply and intensified their agricultural activities while other farmers divested from agriculture altogether and migrated.

The empirical setting, which offers a unique setting to examine the impact of an input subsidy on a variety of household decisions, has limitations. First, I do not observe the destination of outmigrants or the origin of inmigrants, which limits the extent to which I can infer the changes in welfare for beneficiary households. Another limitation is that I do not directly observe resale markets, this implies that I am losing some precision on the importance the demand of 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 seasonal migration from long term migration.

Future work can try to explore the dynamic effect of these policies. Though migration decisions are not the only objective of these policies, this paper is a first step to exploring indirect impacts policies might have on migration pattern over time and within countries. The findings of the paper can provide information to policy makers when deciding on the allocation or resources. More specifically, these dynamics would further elucidate the process of structural transformation, but also explore the dynamic push and pull for migrants as a result of productivity changes.

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A Appendix

A.1 Some context on rural antipoverty programs

This paper further speaks to two literatures that both are set in rural areas. A first strand of literature is one that explores productivity enhancement via input subsidy programs and in-kind transfers. Another is the literature on migration decisions of rural agents.

In a simple model incorporating known market failures, I show that these rural policies can lead to more migration tying-in these two literatures. The links happens via the existence of resale markets that move inputs from potential migrants to farmers with a comparative advantage in agriculture, in exchange of liquidities, and migration-driven structural transformation.[24]

In this section, I present the state of both literatures and show how this paper builds on them.

A.1.1 Literature on existing rural antipoverty policies

Input Subsidy and In-kind transfer Programs: The average fertilizer use in African countries is less than 10% of the world average. To stimulate the use of productive inputs and to improve the welfare of farmers, many countries subsidize inputs such as fertilizer, pesticides, and seeds. Input Subsidy Programs (or ISPs) serve both to reduce the overall cost of production and to address credit constraints that may inhibit farmers from purchasing inputs. Economists have historically analyzed subsidies in terms of their perceived (in)efficiency, especially in relation to alternatives such as cash-transfers (Jayne and Rashid, 2013; Jayne et al., 2018; Ricker-Gilbert and Jayne, 2017). However, often these assume that subsidies are introduced in a first-best, friction-less environment. In reality, farmers are in an environment where they face both a learning externality in the adoption of the fertilizer technology (Conley and Udry, 2010; Carter et al., 2021) and credit constraints hindering their ability to invest in this technology. This learning externality implies that as more neighboring farmers use fertilizers, a farmer changes her

[24] Find more on these programs and their effects on Appendix 2.

beliefs about the return of the fertilizer-intensive agriculture.

As a result, a dozen African countries signed the Maputo, and Abuja declarations to respectively spend 10% of their income on agriculture and to increase the use of fertilizer across these countries (Jayne and Rashid, 2013). These countries overwhelmingly adopted fertilizer subsidy programs and more generally ISPs to support the use of fertilizer, improved seeds, and pesticides. When resale markets for fertilizer exist, a subsidy on agricultural inputs can be a viable second-best policy. These resale markets improve allocative efficiency by moving the fertilizer from farmers who need it less to those who need it most, while generating income to fund migration and other activities for the former group. Such a policy would certainly introduce distortions (Diamond and Mirrlees, 1971; Mirrlees, 1986), potentially making farmers substitute labor for cheaper fertilizer; and therefore increase levels of unemployment in the economy. That is a concern if fertilizer inputs and labor are substitutes, and if labor markets function relatively well. Beaman et al. (2013) have shown in similar contexts that labor and fertilizers are complements, implying that if anything, an increase in the use of fertilizer should lead to a decrease in unemployment. Additionally, in such rural contexts, labor markets can be incomplete or absent making the unemployment concern irrelevant (Behrman, 1999).

In a related literature, Duflo et al. (2008, 2011) documented the ways in which subsidies can mitigate behavioral biases while Jayne and Rashid (2013), Conley and Udry (2010) and Carter et al. (2021) identify market failures that cause low fertilizer use.

This paper further adds to a strand of literature analyzing how infrastructure and in-kind transfers modify households' labor supply decisions and in fact migration. For example, recent papers in this literature have studied how state investments in roads, electrification, land titles, public works, and housing can affect labor markets (Asher and Novosad, 2020; Dinkelman, 2011; Franklin, 2020; Field, 2007; Moneke, 2020; Abebe et al., 2021).

Furthermore, this paper tests — and indeed counters — two prevailing thoughts. A first thought, rooted in classical economic theory is that subsidies lead to inefficiencies through price distortions (Suri, 2011; Mirrlees, 1986; Diamond and Mirrlees, 1971). I find that inefficiencies are greatly reduced in the presence of resale markets (and fully eliminated if resale markets are frictionless).

A second thought from policy makers is that ISPs render agriculture more attractive, thus delaying outmigration (Food and Agriculture Organization et al., 2018). I show that subsidies intended to increase agricultural productivity may, on the contrary, alleviate credit constraints and drive migration.

Cash-transfers: In 2015, 130 countries had unconditional cash-transfers and 63 had conditional cash-transfers in place (World Bank, 2015). As a result, there is a large number of experimental studies exploring the impact of cash-transfers on various outcomes primarily in Latin-America (Parker and Todd, 2017; Bastagli et al., 2016). The handful of studies exploring the impact of cash-transfers on migration cite financial constraints as the main barrier to migration (Angelucci, 2015; Gazeaud et al., 2020; Bazzi, 2017; Adhikari and Gentilini, 2018; Bryan et al., 2014). In another study, Cai (2020) shows in China, that access to credit relaxes liquidity constraints and leads to more migration, especially in areas with low assets and high migration costs. Finally, Bryan et al. (2014) find in Bangladesh that a \$8.5 cash-transfer induces 22% households to have temporary outmigrants.

In Zambia, the ISP took the form of a fertilizer subsidy program, with an average monetary equivalent of \$46. With such lump sum transfer of this size, we expect — and in fact, we do see that — the ISP to relax households' credit constraints and to lead to substantially higher migration responses than found in Bangladesh (Bryan et al., 2014). Furthermore, the ISP can allow farmers to invest in both migration and the improved agricultural technology, by only partially reselling its vouchers thus addressing the credit constraint in both agriculture and migration. In comparison, in 2010, Zambia started an unconditional cash-transfer program or \$12 per month paid every two months.

In this paper, with resale markets transfers — either subsidies or in-kind transfers — serve to relax credit constraints for those who want to migrate. I find that a subsidy program can have similar impacts on a subset of households — those with a latent comparative advantage in migrating — while also addressing market failures leading to sub-optimal use of fertilizer.

Other rural antipoverty program: Hagen-Zanker and Himmelstine (2013) show in a review paper that social protection programs can increase the likelihood of migration, when it is used to finance migration. Yoong et al. (2012) show in a review paper that old-age pension programs rather than stifling migration, do in fact relax the liquidity and childcare constraints thus making prime-aged adults more likely to migrate (Kabeer et al., 2012; Ardington et al., 2009). Such findings, is an interesting premise of this paper, announcing the possibility of finding positive results of rural antipoverty programs on migration.

In the following section I focus on a specific antipoverty program. In Zambia, it took the form of a fertilizer input subsidy program. I proceed to present the data and descriptive statistics.

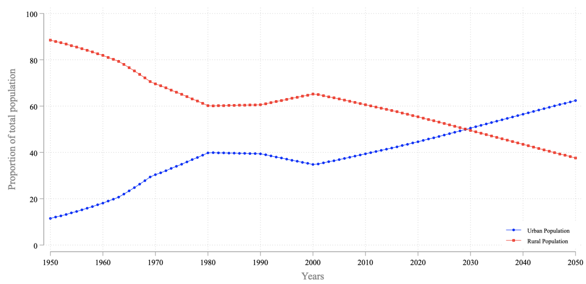


Figure 9: Rural and Urban Population in Zambia (with projections)
Source: United Nations, World Urbanization Prospects: The 2018 Revision.

Table 9: Public budget: Agricultural Sector, 2004/05, Zambia

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

Source: World Bank Fertilizer toolkit: Promoting effective and sustainable fertilizer use in Africa - using Ministry of Finance data files.

A.2 Data and descriptives

First, Census Supervisory Areas (CSA) were chosen within each district. Second, Standard Enumeration Areas (SEA) were sampled out of each CSA and finally households within each SEA were randomly chosen to be interviewed.[25].

In addition to the household survey conducted in 2000, 2001, 2004 and 2008, the 2008 survey includes community level information gathered from the community headman. That dataset provides information on basic features of communities, rules, constituencies as well as distances to main provincial landmarks.

Measurement: To measure adoption adoption, I use self-reported measures of whether the household used any fertilizer on their field (whether or not it is from the subsidized program). I report the extensive use of fertilizer, i.e. households going from not using fertilizer to using any quantity of fertilizer.

To measure the yields, I use the quantity of maize produced (the target crop of the subsidy) per land owned including cultivated and fallow lands.

To disentangle the different types of migration, I construct several measures, each extensive or intensive margins.

[25]Geographic units from the more aggregated to the least aggregated are the following: Country, Province, District, CSA, Village. In these data, SEAs are the least aggregated and include typically one village (see Table 11 of the Appendix).

First I create a measure of each household's extensive outmigration which corresponds to a household outmigrating with all its members, i.e. a household migrating (*en masse*). I construct this variable using the survey response status of the sample. A household that moves away from the SEA is tagged as a migrant household. I am not able to observe households that migrated *en masse* conditional on receiving the subsidy on the same year, because migrant households do not take the survey that records whether or not they receive the ISP. In 2008 some of the households that have moved are still interviewed. Using information on whether they "moved out of SEA" (all households that move have the reason for moving listed, here I exclusively use households that have moved outside of the SEA rather than households that attrited for other reasons — whether or not they took the survey), I constructed household outmigration dummy variable.[26] In this first case of household migration, I am only able to look at the extensive margin of migration, as households can only make a binary decision at that level. I do not observe where households go after they move out. In either case, only rural households are interviewed in this survey, this implies that if a household moves to an urban area, it will not be found again.

Second, I create migration at the individual level for members of the household conditional on the household remaining. Using data from the baseline (in 2000) and for each subsequent follow-up, I create an measure of inmigration and outmigration that captures the extensive margins of migration using information on whether a household i) hosted new members since the previous survey, or ii) sent members out of the household. This measure of outmigration includes marriage, establishing a new household and moving to other relatives. The measure of inmigration includes added members who were never in the households, returnees and marriage. At the intensive margins, I look at the number of members who migrated (intensive individual migrations).[27]

For the main explanatory variable, the FSP, I have built a dummy that takes the value

[26] This is a conservative measure of migration as some farmers are tracked after they moved out in the 2008 survey.

[27] At baseline, in the 1999-2000 agricultural season, there are by construction no household and individual migrants.

1 for households resides in an area that received the subsidy. I also construct a variable equal to the amount received by households through the program; which corresponds to the total quantity acquired through the Food Reserve Agency (FRA) multiplied by the proportion subsidized (0.5 of the price in 2004 and 0.6 in 2008).

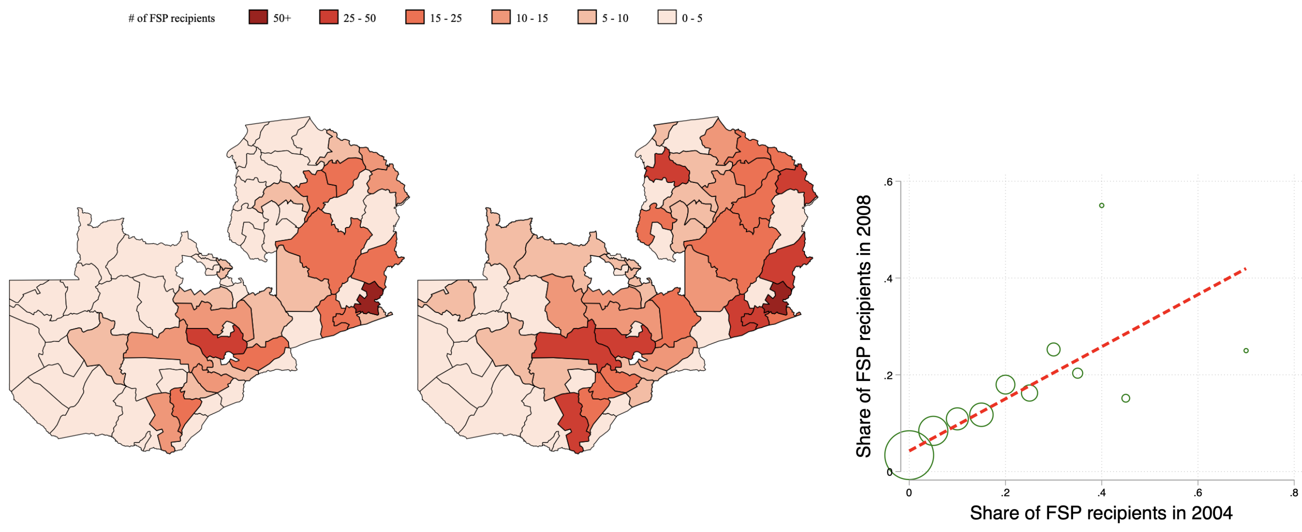
Table 10 reports descriptive statistics on intensive migration and FSP. In 2001, no household receives the ISP. It shows in row 2 that the rate of migration is highest for households that receive the FSP, and that migration increases over time, between 2004.

Table 10: Household receiving FSP

		2001		2004		2008	
		Total	Percent	Total	% Population	Total	% Population
Total FSP hh		0	0	496	7.17%	525	9.02%
		2001		2004		2008	
		Total	Percent	Total	% FSP subset	Total	% FSP subset
Received FSP	has outmigrant	0	0	226	46.56%	328	62.48%
	no outmigrants	0	0	270	54.44%	197	37.52%
Received FSP	has inmigrant	0	0	131	26.41%	165	31.43%
	no inmigrants	0	0	365	73.59%	360	68.57%

Source: Author's calculations using the Supplemental Survey to the 1999/2000 Post Harvest Survey - Zambia Data Documentation, revised June 2010.

Figure 10: Maps of FSP recipients per districts in 2004 and 2008



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

Notes: Based on author's calculations. These are recipients in the sample. The shape files used are those corresponding the the time period of the study. There has since been changes in districting starting in 2011.

A.2.1 More details on resale markets

Figure 11 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.[28]

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 has 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 (1-5ha)

[28]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-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.

use exactly the amount provided via the voucher subsidy and top-ups with commercial markets. However, some farmers — those with very large farms — use more subsidized fertilizer than officially received and the farmers with small farms use less than they have received. This implies a redistribution — across farmers, based on farm sizes and needs.

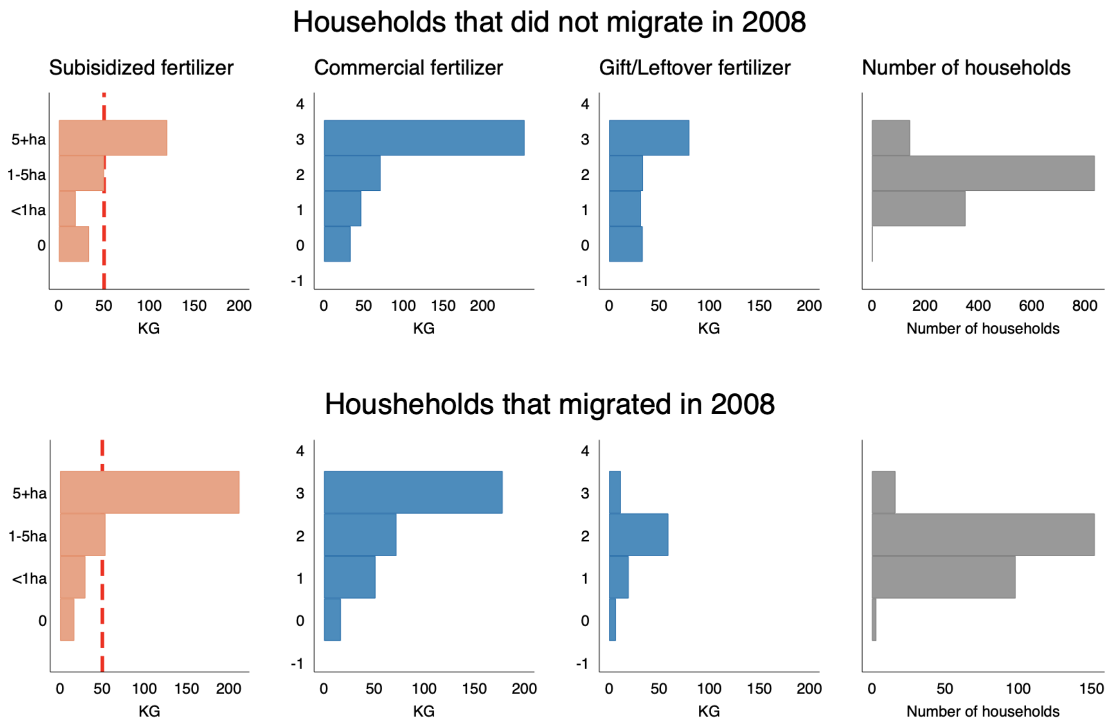


Figure 11: Source of fertilizer used on the farm in 2004

Notes: Using self-reported data from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel).

Table 11: 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

Source: author's Calculations using the supplemental the 1999/2000 Post Harvest Survey and its supplementary surveys.

Table 12: 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 move to another SEA	0	0	269
Moved out of SEA	352	707	810
Total number of households	7,699	6,922	5,823

Source: author's Calculations using the supplemental Survey to the 1999/2000. Panel A of 12 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.

A.2.2 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 fertilizers and improved seeds' adoption by addressing both the lack of liquidity and the low profitability of fertilizers. Until 2001 a loan program called *Fertilizer Credit Program* was in place, allowing farmers to mitigate credit constraints they were facing. As a loan program, the *Fertilizer Credit Program* did not meet its repayment goals with a repayment rate of only 30%. In 2001, the *Fertilizer Support pro-*

gram (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 hectare of land. This subsidy rose to 60% in the 2006/2007 season to reach 76% in the 2010/2011 season.

The FSP was a substantial financial effort on the part of the Zambian government. To illustrate this, between 2004 and 2011, the FSP alone made-up approximately 30% (Table 13) of Zambia's agricultural spending and 47% of the government's agricultural sector Poverty Reduction Program (Mason et al., 2013a).

Table 13: Public budget: Agricultural Sector, 2004/05, Zambia

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

source: World bank Fertilizer toolkit: Promoting effective and sustainable fertilizer use in Africa - using Ministry of Finance data files

Improving agricultural productivity is the main goal of this policy. However, such large investments could have substantial indirect impact on migrations to urban poles. Figure 9 shows the evolution and previsions of urban and rural populations in Zambia. 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 phonomenon happened concurrently with large investment in input subsidies.

A.2.3 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 going from an average a 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, as opposed to previous credit programs; it subsidized at a 50% rate fertilizer purchases with a focus 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., 2013b). 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. (2013b), this program has very low political inference.

In Figure 12, I summarize the main agricultural programs in the period 1991 – 2008, including fertilizer subsidy programs that preceded the FSP. In 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 on the cooperative level, field size and financing capacity criteria. Farmer organizations as well as cooperatives are channels through which FSP inputs are distributed. Farmers are, on the other hand, required to be member of a cooperative or an organization; 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

1. Should be a small scale farmer and involved in farming within the cooperative coverage area;

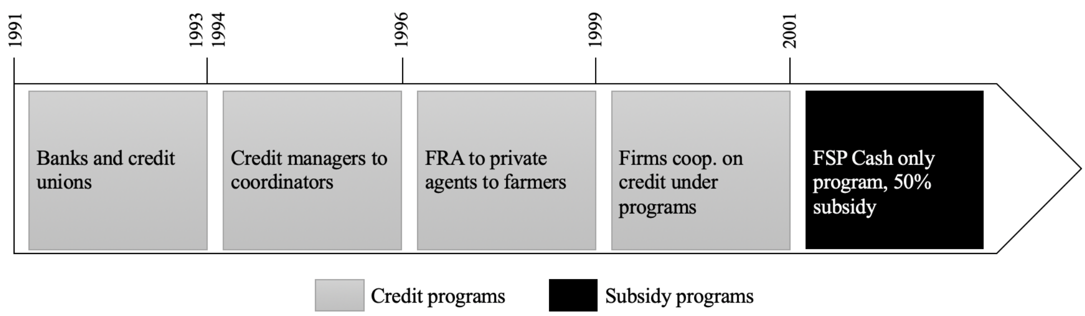
2. Has the capacity to grow 1-5 hectares of maize;

3. Should 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.

Figure 12: Timeline of agricultural programs (from 1991 onwards)



Source: Author.

In reality these selection criteria do not fully apply. Figure 13 shows the distribution of FSP beneficiary over the years and across land holdings. I use Mason et al. (2013a) definition of land holdings, i.e 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" receives 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 under the one of medium land holders. This is likely due to the existence of the PAM program for farmers with landholdings under 1ha.

Knowing the impacts of the FSP on productivity is relevant, as it matters for migration flows (Todaro, 2000). Xu et al. (2009) showed an increase of the marginal value-cost ratio[29] resulting from subsidizing fertilizer in the period of focus. They found a 16% partial effect of fertilizer use (nitrogen) on yields for households that received fertilizer on time through governmental channels. They explain this increase by either an information diffusion by agencies involved or by biases of the subsidy toward more productive within-sample farmers and areas. Still on previous impact evaluations of the FSP, Mason and Jayne (2013) found strongly significant crowding out of commercial fertilizer channels by the FSP, especially in high Private Sector Activity (PSA) areas. In those high PSA areas, a one kilogram increase of subsidized fertilizer reduces commercial fertilizer purchases by 0.23 to 0.32 kilograms (Mason and Jayne, 2013).This crowding out effect of the program is higher for farmers holding over two hectare of land. They also find the program to not be cost effective, i.e. benefits in terms of maize output do not outweigh the cost of the Farmers Support Program. Note that results from Xu et al. (2009) and Mason and Jayne (2013) are not contradictory: cost effectiveness does not necessarily imply negative partial impact of the subsidized-fertilizer on yield, it rather means that the benefits do not equate the costs.

[29] The marginal value-cost ratio (MVCR) divides the value of the Marginal product by the price of nitrogen

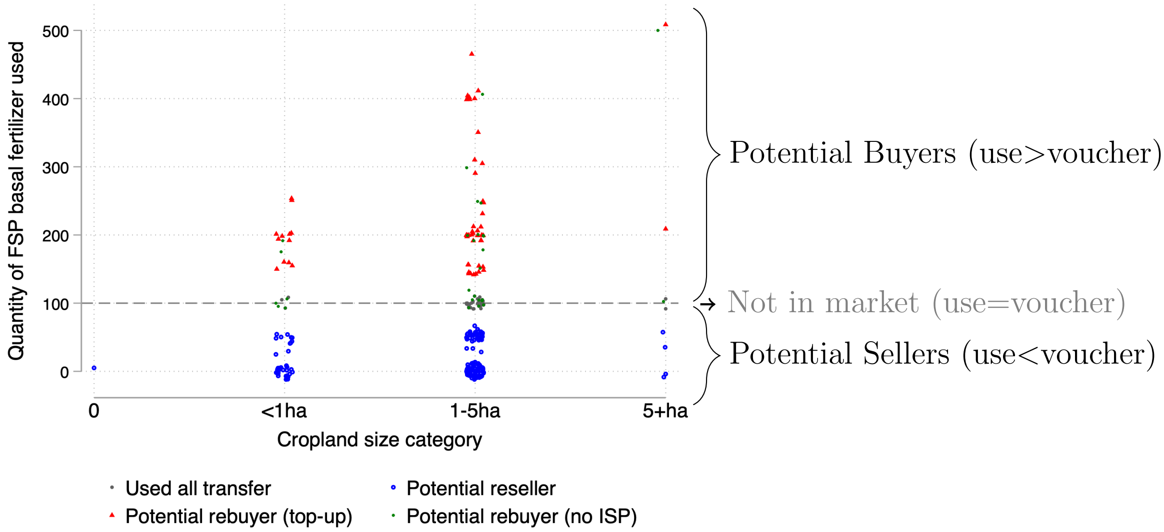
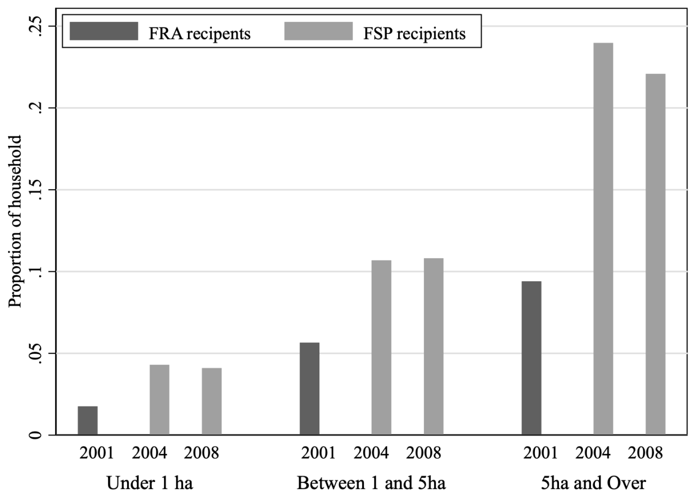


Figure 14: Subsidized top-dressing fertilizer used on farm compared to quantity transferred

Notes: 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 13: Proportion of FRA and FSP recipients over effective field size



Source: Author's computations

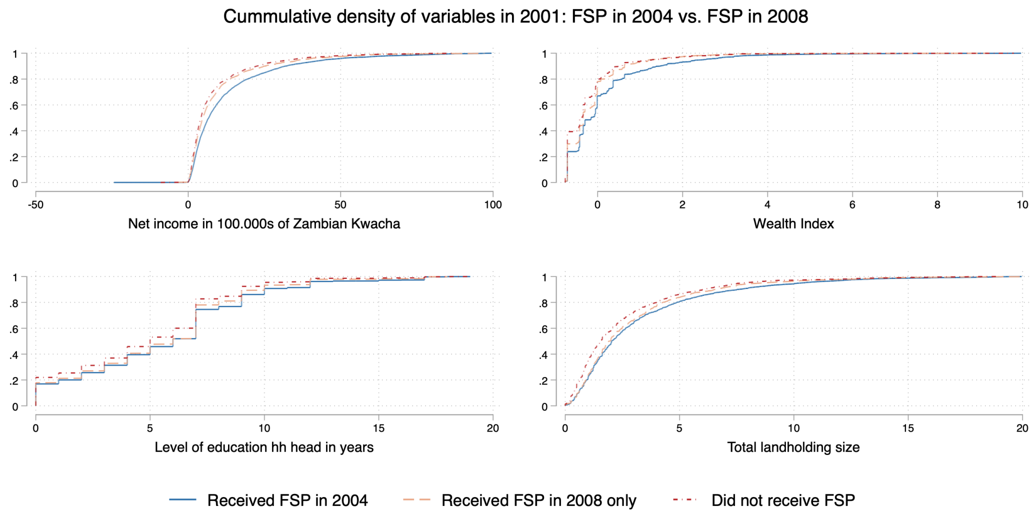


Figure 15: Baseline characteristics between households in areas that received the subsidy in 2004, 2008 and in areas that did not receive the subsidy

Figure 16: Plot of household outmigrations per treatment group

Table 14: Descriptive statistics: Check of the randomness of attrition

		2001 (marginal migration)						
		Control		hh that migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Baseline Data (2000)	# of hh members at	6.4471213	7347	6.0596591	352	6.4294064	7699	3.810914
	Gender of hh head	.77991017	7347	.77272727	352	.77958176	7699	.10083262
	Age of the hh Head	43.742344	7347	40.849432	352	43.610079	7699	14.084706
	Wealth: plough/harrow/oxcart	.0197822	7347	-.24689173	352	.00758981	7699	23.535343
	hh head is relative to headman	.29875758	6922	.	.	.	.	.
Data from 1st wave	Dwelling has concrete walls	.23793701	6922	.	.	.	.	.
	Dwelling has traditional doors	.63218723	6922	.	.	.	.	.
	Dwelling has traditional floor	.82692863	6922	.	.	.	.	.
	hh head is single	.02879051	6912	.	.	.	.	.
	hh head is monogamous	.68156829	6912	.	.	.	.	.
	hh head is polygamous	.10026042	6912	.	.	.	.	.
	hh head is divorced	.06438079	6912	.	.	.	.	.
	hh head is widowed	.11212384	6912	.	.	.	.	.
	hh head is separated	.01229745	6912	.	.	.	.	.
	hh head went over primary	.22468171	6912	.	.	.	.	.
	Crop land: purchased	.02531646	7347	.	.	.	.	.
	Crop land: inherited	.26391725	7347	.	.	.	.	.
	Crop land: allocated	.47515993	7347	.	.	.	.	.
	Crop land: rented or borrowed	.03906356	7347	.	.	.	.	.
	Crop land: walked in	.10984075	7347	.	.	.	.	.

		2004 (marginal migration)						
		Control		hh that migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Baseline Data (2000)	# of hh members at	6.5129525	6215	6.115983	707	6.4724068	6922	7.4347452
	Gender of hh head	.78213998	6215	.78076379	707	.78199942	6922	.00705016
	Age of the hh Head	44.221078	6215	40.707214	707	43.862179	6922	39.076983
	Wealth: plough/harrow/oxcart	.04877885	6215	-.15651119	707	.02781092	6922	25.091304
	hh head is relative to headman	.30893001	6215	.20933522	707	.29875758	6922	30.177228
Data from 1st wave 2001	Dwelling has concrete walls	.23604183	6215	.25459689	707	.23793701	6922	1.2051765
	Dwelling has traditional doors	.6305712	6215	.64639321	707	.63218723	6922	.68327767
	Dwelling has traditional floor	.83185841	6215	.78359264	707	.82692863	6922	10.345162
	hh head is single	.02690511	6207	.04539007	705	.02879051	6912	7.7428842
	hh head is monogamous	.67794426	6207	.71347518	705	.68156829	6912	3.6834954
	hh head is polygamous	.10359272	6207	.07092199	705	.10026042	6912	7.4969356
	hh head is divorced	.0650878	6207	.05815603	705	.06438079	6912	.50490163
	hh head is widowed	.11390366	6207	.0964539	705	.11212384	6912	1.9363841
	hh head is separated	.01192202	6207	.01560284	705	.01229745	6912	.70604446
	hh head went over primary	.21636862	6207	.29787234	705	.22468171	6912	24.219666
	Crop land: purchased	.02606597	6215	.03394625	707	.02687085	6922	1.5074044
	Crop land: inherited	.28897828	6215	.20226308	707	.28012135	6922	23.745211
	Crop land: allocated	.50329847	6215	.51343706	707	.50433401	6922	.260956
	Crop land: rented or borrowed	.03700724	6215	.08062235	707	.04146201	6922	30.509018
	Crop land: walked in	.11713596	6215	.11173975	707	.1165848	6922	.17942649

		2008 (marginal migration)						
		Control		hh that migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Baseline Data (2000)	# of hh members at	6.6892917	4744	6.0889713	1079	6.5780526	5823	22.969793
	Gender of hh head	.78604553	4744	.79147359	1079	.78705135	5823	.15448711
	Age of the hh Head	44.657884	4744	41.947173	1079	44.15559	5823	32.295405
	Wealth: plough/harrow/oxcart	.10329099	4744	-.14177328	1079	.05788066	5823	46.175744
	hh head is relative to headman	.32145868	4744	.26227989	1079	.31049287	5823	14.410725
Data from 1stwave 2001	Dwelling has concrete walls	.22934233	4744	.28174235	1079	.23905204	5823	13.294638
	Dwelling has traditional door	.65029511	4744	.52548656	1079	.62716813	5823	59.135948
	Dwelling has traditional floor	.83579258	4744	.80537535	1079	.83015628	5823	5.772057
	hh head is single	.02617138	4738	.03061224	1078	.0269945	5816	.65922519
	hh head is monogamous	.68235542	4738	.70315399	1078	.68621045	5816	1.7641794
	hh head is polygamous	.10827353	4738	.09276438	1078	.1053989	5816	2.2403616
	hh head is divorced	.05951878	4738	.07606679	1078	.06258597	5816	4.1004275
	hh head is widowed	.11059519	4738	.09183673	1078	.10711829	5816	3.2316019
	hh head is separated	.01266357	4738	.00556586	1078	.01134801	5816	3.944645
	hh head went over primary	.20768257	4738	.26437848	1078	.2181912	5816	16.589879
	Crop land: purchased	.01499758	8268	.02780352	1079	.01647587	9347	9.6670785
	Crop land: inherited	.16872279	8268	.26506024	1079	.1798438	9347	60.430249
	Crop land: allocated	.29354136	8268	.48007414	1079	.31507436	9347	156.43007
	Crop land: rented or borrowed	.01717465	8268	.06209453	1079	.02236012	9347	88.91885
	Crop land: walked in	.06470731	8268	.1334569	1079	.07264363	9347	67.433468

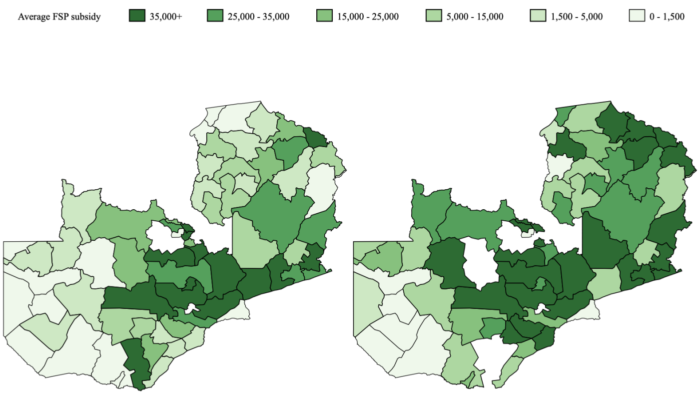
Table 15: Descriptive statistics on migrant households

		2001 Over whole population			2004 Over Household migrant groups		
	variables	Control SEAs	Treated SEAs	Overall mean	Control SEAs	Treated SEAs	Overall mean
	head count	2,824	4,098	6,922	314	393	707
Baseline Data (2000)	Gender of hh head	.7510623	.8033187	.7819994	.7611465	.7964377	.7807638
	Age of the hh Head	43.85021	43.87043	43.86218	41.707	39.9084	40.70721
	Wealth: plough/harrow/oxcart	-.0898935	.108923	.0278109	-.2271424	-.1000781	-.1565112
	hh head is relative to headman	.3427762	.2684236	.2987576	.2133758	.2061069	.2093352
Data from 1^{st} wave	Dwelling has concrete walls	.207153	.2591508	.237937	.2070064	.2926209	.2545969
	Dwelling has traditional floor	.8626062	.8023426	.8269286	.8184713	.7557252	.7835926
	Dwelling has traditional doors	.6745751	.602977	.6321872	.6910828	.610687	.6463932
	hh head is single	.030873	.0273571	.0287905	.0319489	.0561224	.0453901
	hh head is monogamous	.6628815	.6944309	.6815683	.7060703	.7193878	.7134752
	hh head is polygamous	.092264	.1057645	.1002604	.0638978	.0765306	.070922
	hh head is divorced	.0798439	.0537372	.0643808	.0798722	.0408163	.058156
	hh head is widowed	.1192335	.1072301	.1121238	.1022364	.0918367	.0964539
	hh head is separated	.0138396	.011236	.0122974	.0159744	.0153061	.0156028
	hh head went over primary	.1816891	.2542745	.2246817	.2428115	.3418367	.2978723

Table 16: Quantity and revenue per hectare (ha) in 2001 for FSP recipients in 2004, by migration status in 2008

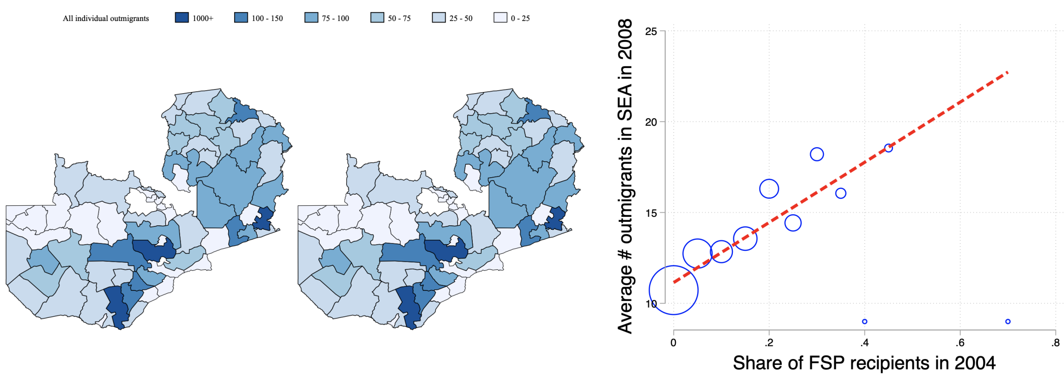
2001 harvest per ha	Household migrated in 2008							
	Outcomes in 2001				Outcomes in 2008			
	Migrated	Stayed	Diff.	P-value	Migrated	Stayed	Diff.	P-value
Total land holdings	9.53	5.28	81%	0			.	
Adults in the household	4.16	4.39	-5%	.033			.	
Kg of maize	1085	1021	6%	0			.	
GV of maize	245032	227986	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			.	
	Household with 1+ inmigrant 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
	Household with 1+ outmigrant in 2008							
	Outmig.	No outmig.	Difference	P-value	Outmig.	No outmigrants	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

GV: Gross value



2004 2008

Figure 17: Average amount (FSP) disbursed per household in 2004 and 2008 - by district



2004 2008 Average count of outmigrants in SEA in 2008 vs. Share of FSP recipients in 2004

Figure 18: Maps of the number of individual outmigrants in 2004 and 2008 - Per district

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 make-up the first round of data after the introduction of the subsidy policy. Given this data structure, I observe four SEA groups: i) areas that never received the FSP subsidy, ii) areas that received the FSP subsidy in 2004, iii) areas that received the FSP subsidy in 2008 and finally iv) areas that received the subsidy in both 2004 and 2008. In the remainder of this section, I group the areas that received the FSP subsidy in 2004 and those that received the subsidy both in 2004 and 2008. I look at FSP beneficiaries in 2004 as a treatment. In the analysis, 2004 is the year the treatment is first observed with 2000' 2004 and 2008 are the post treatment year. There is no staggering of treatment.

A.4 Externality of adoption

	(1)
VARIABLES	Adoption
Post2004	0.136***
	(0.0178)
Post2004 × High share of adopters	0.303***
	(0.0331)
Post2004 × FSP	0.117***
	(0.0158)
Post2004 × FSP × High share of adopters	0.452***
	(0.0172)
Observations	12,052
R-squared	0.514
Controls	Yes
# Households	4845
# SEA	273

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

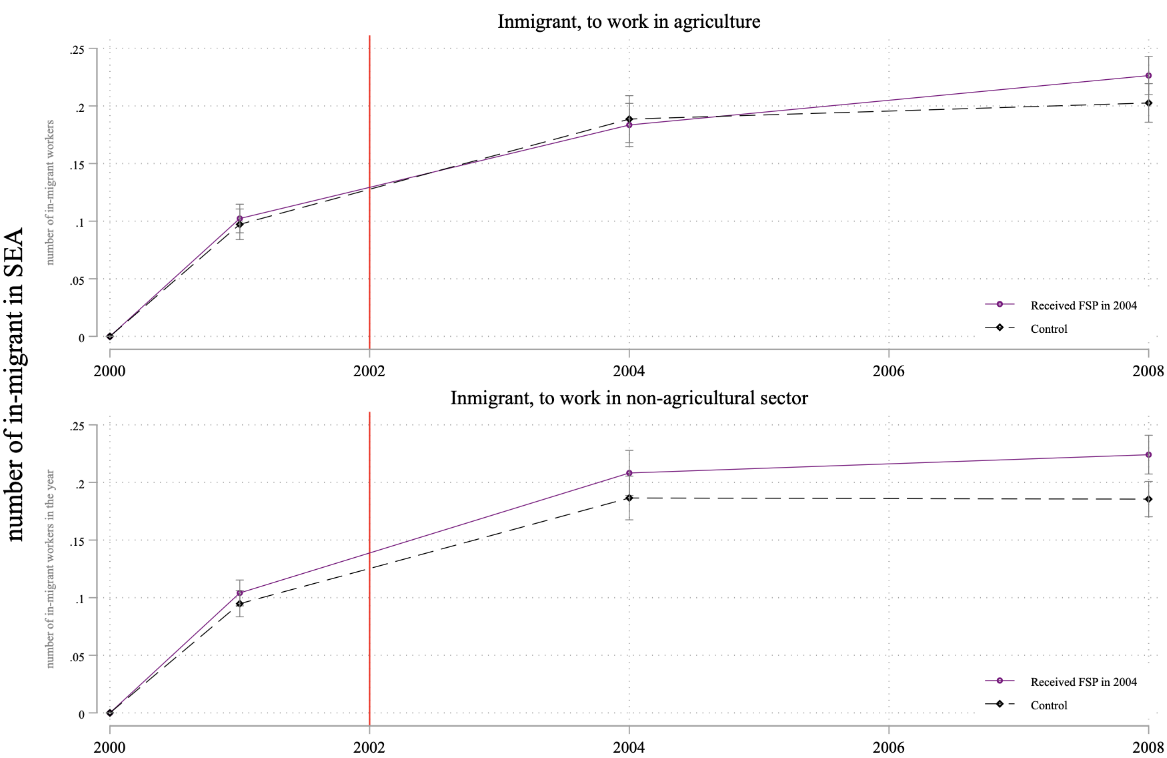
Table 17: Externality of adoption

A.4.1 Labor market impacts

I explore changes in the labor markets, as a way to understand whether the policy has changed households' labor allocation across the agricultural and non-agricultural sectors, within the rural economy. The model predicts that when the policy is in place, the resulted migration into the households would not lead to a shift of labor away from agriculture. If the model yields good predictions, we should expect minimal changes in the labor allocation within households that stayed and hosted new inmigrants. Note that any additional inmigration, even when engaging in non-agricultural work, should free-up more labor for agriculture.

In order to explore the aforementioned mechanisms, we expand the analysis to an additional non-agricultural sector in the local economy. I investigate the impact of the FSP on the sorting of agricultural and non-agricultural labor. I define agricultural labor as paid work — wage work mostly — of one household member outside on the household in either big or small farms and non agricultural work as either industrial work, civil servantship or non agricultural piece work. This paid work does not include self employment. Figure 19 plots the evolution of average proportion of both agricultural and non agricultural work. A main shortcoming of this strategy is the impossibility to check the parallel trends. That is because there is no information on labor markets at baseline. We seem to be underpowered to detect any change in agricultural work, however, can be observed in areas receiving the FSP and a slight increase of non-agricultural work in comparison to the control SEAs.

Figure 19: Plot of labor allocation of inmigrants



The model I use for this estimation is the same as model used for household outmigrations (see equation 1) but with respectively proportions of agricultural work and non-agricultural work as outcome variables.

Because of the sampling method, it is unrealistic to assume independent and identically distributed observations. There are very likely in-sample intra-census supervisory areas (CSA) correlation as well as auto-correlation (correlation of error terms over time). I therefore correct for these standard errors biases and the standard errors used should be robust to heteroskedasticity and auto-correlation.

Results

Beyond the model I sketched in section 6, one important component of the migration flows is its spill-overs on the labor allocation for non-farmers; that is because it has the potential to change the production technology. Here, I define agricultural work as paid work in either big or small farms and non agricultural work as the combination of industrial work, civil servant-ship and non agricultural piece work. Hence, we are dealing with actual labor markets and not proxies. The double difference (see table 18) shows no impact of the FSP on non-agricultural or agricultural work at the SEA level. This result could be an artifact of poorly functioning labor markets. Indeed, individuals who leave agricultural labor markets could have ended-up working (unpaid work) within their family farm; I do not have information on family labor, but the results on reasons for inmigration tend to strengthen this hypothesis of substitution between paid labor outside the household and family labor. There is no evidence of a substitution between agricultural and non agricultural work. Externalities of the program did not translate into more non-agricultural work; I do not have impacts on entrepreneurial activities but in addition to a substitution of paid agricultural work and family work, I expect more businesses and thus more diversification of activities with households members leaving the agricultural labor market[30].

[30] Data provides information on labor markets only from 2001 onwards, I can therefore not check the parallel trend assumption

Table 18: Double Difference for labor occupation

	agricultural paid work		non-agricultural paid work	
	rate	rate	rate	rate
Treatment SEA x Post	-0.0103	-0.0118	0.00973	0.0163
	(0.0179)	(0.0113)	(0.0171)	(0.0104)
Observations	16,544	11,819	16,544	11,819
Baseline # hh	6,762	6,719	6,762	6,719
Mean control t(0)	0.110	0.109	0.0617	0.0989
Mean treated t(0)	0.118	0.114	0.0712	0.107
Diff t(0)	0.00839	0.223	0.00955	0.206
Mean control t(1)	0.259	0.216	0.189	0.203
Mean treated t(1)	0.257	0.0975	0.209	0.115
Diff t(1)	-0.00195	0.218	0.0193	0.198
hh and year FE	no	yes	no	yes

Pre-treatment: 2001 – Post-treatment: 2004

Robust Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A.5 Robustness checks

A.5.1 No FSP as comparison group

Table 19: Agricultural outcomes: No FSP as comparison group

	(1)	(2)	(3)	(5)	(6)	(7)
	08 vs. No	04/08 vs. 08	Yields	inmig	inmig	inmig-comp
PostxFSP	0.189***	0.352***	249.7***	0.0738***	-1.111***	0.952***
	(0.0239)	(0.0197)	(51.53)	(0.00653)	(0.0305)	(0.0699)
FSP	0.0909***	0.248***	338.8***	-0.00683	0.0817**	0.0163
	(0.0262)	(0.0218)	(62.23)	(0.00534)	(0.0342)	(0.0648)
Post	0.0320***	0.0318***	-68.04**	0.0839***	-1.059***	0.888***
	(0.0114)	(0.0114)	(33.69)	(0.00910)	(0.0344)	(0.0325)
Observations	6,601	12,799	12,606	16,336	18,288	13,716
R-squared	0.120	0.217	0.103	0.024	0.150	0.365
Controls	Yes	Yes	Yes	Yes	Yes	Yes
# Households	2377	4572	4566	16336	4572	4572

Table 20: Migration outcomes: No FSP as comparison group

	(1)	(1)	(2)	(3)	(4)	(5)
	hh mig	outmig	outmig	outmig-comp	netmig	netmig-comp
PostxFSP	0.0791***	0.383***	0.709***	1.119***	1.859***	0.951***
	(0.00562)	(0.00987)	(0.0253)	(0.0421)	(0.0371)	(0.0424)
FSP	-0.000500	-0.00976	-0.0576***	-0.110***	-0.137***	-0.0802**
	(0.000616)	(0.00613)	(0.0161)	(0.0308)	(0.0355)	(0.0336)
Post	0.109***	0.367***	0.596***	0.999***	1.684***	0.848***
Observations	18,288	17,154	18,288	13,716	17,150	12,799
R-squared	0.050	0.218	0.173	0.169	0.205	0.114
Controls	Yes	Yes	Yes	Yes	Yes	Yes
# Households	4572	4572	4572	4572	4572	4572
# SEA	331	331	331	331	331	331

A.5.2 "Forbidden" comparison

A.5.3 An instrumental variable approach to political clientelism

To circumvent potential issues of omitted variable bias in identifying the impact of the subsidy on individual migrations I will use political clientelism findings by Mason et al. (2013b) and Mason et al. (2017) in an instrumental variable design. Mason et al. (2013b) find high dependence of the allocation on political variables — farmers in constituencies won by the incumbent president receive higher quantities of subsidized fertilizer — confirming political clientelism in the allocation of FSP subsidies. We can exploit the variations in the distribution of subsidies at the constituancy level created by political clientelism to measure the impact of the policy on migrations.[31] In this setting we would only be capturing the variations in migrations due to political-clientelism-motivated-subsidies; a Local Average Treatment Effect (LATE) on those who benefited from the

[31] The constituencies in Zambia are larger than the SEA, so these political economy results should not invalidate out cross-SEA measures of migration found with the difference-in-differences estimation.

subsidy due to presidential elections outcomes in their constituency. In this section I explore the variations in the probability of receiving the subsidy within across constituencies rather than the SEAs of the main specification. An instrumental variable strategy offers the opportunity to see if the FSP impacts migrations disproportionally through political clientelism, which would differ from the the difference-in-differences estimator of the main specification.

In order to pursue this strategy, I use results of the 1996, 2001 and 2006 presidential elections from the the Electoral Commission of Zambia (ECZ).

In this design, I use the interaction between the election results at the constituency level — I matched all household in the sample to constituencies results at the presidential elections of 1996, 2001 an 2006 — and the distance to the closest subsidized inputs' provider to instrument the reception of subsidies by a household. I estimate the effects with the following model:

$$\text{1st Stage:} \quad T_{h,t} = \pi_0 + \pi_1 V_{c,t} * dist_{h,t} + \pi_2 V_{c,t} + \pi_3 dist_{h,t} + \nu_h + \eta_t + u_{h,t} \tag{23}$$

$$\text{2nd Stage:} \quad Y_{h,t} = \alpha + \beta \widehat{T}_{h,t} + \nu_h + \eta_t + \epsilon_{h,t} \tag{24}$$

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: a dummy for FSP recipientship; $V_{c,t}$ 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.

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]. For this interaction term to be a valid instrument it needs to have two basic features. First it needs to be correlated with the endogenous variable and second it needs to be excluded from the second stage, meaning it is necessary for it to be correlated to the dependant variable only through its correlation with the endogenous variable.

Mason et al. (2013b) 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 switches when the incumbent wins a constituency and does not change gradually with the margin of the win. Because I use the data from presidential elections preceding each survey dates, the clientelism is about rewarding a vote for an incumbent. 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.

Voting behaviors and distance are both endogenous variables as they can affect receiving FSP through channels such as distance to the capital and distance spatial correlation of party affiliation. It is unlikely that voting patterns in a constituency influences the decision to migrate only through the FSP subsidy. That is because, the distance to Lusaka could be both correlated with decisions to migrate and voting outcomes. Although this can be addressed with panel fixed effects, we assume that other variables such as the level of information and the size of cooperative heads' network are correlated with both the outcomes (propensity to migrate and number of migrants) and the instrument,

[32]Distance to FRA buying point is measured at the community level

challenging the use of voting pattern only as an instrument. In addition, there is evidence that voting patterns affect public goods provision (Burgess et al., 2013; Easterly and Ross, 1997), including the provision of roads which clearly affects migrations outside of the FSP framework. Yet, because constituencies are higher level of aggregation than SEAs, we can assume that voting pattern at the SEA level have little impact on the voting pattern at the level of constituencies and thus I believe the bias through this variable to be lower than if constituencies corresponded to SEAs.

Proximity to an FRA buying point alone could also be correlated to other agricultural programs such as the PAM (another fertilizer program for very small land owners)[33], which could also have an impact on migrations. Furthermore, it is hard to believe that proximity to fertilizer providers cab have an impact on decisions to migrate through other channels. Yet, if FSP fertilizer providers' locations are highly correlated (positively or negatively) with urban areas, there might be an issue in terms the decision to migrate. One can argue that distance to main cities have an impact on migrations through, for instance, determinants of the labor markets in the city. This could bias the estimation but it is unlikely, and to address this concern, I can control for distance to urban areas and other relevant landmarks.

The interaction of these two variables on the other hand should rule out most biases. Indeed Mason et al. (2013b) showed that PAM program is not subject to much political manipulations and it is hard to think of variables correlated with the interaction of both variables that can affect migrations. If one considers the example used earlier, i.e. non-related policies being sensitive to election results, I believe they should not be sensitive to the distance to FRA buying points and thus the interaction should capture only the FSP. On the other hand, if the reception of the PAM is correlated to the distance to FRA buying points, it was shown by Mason et al. (2013b) not to be very sensitive to political

[33] In conjunction with the FSP and on a much smaller scale, the Zambian government rolled-out another program call the Food Security Pack or Program Against Malnutrition (PAM). PAM is seen primarily as a social transfer program, rather than an productivity enhancing program; it targets vulnerable households with holdings under one hectare and promotes diversification and conservation farming (Chirwa and Dorward, 2013). According to Mason et al. (2013b), PAM has very low political interference and has no overlap at the household level with the FSP.

variations, again in this case the interaction should capture only the effect of the FSP.

Table 21 shows the first stage regression of the Instrumental variable estimation. There is a strong positive correlation between the instrument and the FSP variable, and an F-statistic at 74.58. It means that households further away from FRA collection points get more subsidies when they are in constituencies won by MMD. In other words, authorities put more efforts in reaching households further away from FRA points when they voted for MMD. Albeit, a small point estimate, if scaled by the distance of each individual dwelling to the FRA buying point, it can become quite substantial. For instance, the average household lives 21.7km from the closest FRA buying point, this implies that there is a 3 percentage point change in the likelihood that the average household gets the FRA if they are from a constituency that has voted for the incumbent. Note that living in a constituency won by MMD offsets the negative effect of distance.

In the second stage, we see a strong and significant effect of the FSP on outmigrations and inmigration, implying an arbitrage of the household on who to assign to which activity. Table 21 shows results of the IV-estimation of the impact of the FSP on the outmigration and inmigration. Similarly to implications of the model in section 6, when additional income is given to the household, and relaxes the credit constraint of households, they make allocative decisions on who to send and who to host based on respective comparative advantages of household current and prospect members. Keeping in mind the LATE interpretation of the coefficient, we can only make these conclusions for households that benefit from the subsidy due to the FSP.

Table 21: Individual outmigrations and inmigration IV estimations

	First Stage		Extensive Migration		Intensive Migration		
	Stage 1 OLS iv	Stage 1 probit	Outmig 2SProbit	Inmig 2SLS	Outmig 2SProbit	Inmig 2SLS	Netmig 2SLS
MMD*Distance	0.00141***	0.000915***					
	(0.000166)	(0.000214)					
FSP			0.123	0.174**	3.031***	0.691*	2.435***
			(0.114)	(0.0786)	(0.739)	(0.375)	(0.796)
MMD won	-0.0986***	-0.0569***	-0.119***	-0.0683***	-0.167***	-0.0939***	-0.0676
	(0.00758)	(0.00518)	(0.00977)	(0.00761)	(0.0567)	(0.0273)	(0.0615)
Distance to FRA (km)		-0.00132***	-0.000383***	-0.000306**			
		(0.000197)	(0.000141)	(0.000120)			
Observations	11,464	14,056	14,056	14,056	11,464	11,716	11,464
R-squared					-0.251	-0.028	-0.141
F-Statistic	74.58						
Number of hhid	4,258	5870	5870	5870	4,258	4,290	4,258
hh fixed-effect	Yes	No	No	No	Yes	Yes	Yes
Cluster hh level	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors clustered at the household level in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

On the household level (Table 22), the IV estimation shows a positive impact of the FSP on agricultural work however that is an impact through political clientelism. This finding seems quite surprising as it implies that although on average, treated areas do not see a change in their labor supply in agriculture. That is likely due to many frictions impeding the functioning of these labor markets. However, areas taht benefit from political clientelism do. A potential mechanism could be that households who benefit from clientelism also get other infrastructure and access that may dampen the effect of these frictions. Households can thus make a set of adjustments (or adjustment with higher marginal returns) than other households who have had earlier opportunities to do them (and who face diminishing marginal return of income).

In Figure 20, I show all individual migration estimates of the main estimation. The *DID estimates* panel shows the results at the SEA level and the *IV estimates* panel shows results at the household level. The results of this instrumental variable estimation strengthen the results of the DID estimation. The results are qualitatively similar with the exception of the sign of the extensive margin of individual inmigration, which speaks

Table 22: Instrumental Variable: Labor market impacts of the FSP program

	(1) 1st Stage	(2) Agricultural-work	(3) Non-Agricultural
MMD won * Distance to FRA	0.00106***		
	(0.000196)		
FISP		1.146***	0.159
		(0.345)	(0.256)
Observations	13,997	13,997	13,997
Number of households	5,237	5,237	5,237
Household and year FE	yes	yes	yes

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

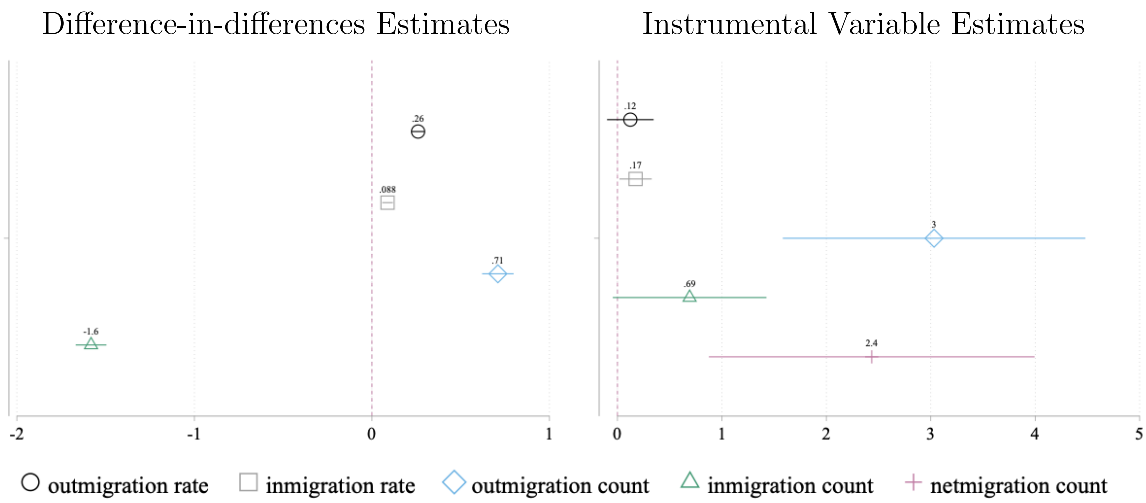


Figure 20: Summary of results for individual migrations: difference-in-differences and IV point estimates

to the underlying heterogeneity of households. That is, the estimators — a LATE in the case of the IV and a treatment on the treated identified in the DID — are picking up different heterogeneities. However, one constant in these estimations is the positive effect of the subsidy on outmigration, both at the household and the individual level, on all margins.

Having shown that the subsidy has indeed led to an increase migration, as suggested by the model, I next show, using the model of section 6 the impact different policies could have on the choices households make on the allocation of their members to migration.

Table 23: 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	-1.71e-06***	-3.10e-06*
	(3.77e-07)	(1.84e-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

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

A.6 A structural model of sorting via resale markets

In this section, I explore the mechanisms through which a subsidy on fertilizer can affect migration. Importantly, I will show sequentially two equilibria, one without the subsidy and one with the subsidy. I am interested in understanding the impacts of input subsidies on migration for households that are heterogeneous in land holdings, in household size (L_i), in the returns to migration for individual household members, and in the returns to fertilizer-intensive agriculture. In this model, households makes a joint decision between i) adopting the fertilizer agriculture (hereafter referred to as traditional agriculture) and ii) sending any members out to migrate.

This model is static Roy model of selection across the fertilizer and the traditional technology with migration as an outside option. Farmers' decision to adopt the fertilizer technology is affected by a positive externality and households might not adopt the fertilizer even in cases where it would be profitable to do so. Farmers' migration decision on the other hand is affected by their inability to borrow against their migration income.

When the fertilizer subsidy is introduced, households who have a comparative advantage in migrating but cannot afford to move will see their credit constraint relaxed as they can

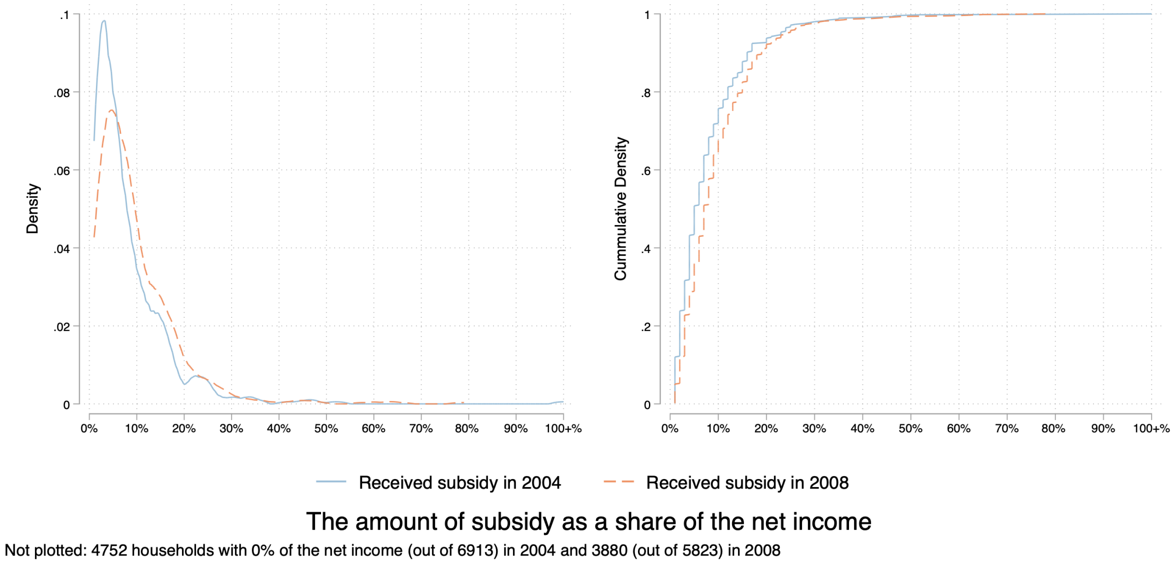


Figure 21: Total amount of the subsidy over the net income of the household
Note: The variable plotted is $\frac{\text{Subsidy}}{\text{Subsidy + Income}}$

trade the subsidized fertilizer in resale markets and migrate. Alternatively, those with a comparative advantage in the fertilizer agriculture but are credit constrained see costs go down and usage go up. The subsidy here both lifts the credit constraints and increases usage across the board, thus addressing the externality. Some distortions are introduced, as households at the margin that would use their labor units in other activities absent the subsidy, divert units of labor to the fertilizer agriculture as a result of the price distortion (Mirrlees, 1986; Diamond and Mirrlees, 1971). Depending on the importance of market frictions — credit constraint, and learning externality — the gains in allocative efficiencies can offset these distortions.

In the remainder of the section, I focus on the decision of a unique household across these different options.

A.6.1 Adoption of the technology without subsidies

I start with a simplified framework with no subsidy. In this first case, the household makes a decision on whether or not to adopt fertilizers and whether to migrate. The household (indexed i) maximizes its surplus across all its options similarly to Suri (2011).

Households vary in factor endowments and have multiple members. The comparative advantage of households in migration stems partially from productivity differentials in technologies. Furthermore, there is the outside option of migration for the household.

The household has L_i members. It decides on labor units $L_{i,A}$, $L_{i,M}$ to allocate to agriculture, and to migration respectively. If the household allocates any labor to agriculture, it has to choose across two technologies; i) the traditional technology which uses labor and land as inputs, and ii) a fertilizer-augmented technology that requires fertilizer as an additional input. For the traditional agriculture, land holdings are not binding. However, in the fertilizer-augmented technology, landholdings X enter the production function explicitly. $L_{i,A}$, $L_{i,M}$ are continuous in the $[0, L_i]$ interval, as households can divide an individual's members' time across activities. Within a household, workers are homogeneous.

In this model, learning externalities in agricultural technology adoption enter farmers' problems via the cost of adoption (Conley and Udry, 2010; Carter et al., 2021; Foster and Rosenzweig, 1995). Without the subsidy, the community faces a fixed cost T of adopting the fertilizer that must be split across all adopting households in the community. The individual cost is then $T - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N} T$ where $\mathscr{D}_j = 1$ when a household in the community adopts the fertilizer-intensive technology and N is the total number of farmers in the community. In other words the fixed cost of using fertilizer depends on the share of households in the community that adopts the fertilizer-augmented technology.

I further assume that the wage w in the destination area, should the household decide to migrate is a function of characteristics of the household that is known to them. It is a measure of "how good" members would be at migrating. Effectively, the household allocates labor units to each activity to maximize its total surplus across all activities. The two agricultural technologies produce a homogeneous output.

The household chooses whether to engage in the fertilizer-augmented agriculture if its expected surplus using the fertilizer-augmented technology and having migration as an outside option is larger than its expected surplus using the traditional agriculture and having migration as an outside option. Formally the household adopts the fertilizer technology (i.e. $\mathscr{D}_i = 1$) if $\pi_i^{F,M} \geq \pi_i^{T,M}$.

Migration: The household splits its labor across agriculture and migration. The surplus generated by the labor allocated to migration is is the following:

$$\pi^M = (L_i - L_{i,A}) \cdot (w - m_i(\theta_{vil}, \zeta_i)) - c \tag{25}$$

Where L_i is the size of the household, $L_{i,A}$ are the labor units allocated to agriculture, w the exogenous wage at destination, m the marginal cost of migration and c the fixed cost of migration.

A.6.2 The Fertilizer Agriculture (i.e. $\mathscr{D}_i = 1$) with and without Migration

In this setting, the household purchases an amount $\tilde{f}$ of fertilizer at a price q. The household is a price taker in the fertilizer market, and q is the manufacturing price of fertilizer. There is a fixed cost of adoption $T_{area} \cdot (1 - \frac{\sum_{j=1}^{N} \mathscr{D}_i}{N})$ (where j indexes all households of the community) of acquisition that is a function of the number of households utilizing the fertilizer technology. Here, one can think of this fixed cost as the cost of getting a vendor to set-up shop in a community, or the cost of renting out a truck to transport the fertilizer to the community. This cost is fixed but is shared among all the users in the community. The household also chooses the optimal share of labor units to allocate to the fertilizer-intensive agriculture ($L_{i,A}$) and to migration ($L_{i,M}$).

Below are the production function for the fertilizer-intensive technology (Y^F), the surplus function stemming from it (π^F) and the total surplus function, including returns to migration ($\pi^{F,M}$).

$$Y^F = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} \tag{26}$$

$$\pi_i^F = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i) \tag{27}$$

$$\pi^{F,M} = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i) - T_{area}\left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right) + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c \tag{28}$$

Where P is the price of the output, A_i the household's idiosyncratic productivity, L_i is the size of the household, $L_{i,A}$ are the labor units allocated to agriculture, F_i the total amount of fertilizer used on the farm, w the exogenous wage at destination, m the marginal cost of migration and c the fixed cost of migration.

The household maximizes it total product, and its optimization problem is the following

$$\max_{L_{i,A}, F_i} \pi^{F,M} = \left\{ p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i) \right\} \tag{29}$$

$$\pi^{F,M} = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i) - T_{area}\left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right) + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) \tag{30}$$

The first order conditions:

$$\frac{\partial \pi_i^{F,M}}{\partial L_{i,A}} = \alpha p \cdot A_i \cdot L_{i,A}^{\alpha-1} F_i^{\beta} X_i^{1-\alpha-\beta} - (w - m_i(\theta_{vil}, \zeta_i)) = 0 \tag{31}$$

$$\frac{\partial \pi_i^{F,M}}{\partial F_i} = \beta P \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta-1} X_i^{1-\alpha-\beta} - q = 0 \tag{32}$$

Fertilizer and Migration: The migration decision is in two steps, first the household decides whether to have any outmigrants. If the household decide to have outmigrants, then it optimally chooses the number of outmigrants $L_{i,M}^*$ to maximize its returns to migration. The household decides to engage in migration (i.e. $\mathscr{M}_i = 1$) if its believes that migration wage is larger than the opportunity cost of migration. Formally it means the following:

$$\mathbb{E}_i(w) \geq \frac{PA_iX_i^{1-\alpha-\beta} \cdot (L_i - L_{i,A}^{mig})^{\alpha} \cdot (F_i^{nomig} - F_i^{mig})^{\beta} - q(F_i^{nomig} - F_i^{mig})^{\beta} + c}{L_i - L_{i,A}} + m \tag{33}$$

Provided that the household chooses to have outmigrants, the optimal labor allocated to migration from the FOCs for a farmer who does not use fertilizer is the following:

$$L_{i,M}^{*} = L_i - \left[\left(\frac{p \cdot A_i \cdot \alpha}{w - m_i} \right)^{(1-\alpha)\cdot(1-\beta)} \cdot \left(\frac{\beta}{q} \right)^{\beta} \right]^{\frac{1}{1-\alpha-\beta}} \cdot X_i$$

Fertilizer and No-Migration:

$$L_{i,M}^{*} = 0$$

$$L_{i,A}^{*} = L_i$$

$$F_i^{*} = \left[\frac{P \cdot A_i \beta L_i^{\alpha} X_i^{1-\alpha-\beta}}{q} \right]^{\frac{1}{1-\beta}}$$

A.6.3 The Traditional Agriculture ($\mathscr{D}_i = 0$) with and without Migration

In this setting, the household also chooses the optimal share of labor units to allocate to the traditional agriculture agriculture ($L_{i,A}$) and to migration ($L_{i,M}$) and does not purchase fertilizer.

Below are the respectively the technology for the traditional technology (Y^T), the surplus stemming from it (π^T) and the total surplus, including returns to migration ($\pi^{T,M}$).

$$Y^T = a \cdot L_{i,A}^{\gamma} \tag{34}$$

$$\pi^T = p \cdot a \cdot L_{i,A}^{\gamma} \tag{35}$$

$$\pi^{T,M} = p \cdot a \cdot L_{i,A}^{\gamma} + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c \tag{36}$$

Where γ is the output elasticity of labor in the traditional agriculture. The maximization problem is:

$$\max_{L_{i,A},F_i} \quad \left\{p \cdot a \cdot L_{i,A}^{\gamma} + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c\right\} \tag{37}$$

The first order conditions: $\frac{\partial \pi^{T,M}}{\partial L_{i,A}} = \gamma \cdot p \cdot a L_{i,A}^{\gamma-1} - (w - m_i(\theta_{vil}, \zeta_i)) = 0$

Migration: The migration decision is in two steps, first the household decides whether to have any outmigrants. If the household decide to have outmigrants, then it optimally chooses the number of outmigrants $L_{i,M}^{*}$ to maximize its returns to migration.

Provided that the household chooses to have outmigrants, the optimal labor allocated to migration for a farmer who does not use fertilizer is the following:

$$\Rightarrow L_{i,M} = L_i - \left[\frac{\gamma \cdot p \cdot a}{w - m_i}\right]^{\frac{1}{1-\gamma}}$$

The household would allocate more labor to agriculture, and less to migration when the output elasticity of labor (γ), the price of the agricultural product (P) and the productivity of labor (a) increase. Alternatively, it would allocate less labor to agriculture and more to migration as the return to migration ($w - m_i$) increase.

The household chooses to have outmigrants i.e. $\mathscr{M}_i = 1$ if its beliefs about the migration wage is the following:

$$\mathbb{E}_i(w) \geq \frac{p \cdot a \cdot (L_i - L_{i,A}^{mig})^{\gamma} + c}{L_i - L_{i,A}} + m \tag{38}$$

Choice to Adopt Fertilizer and to Migrate Without the Subsidy

The household will adopt fertilizer if its surplus in the fertilizer agriculture is larger than in the traditional agriculture. In both cases, having the outside option of migration. Formally, it we have:

$$\mathscr{D}_i = 1 \text{ iff } \pi_i^{FM*} \geq \pi_i^{TM*}$$

Which only occurs when:

$$A_i \geq \left[\frac{(p \cdot a \cdot \gamma)^{\frac{\gamma}{1-\gamma}} \cdot (p \cdot a - w + m)}{\left(\frac{1}{Z}\right)^{\alpha} (B)^{\frac{\beta}{\omega}} \cdot X_i - q \left(\Psi \cdot (B)^{1-\alpha}\right)^{\frac{1}{\omega}} \cdot X_i - \frac{\alpha}{Z} \left(\Psi \frac{(B)^{\beta}}{Z}\right)^{\frac{1}{\omega}} - T_{area} \left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right)} \right]^{1-\alpha-\beta}$$

Where $Z = \frac{\alpha}{w-m_i}$, $B = \frac{\beta}{q}$, and $\omega = 1 - \alpha - \beta$ and $\Psi = P \cdot A_i \left(\frac{\alpha}{w-m_i}\right)^{\alpha}$ A household adopts the fertilizer-intensive agriculture if and only if its idiosyncratic productivity A_i if above a given threshold. Notably, adoption is thus increasing in the number of households who adopt the fertilizer in the community $\left(\frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right)$, which is the externality. It is also decreasing in the returns to migration.

In this setting only the most productive farmers choose to adopt. And the outside option of migration is attractive to both traditional and fertilizer-intensive farmers.

A.6.4 Adoption of the fertilizer technology with subsidies and migration as an outside option

From the baseline model, we infer that households, that absent the subsidy, have a comparative advantage in migrating and are not credit constrained, should migrate even without a subsidy.[34] Because of the externality however, some households who have a comparative advantage in the fertilizer technology may still not invest in the technology. Additionally, some credit-constrained households with a comparative advantage in the fertilizer technology may still not be able to afford to purchase the fertilizer despite having a large number of neighboring farmers using the subsidy.

The combination of the externality and the credit constraint lead to a number of households being unable to identify or exercise their true comparative advantage. More specifically, when the government introduces a fertilizer subsidy by distributing vouchers, each household can either choose to use the subsidized fertilizer in their production; or trade

[34] However, note that households cannot know their true comparative advantage without the fertilizer subsidy, because they do not know their true productivity in fertilizer agriculture.

the vouchers in resale markets at a price q. In this case, transportation costs are no longer an issue for the household because the government internalizes the externality. This way, the transportation cost is equal to the marginal cost of transportation, and is folded into the unit of fertilizer.

The household can trade a quantity $\tilde{f}_i$ in resale markets (either selling or buying). The household can sell its entire subsidized allocation, or it can buy any affordable amount; thus: $\tilde{f}_i \in [-\bar{f}; \infty)$. The total available quantity of fertilizer available for production is $F_i = \tilde{f}_i + \bar{f}$. In the model, I make the simplifying assumption that the total cost of the fertilizer is subsidized, and so the household receives a bag of a quantity $\bar{f}$ for free.

Again, the household decides on whether to adopt the fertilizer ($\mathscr{D}_i = 1$) or not ($\mathscr{D}_i = 0$), and on the share of its household it allocates to migration ($L_{i,M}$).

A.6.5 The Fertilizer Agriculture ($\mathscr{D}_i = 1$) with and without Migration

In this setting, the household receives the subsidized fertilizer $\bar{f}$ and chooses the amount $\tilde{f}$ of fertilizer it will trade in the resale markets — either to top-up and use on their farm, or to trade out to generate some income. The household also chooses the optimal share of labor units to allocate to the fertilizer-intensive agriculture ($L_{i,A}$) and to migration ($L_{i,M}$).

Below are the expressions for the technology for the fertilizer-intensive technology (Y^F), the surplus stemming from it (π^F) and the total surplus, including returns to migration ($\pi^{F,M}$).

$$Y^F = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} \tag{39}$$

$$\pi^F = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i - \bar{f}) \tag{40}$$

$$\pi^{F,M} = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q \cdot (F_i - \bar{f}) + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c \tag{41}$$

Where P is the price of the output, A_i the household idiosyncratic productivity, L_i is the size of the household, $L_{i,A}$ are the labor units allocated to agriculture, F_i the total amount of fertilizer used on the farm, $\bar{f}$ the amount of subsidized fertilizer, w the exogenous wage at destination, m the marginal cost of migration and c the fixed cost of migration. Note that A_i follows is a made up of two components: $A_i = \upsilon_i + \theta_{vil}$ where θ_{vil} is known to the households and common to the SEA, such as soil quality. υ_i is an idiosyncratic productivity shock unknown to the household when it makes technology and migration decisions. υ_i is normally distributed. The household maximizes it total surplus, and its optimization problem is the following

$$\max_{L_{i,A},F_i} \pi^{F,M} = \Big\{ p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q(F_i - \bar{f}) + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c \Big\} \tag{42}$$

The first order conditions are the following:

$$\frac{\partial \pi^{F,M}}{\partial L_{i,A}} = \alpha p \cdot A_i \cdot L_{i,A}^{\alpha-1} F_i^{\beta} X_i^{1-\alpha-\beta} - (w - m_i(\theta_{vil}, \zeta_i)) = 0 \tag{43}$$

$$\frac{\partial \pi^{F,M}}{\partial F_i} = \beta P \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta-1} X_i^{1-\alpha-\beta} - q = 0 \tag{44}$$

Migration: The household sends any migrants if its expected returns to migration are higher than a threshold given by:

$$\mathbb{E}_i(w) \geq \frac{P A_i X_i^{1-\alpha-\beta} \cdot (L_i - L_{i,A}^{mig})^{\alpha} \cdot (F_i^{nomig} - F_i^{mig})^{\beta} + q(F_i^{nomig} - F_i^{mig})^{\beta} + c}{L_i - L_{i,A}} + m_i \tag{45}$$

Where $m_i = \zeta_i + \theta_{vil}$ and ζ_i is normally distributed

Leading to the following optimal levels of fertilizer use and Labor allocated to migration:

$$F_i = \left[p \cdot A_i \cdot \left(\frac{\alpha}{w - m_i} \right)^{\alpha} \cdot \left(\frac{\beta}{q} \right)^{1-\alpha} \right]^{\frac{1}{1-\alpha-\beta}} \cdot X_i \tag{46}$$

$$L_{i,M} = L_i - \left[p \cdot A_i \cdot \left(\frac{\alpha}{w - m_i} \right)^{\alpha-1} \cdot \left(\frac{\beta}{q} \right)^{\beta} \right]^{\frac{1}{1-\alpha-\beta}} \cdot X_i \tag{47}$$

A.6.6 The Traditional Agriculture ($\mathscr{D}_i = 0$) with and without Migration

In this setting, the household receives the subsidized fertilizer $\bar{f}$ sells all of it in the resale market (i.e. $\tilde{f} = -\bar{f}$) at a unit price of q. The household also chooses the optimal share of labor units to allocate to the traditional agriculture agriculture ($L_{i,A}$) and to migration ($L_{i,M}$).

Below are the respectively the technology for the traditional technology (Y^T), the surplus stemming from it (π^T) and the total surplus, including returns to migration ($\pi^{T,M}$).

$$Y^T = a \cdot L_{i,A}^{\gamma} \tag{48}$$

$$\pi^T = p \cdot a \cdot L_{i,A}^{\gamma} + q \cdot \bar{f} \tag{49}$$

$$\pi^{T,M} = p \cdot a \cdot L_{i,A}^{\gamma} + q \cdot \bar{f} + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c \tag{50}$$

The maximization problem:

$$\max_{L_{i,A},F_i} \quad \left\{p \cdot a \cdot L_{i,A}^{\gamma} + q \cdot \bar{f} + (L_i - L_{i,A})(w - m_i(\theta_{vil}, \zeta_i)) - c\right\} \tag{51}$$

The first order conditions:

$$\frac{\partial \pi^F}{\partial L_{i,A}} = \gamma \cdot p \cdot aL_{i,A}^{\gamma-1} - (w - m_i(\theta_{vil}, \zeta_i)) = 0 \tag{52}$$

$$\tag{53}$$

Migration: The household chooses to have outmigrants i.e. $\mathscr{M}_i = 1$ if its beliefs about the migration wage is the following:

$$\mathbb{E}_i(w) \geq \frac{p \cdot a \cdot (L_i - L_{i,A}^{mig})^{\gamma} + q\bar{f} + c}{L_i - L_{i,A}} + m \tag{54}$$

With an optimal amount of labor units allocated to migration when the $\mathscr{M}_i = 1$ equal to:

$$L_{i,M} = L_i - \left[\frac{\gamma \cdot p \cdot a}{w - m_i}\right]^{\frac{1}{1-\gamma}}$$

Note that with the subsidy, the labor allocation for those who choose the traditional agriculture remains unchanged, when compared to the labor allocation of the traditional agriculture without the subsidy.

Resale Market Clearing Condition: When resale markets exist, they clear (the net quantity bought must equate the net quantity sold), endogenizing resale prices q. Because those who do not adopt the fertilizer-intensive agriculture resell the entire subsidized quantity they trade $\tilde{f} = -\bar{f}$. Formally, we have:

$$\sum_{j=0}^{N} \tilde{f}_j = 0 \tag{55}$$

$$\sum_{j=0}^{N} \tilde{f}_j = \sum_{i=0}^{N} \left[\mathscr{D}_j \cdot \tilde{f}_j - (1 - \mathscr{D}_j) \cdot \bar{f}\right] = 0 \text{ where } \mathscr{D}_j = 1 \text{ if } \pi_j^{FM*} \geq \pi_j^{TM*} \tag{56}$$

$$= \sum_{i=0}^{N} \left[\mathscr{D}_j \cdot \left[\left(p \cdot A_j \cdot \left(\frac{\alpha}{w - m_i}\right)^{\alpha} \cdot \left(\frac{\beta}{q^*}\right)^{1-\alpha}\right)^{\frac{1}{1-\alpha-\beta}} \cdot X_j - \bar{f}\right] - (1 - \mathscr{D}_j) \cdot \bar{f}\right] \tag{57}$$

At equilibrium, the resale prices q^*, the total fertilizer used F^*, and labor share migrating $L_{i,M}$ are the following:

$$\Rightarrow q^* = \beta \left[\left(\frac{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)}{N \bar{f}}\right)^{1-\alpha-\beta} \cdot P \cdot \left(\frac{\alpha}{w - m_i}\right)^{\alpha}\right]^{\frac{1}{1-\alpha}}$$

$$\Rightarrow F_i^* = A_i^{1-\alpha-\beta} \cdot \left(\frac{N \bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j (A_j X_j)}\right) \cdot X_i$$

$$\Rightarrow L^*_{i,M} = L_i - A_i^{1-\alpha-\beta} \cdot \left[p \cdot \left(\frac{\alpha}{w - m_i} \right) \cdot \left(\frac{N\bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j(A_j X_j)} \right)^{\beta} \right]^{\frac{1}{1-\alpha}} \cdot X_i$$

A.6.7 Choice to Adopt fertilizer under the Subsidy Program

Similarly to the case without a subsidy, the household will adopt fertilizer if its surplus in the fertilizer agriculture is larger than in the traditional agriculture. Formally, it we have:

$$\mathscr{D}_i = 1 \text{ iff } \pi_i^{FM*} \geq \pi_i^{TM*}$$

Which only occurs when:

$$A_i \geq \left[\frac{(p \cdot a \cdot \gamma)^{\frac{\gamma}{1-\gamma}} \cdot (p \cdot a - w + m)}{\left(P\,(Z)^{\alpha}\,(Q)^{\beta}\right)^{\frac{1}{1-\alpha}} X_i^{\alpha+\beta} - \beta \left[\left(\frac{1}{Q}\right)^{1-\alpha-\beta} \cdot P \cdot (Z)^{\alpha} \right]^{\frac{1}{1-\alpha}} (Q)\, X - \left[Z P\,(Q)^{\beta} \right]^{\frac{\alpha}{1-\alpha}} X \cdot (w - m_i(\theta_{vil}, \zeta_i))^{\frac{1}{1-\gamma}}} \right]^{1-\alpha-\beta}$$

Where $Z = \frac{\alpha}{w-m_i}$ and $Q = \frac{N\bar{f}}{\sum_{j=0}^{N} \mathscr{D}_j(A_j X_j)}$. Similar to the case without a fertilizer subsidy, only the most productive farmers choose to adopt. Here, the price of the fertilizer has been endogenized. Furthermore, the threshold is lower due to the fixed cost of adoption $T_{area} \cdot \left(1 - \frac{\sum_{j=1}^{N} \mathscr{D}_i}{N}\right)$ being eliminated due to the subsidy. Here, the number of households who adopt the fertilizer in the community $\left(\frac{\sum_{j=1}^{N} \mathscr{D}_j}{N}\right)$ as an externality disappears, but is present as an argument of the decision via the resale markets.

A.7 Structural estimation

Table 24: Structural estimation of the joint decision over fertilizer adoption and migration

	(1)	(2)	(3)	(4)	(5)	(6)
	With the subsidy: $\bar{f} > 0$			Without the subsidy: $\bar{f} = 0$		
Parameters	$\mathscr{D}_i$	L_{iM}	$\mathscr{M}_i$	$\mathscr{D}_i$	L_{iM}	$\mathscr{M}_i$
p	0.0223***	-0.000994	-0.000626	2.73e-05	-0.00163**	-0.00328***
	(0.00347)	(0.000660)	(0.000416)	(0.000927)	(0.000763)	(0.000492)
$(w - m_i)$	-0.159***	0.00665***	0.00418***		0.00234***	0.0101***
	(0.0156)	(0.000394)	(0.000263)		(0.000326)	(0.000494)
X_i	-0.0463		0.000303	0.0328*		0.0216**
	(0.0297)		(0.00182)	(0.0173)		(0.0101)
q	0.000709			1.67e-05		
	(0.000473)			(0.000146)		
L_i	-0.177***	0.490***	0.306***	0.0566***	0.268***	0.432***
	(0.0321)	(0.0101)	(0.00794)	(0.0120)	(0.0126)	(0.0122)
$\frac{\sum_i \mathscr{D}_j}{Nf}$	-0.274***					
	(0.101)					
$\widehat{\mathscr{D}_i}$		0.918***	0.576***		1.127***	2.820***
		(0.0858)	(0.0554)		(0.128)	(0.132)
A_i			0.000152			-0.0182
			(0.00452)			(0.0374)
$\sum_i \mathscr{D}_j$				0.237***		
				(0.0177)		
Constant	1.276	-2.349***	-2.046***	-2.117***	1.351***	-2.589***
	(1.371)	(0.345)	(0.219)	(0.513)	(0.371)	(0.248)
Log Likelihood		-3659.5899			-3028.086	
P-value LR chi2		0.0000			0.0000	
Households	2,341	2,341	2,341	1,683	1,683	1,683

Notes: This model is estimated using maximum likelihood. Naive standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

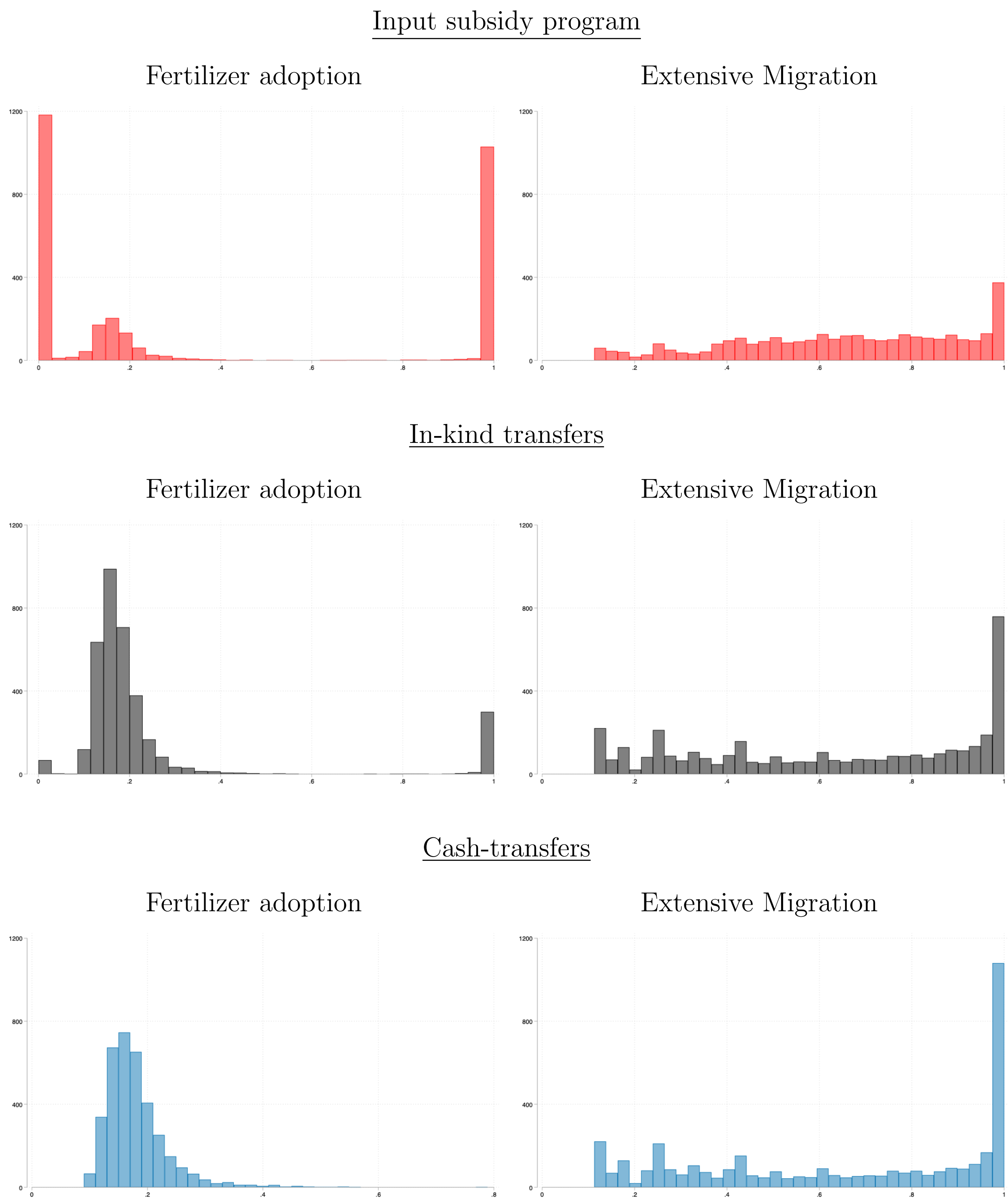


Figure 22: Cash-transfer and input subsidy scenarios for adoption and migration

A.8 Optimal policy design and discussion of results

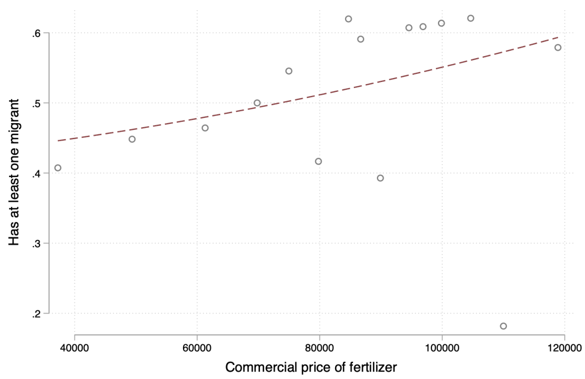


Figure 23: Commercial price of fertilizer vs. extensive individual migration

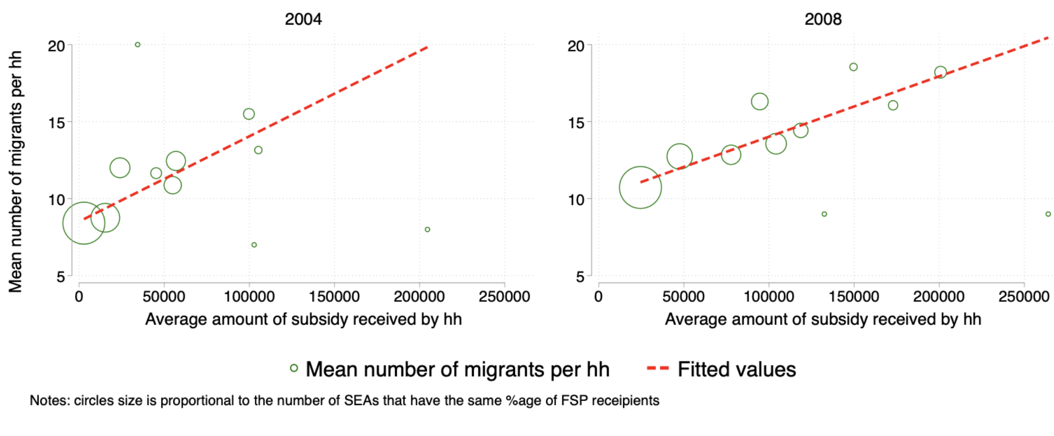


Figure 24: Impact of the Volume of Subsidy on Migration Decisions' of Individuals

A.9 An alternative model of migration and agricultural production

In this section, I explore the mechanisms through which a subsidy on fertilizer can affect migration. Importantly, I will show sequentially two equilibria, one without the subsidy and then one with the subsidy. I am interested in understanding the impacts of input subsidies on migration for households that are heterogeneous in land holdings, in household size (L_i), in the returns to migration for individual household members, and in the returns to fertilizer-intensive agriculture. In this model, households choose between two options: i) staying in the rural area, either in the agricultural sector, or in other rural activities (hereafter referred to as traditional agriculture) or ii) migrating.

This model is a Roy model of selection in which households vary in factor endowments and have multiple members. The comparative advantage of households in migration stem partially from productivity differentials in technologies. Furthermore, there is the outside option of migration for the household. Adoption of the fertilizer technology is affected by an externality and households might not adopt the fertilizer even in cases where it would be profitable to do so.

When the fertilizer subsidy is introduced, households who have a comparative advantage in migrating but cannot afford to move prior to the policy will see their credit constraint relaxed as they can trade the subsidized fertilizer in resale markets and migrate. Alternatively, those with a comparative advantage in the fertilizer agriculture but are credit constrained and (or) did not internalize the learning externality, see costs go down and usage go up both lifting the credit constraints and increasing usage across the board, thus addressing the learning externality. Some distortions are introduced, as households at the margin that would have been used their labor units in other activities absent the subsidy, might diverts units of labor to the fertilizer agriculture because of the price distortion (Mirrlees, 1986; Diamond and Mirrlees, 1971). Depending on the importance of market frictions — credit constraint, and learning externality — the gains in allocative efficiencies can offset these distortions.

In the remainder of the section, I focus on the decision of a unique household across these different options.

A.9.1 Adoption of fertilizers without subsidies

I start with a simplified framework with no subsidy. In this first case, the household makes a decision on whether or not to adopt fertilizers and whether to migrate. Their decisions are made at the beginning of the planting season, before the rainy season, i.e. before the realization of any productivity shocks. The household (indexed i) makes its decision based on all the available information and has forward looking expectations on the farming conditions and the outputs across its different options (fertilizer-improved technology, traditional technology and migration). I assume that the household functions as a firm that is risk-neutral, and maximizes profits across all its options.

The household has L_i members. It decides on labor units L_i^A, L_i^M to allocate to agriculture, and to migration respectively. If the household allocates any labor to agriculture, it has to choose across two technologies; i) the traditional technology which uses labor and land as inputs, and ii) a fertilizer-augmented technology that requires fertilizer as an additional input.[35] L_i^A, L_i^M are continuous in the $[0, L_i]$ interval, as households can divide an individual's members time across activities. Within a household, workers are homogeneous.

In order to account for learning externalities in agricultural technology adoption (Conley and Udry, 2010; Carter et al., 2021; Foster and Rosenzweig, 1995), I assume that the household underestimates the profit it would make with the fertilizer technology, but their expectations adjust as more farmers around them use the fertilizer. The adjustment rate is a function of the proportion of farmers who use the subsidy. I further assume that the wage w_i^M in the destination area, should the household decide to migrate is a function of characteristics of the household that is known to them. It is a measure of "how good" members would be at migrating. Effectively, the household allocates labor units

[35] Here I further assume (though without explicitly expressing it in the production function) that land holdings are not binding. In the simulations coming up however, I relax these assumption and allow for landholdings X by farmers to be limited.

to each activity to maximize its total profits across all activities. The two agricultural technologies produce a homogeneous output. The maximization problem is the following:

$$\max_{L_i^A, L_i^M} \quad \{\pi_i^A(L_i^A) + \pi_i^M(L_i^M)\} \tag{58}$$

$$s.t. \quad L_i^a + L_i^M = L_i \tag{59}$$

$$Y_i^A = \begin{cases} (L_i^A)^{\alpha_2}(X)^{\beta_2} & \text{if } f_i = 0 \\ (L_i^A)^{\alpha_1}(X)^{\beta_1}(\tilde{f}_i)^{\gamma} & \text{if } f_i \geq 0 \text{ and} \end{cases} \tag{60}$$

Where $\pi_i^A(L_i^A)$, $\pi_i^M(L_i^M)$ are the profits from the agriculture sector and from migration. Y_i^A is household i's total production when they engage in the agricultural sector A. The household can choose the fertilizer-augmented technology or traditional agriculture.The amount of fertilizer used on the farm is f_i. p is the market price of the crop, b is the per-unit cost of fertilizers and a the fixed cost of adopting fertilizers. These fixed costs of adopting fertilizers can be for example the costs of buying spraying equipment or getting training on how to use these fertilizers. w is the cost of labor in the two technologies of the agricultural sector. Wages equalize across the two farming sectors, because rural agricultural households typically employ their members, and therefore is a monopsony and pays only a subsistence wage.

I do not account for inmigrants. Furthermore, the household would chose to engage in fertilizer agriculture expecting to only have an output equal to ρY^A. ρ is the share of farmers using the fertilizer; it reflects the learning externality: as more neighboring farmers use fertilizers, a farmer corrects upward her previously downward biased expected profits. In the absence of the externality, $\rho = 1$ m_t is the moving cost for each member of the household who migrates, and c the fixed cost of moving out, this cost is incurred only once when a first member migrates. This can be thought about as getting lodging, setting-up a network, understanding how the destination area works. L_i^M is the labor employed in the destination at a wage w_i^M, which is a function of the household's productivity in migrating[36].

The profit functions are the following:

$$\pi_i^A(L_i^A) = \begin{cases} p \cdot Y_i^A - w \cdot L_i^A & \text{if no fertilizer} \\ \rho \cdot \left(p \cdot Y_i^A\right) - b \cdot f_i - a - w \cdot L_i^A & \text{if fertilizer} \end{cases} \tag{61}$$

$$\pi_i^M(L_i^M) = (w_i^M - m_t) \cdot L_i^M - c \tag{62}$$

A.9.2 Adoption of fertilizers with subsidies and migration as an outside option

From the baseline model, we infer that households who absent the subsidy have a comparative advantage in migrating and are not credit constrained, should migrate even without a subsidy[37]. Because of the learning externality, however some households who have a comparative advantage in the fertilizer technology may still not invest in the technology. Additionally, some credit-constrained households with a comparative advantage in the fertilizer technology may still not be able to afford to purchase the fertilizer despite having a large number of neighboring farmers using the subsidy.

The combination of the learning externality and the credit constraint lead to a number of households being unable to identify or exercise their true comparative advantage. More specifically, when the government introduces a fertilizer subsidy, each household can either choose to use the fertilizer in their production; or trade it in resale markets at a price q. The household can trade a quantity $\tilde{f}_i$ in resale markets (either selling or buying). The household can sell its entire subsidized allocation, or it can buy any affordable amount; thus: $\tilde{f}_i \in [-\bar{f}; \infty]$. The total available quantity of fertilizer available for production is $f_i = \tilde{f}_i + \bar{f}$. In a frictionless world, the market price and the resale price would be

[36] These productivities are a measure of how good a household is at migrating. Each household has a different migration productivity.

[37] However, note that households cannot know their true comparative advantage without the fertilizer subsidy, because they do not know their true productivity in fertilizer agriculture.

identical — i.e., $b = q$ — in this case, using resale markets for a net re-seller would be comparable to a pure cash transfer equal to the monetary value of the subsidy. In practice, in the absence of transportation costs to commercial vendors, $b \geq q$, because otherwise net-buyers on resale markets would resort to commercial markets. More formally, the household receives a subsidy t making the effective price of the fertilizer $b - t$. At that subsidized price, the household can only buy a quantity $\bar{f}$ from the government provider. Note that $0 \leq t \leq b$ (the net subsidized price $b - t$ must be positive). We can rewrite equations the maximization problem as:

$$\max_{L_i^A, L_i^M} \quad \left\{\pi_i^A(L_i^A) + \pi_i^M(L_i^M)\right\} \tag{63}$$

$$s.t. \quad L_i^A + L_i^M = L_i \tag{64}$$

$$Y_i^A = \begin{cases} (L_i^A)^\alpha (X)^\beta \text{ if no fertilizer} \\ (L_i^A)^\alpha (X)^\beta (\bar{f} + \tilde{f}_i)^\gamma \text{ if fertilizer} \end{cases} \tag{65}$$

$$\tilde{f}_i > 0 \text{ if net buyer of fertilizer} \tag{66}$$

$$\tilde{f}_i < 0 \text{ if net seller of fertilizer} \tag{67}$$

$$p_t \cdot Y_{it}^A + L_i^M(w_i^M - m) = \mathbb{1}_{\{f_i > 0\}} a + w \cdot L_i^A + \bar{f}(b - t) + \mathbb{1}_{\{L^M > 0\}} c + q\tilde{f}_i \tag{68}$$

The profit functions are the following:

$$\pi_i^A(L_i^A) = \begin{cases} p \cdot Y_i^A - w \cdot L_i^A & \text{if no fertilizer} \\ \rho \cdot \left(p \cdot Y_i^A\right) - \bar{f}(b - t) - q\tilde{f} - a - w \cdot L_i^A & \text{if fertilizer} \end{cases} \tag{69}$$

$$\pi_i^M(L_i^M) = (w_i^M - m) \cdot L_i^M - c \tag{70}$$

The household solutions

	Migrants $L_i^M > 0$	No migrants: $L_i^M = 0$
Fertilizer	$L_i^M = L_i - \left[\left(\frac{\gamma}{q}\right)^{\gamma} \cdot \left(\frac{\alpha}{w+w_i^M-m}\right)^{1-\gamma} \cdot \rho \cdot p \cdot (X)^{\beta}\right]^{\frac{1}{(1-\alpha)\cdot(1-\gamma-\alpha)}}$ $\tilde{f}_i = \left[\frac{\gamma}{q} \cdot \left(\frac{\alpha}{(w+w_i^M-m)}\right)^{1-\alpha} \cdot \left(\rho \cdot pX^{\beta}\right)^{2-\alpha}\right]^{\frac{1}{1-\gamma}} - \bar{f}$	$L_i^M = 0$ $\tilde{f}_i = \left[\frac{\gamma}{q} \cdot \cdot p \cdot \rho(L_i)^{\alpha}(X)^{\beta}\right]^{\frac{1}{1-\gamma}} - \bar{f}$
No Fertilizer	$L_i^M = L_i - \left[\frac{\alpha \cdot \rho \cdot p \cdot (X)^{\beta}}{w+w^M-m}\right]^{\frac{1}{1-\alpha}}$ $\tilde{f}_i = 0$	$L_i^M = 0$ $\tilde{f}_i = 0$

Notes: this table display the analytical solutions of the model with a fertilizer subsidy. It shows the interior solution on the north-west quadrant and the corner solutions on the other quadrants. I display the solutions for the L_i^M and $\tilde{f}_i$. L_i^A is equal to $L_i - L_i^M$.

Table 25: Solutions to the household maximization

Table 25 shows the analytical solutions to the model when there are subsidies available. The first and second rows shows the solutions for households using fertilizers and not using fertilizers respectively; while the first and second columns displays solutions for households with migrants and without migrants respectively.

First and foremost, we see that migration offers a profitable outside option when the price of the crop (p), or the land holdings (X) are low.

The learning externality, represented by ρ, shows that profit in the fertilizer-augmented technology is systematically underestimated and this bias is corrected as adopters (ρ) increases. We thus see that L_i^M is decreasing with ρ.

The subsidy also changes both L_i^M and $\tilde{f}$ via q (through *resale markets*). As q increases, L_i^M increases and $\tilde{f}_i$ decreases. If q is high, the introduction of the subsidy makes the adoption of fertilizers less attractive to households at the margin, as they can get a premium by selling the subsidized fertilizer in resale markets. As q increases, the likelihood of households using the fertilizers in their own farms decreases for households, shifting decisions at the margins. Alternatively, if q is low, households who were at the margin between using the fertilizer technology and using the non-fertilizer technology, would move to the fertilizer technology because of the price distortions.

To summarize, the fertilizer subsidy here plays a complex role in altering the equilibrium allocation of households and individuals to different economic activities. By simultaneously addressing the learning externality and the credit constraints that characterize this environment, the subsidy has the somewhat surprising effect of overcoming multiple market failures and can potentially increase total surplus in the economy.

A.9.3 The social planner's problem

The social planner's problem is to set t at a level that maximizes the aggregate surplus.The planner uses the subsidy lever to increase ρ, the share of farming households using the fertilizer, while limiting the distortion in prices that would incentivize less productive farmers into fertilizer-intensive agriculture. This subsidy takes the form of a transfer t for each unit of fertilizer purchased from the government channel. The upper bound of this transfer is the market price b of the fertilizer, as I further assume that the transfer is not set such that a household pays a negative price for the fertilizer. Finally, I posit that the costs of the subsidy to the economy should not be higher than the gains made by the subsidy in the economy (formalized by the last constraint below). Finally, the social planner does not account for the fact that the household can migrate because regulations often prohibit the use of resale markets. Formally, the social planner's problem is:

$$\max_{t(\rho)} \quad \Pi = \sum_{i=1}^{n} \left\{ \pi_i^A(L_i^{A*}, \rho) \right\} \tag{71}$$

$$s.t. \quad \rho = \frac{1}{n} \sum_i \mathbb{1}_{\bar{f}>0\}} \tag{72}$$

$$0 \le t \le b \tag{73}$$

$$\tag{74}$$

Where n is the number of households in the rural economy and:

$$\pi_i^A(L_i^A, \rho) = \begin{cases} p \cdot Y_i^{A*} - w \cdot L_i^{A*} & \text{if no fertilizer} \\ p \cdot Y_i^{A*} - (b-t)\bar{f} - q\tilde{f}_i - a - w \cdot L_i^{A*} & \text{if fertilizer} \end{cases} \tag{75}$$

which becomes:

$$\pi_i^A(L_i^{A*}, \rho) = \begin{cases} p \cdot Y_i^A - w \cdot L_i \\ p \cdot (L_i)^\alpha (X)^\beta \left(\frac{q}{\rho (L_i)^\alpha (X)^\beta} \right])^{\frac{\gamma}{\gamma-1}} - (b-t) \left[\left(\frac{q}{\rho (L_i)^\alpha (X)^\beta} \right)^{\frac{\gamma}{\gamma-1}} - \tilde{f} \right] - q\tilde{f}_i - a - wL_i \end{cases} \tag{76}$$

The planner's solutions

$$t = b - p \cdot \gamma \cdot (L_i^\alpha \cdot land^\beta)^{2-\gamma} \cdot \left(\frac{\rho}{\gamma} \right)^{1-\gamma}$$

The optimal subsidy is:

- Decreasing with the share of farmers using the fertilizer
- Increasing with the elasticity of fertilizer to agricultural output
- Decreasing with the price of agricultural output
- Decreasing with household size

As the simulations will show, some households will change their labor allocation as a result of the subsidy. Therefore, in the solution to the planner's problem , ρ appears explicitly as a function of t. The social planner's choice of t has an impact on the externality ρ and thus on adoption of the fertilizer technology. There is a trade-off between the distortions through p and b and the efficiency gains from the subsidy that comes via the negative relationship between the externality and the transfer some of the impacts of the externality. Because the planner does not observe households comparative advantages, it must set t independently from individual household's productivities and rely on resale market to improve allocative efficiency.

A.10 Comparative statics and simulations

I compare migration decisions of households with varying comparative advantages.

I first start by showing in Figure 25 the share of the household migrating in equilibrium prior to the introduction of the subsidy. Figure 25 shows that all households have made their optimal decision prior to the subsidy. All households that had a comparative advantage in migrating, and could afford to migrate have migrated. The ones who remain are the ones that either could not migrate because they couldn't afford it, or those who had a comparative advantage in agriculture, either using fertilizers or not.

In Figure 26, I show what happens to migration decisions in a household that has a comparative advantage in migrating. We see that the decision primarily depends on the profitability of selling the subsidized fertilizer on a secondary markets. If the household can cover all of its relocation costs by selling its fertilizer on the resale markets of fertilizers, then the whole household migrates. If q is too small, nobody in the household migrates. For values of q that are large enough but not too large, the household is able to afford to send some of its household members to outmigrate. The share of household members who migrate is proportional to the price of the fertilizer on the secondary market relative to the cost of migrating.

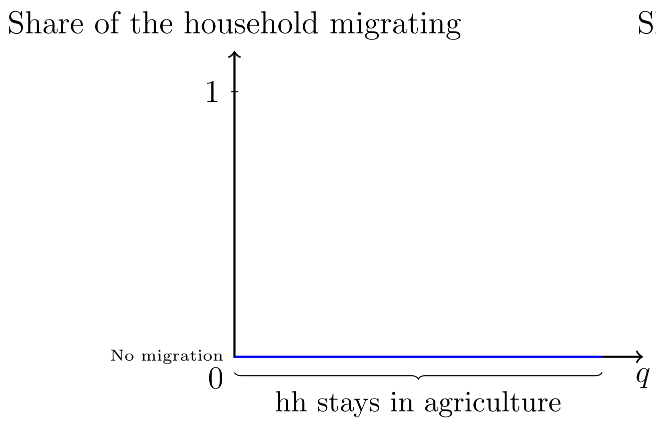


Figure 25: Prior to subsidy

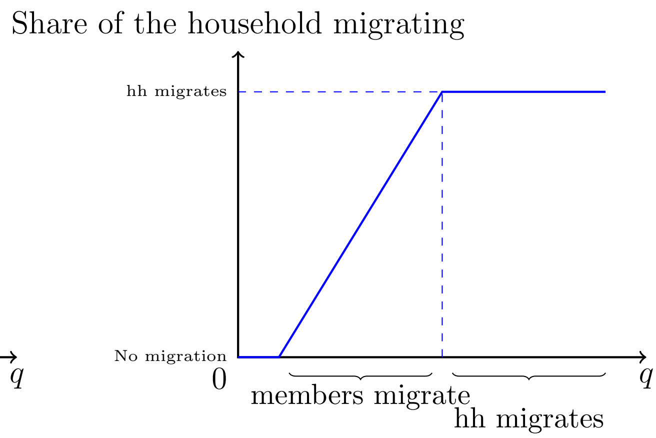


Figure 26: Comparative Advantage in Migration

In Figure 27, we see that households that have a comparative advantage in the non-fertilizer or traditional agriculture technology do not migrate. They would generate income by selling fertilizers on secondary markets, but as we saw earlier, their decision to migrate does not depend on q. They migration decision is thus left unchanged by the subsidy under this framework.

In Figure 28, the household has a comparative advantage in the fertilizer technology. In this setting, with very low q, the household stays and hosts inmigrants (the only margin to increase the labor supply within the household under imperfect labor markets) to help with the production. This feature stems from the complementarity between labor and fertilizers for the household (Beaman et al., 2013). The household decision is a corner solution where all its labor is allocated to the fertilizer technology. As q gets smaller, the household budget constraint is relaxed and it can hire labor absent members of the household. In this analysis, I assume that households do not hire labor except by hosting in-migrants. This corresponds to the real-world observation that small rural farms tend to rely heavily on family labor (Rosenzweig, 1988). As q increases however, migration becomes more attractive and the household start allocating members to migration. We thus see that for high values of q the household either engages in traditional agriculture or migrates depending on its productivities.

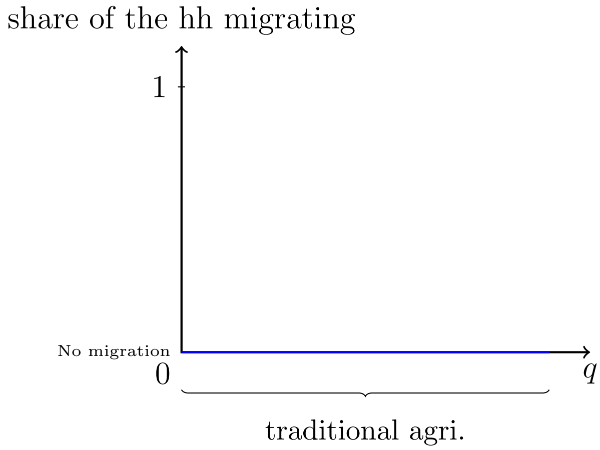


Figure 27: Comparative Advantage in Traditional Agriculture

High ν_i^N and low μ_i and ν_i^F

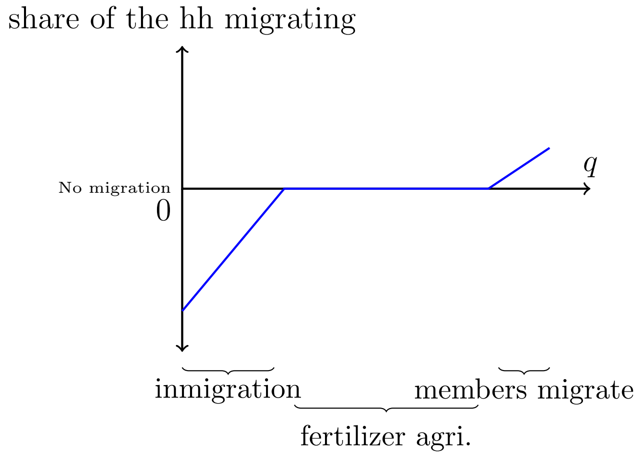


Figure 28: Comparative Advantage in Fertilizer-Augmented Agriculture

High ν_i^F and low μ_i and ν_i^N

Simulations of the model

I next show numerical solutions for households with varying initial endowments. For each of 100 households, I plot the changes in the allocation of labor across the fertilizer agriculture, the traditional agriculture, and migration. I show the aggregated plots of all 100 households in Figure 29. These figures are static, meaning that there is no feedback loop or general equilibrium effect: i.e. each household is a price taker and takes as given the share of households using the fertilizer ρ, the subsidy t and the resale price q. The household then chooses its labor allocation and transaction on resale markets. We see on the left pane of Figure 29 that as the number of fertilizer users increases, the number of labor units allocated to the fertilizer-augmented technology increases substantially, due to the externality. In the middle pane, we notice that as the subsidy increases, in aggregate, households allocate more labor to the fertilizer agriculture.

There is a substantial heterogeneity in household allocative decisions, as shown for the four example households in Figure 30. Each row of Figure 30 shows the change in labor allocation on the y-axis as a result of changes in the share of fertilizer adopters (row 1), the size of the subsidy (row 2) and the resale price (row 3). Each column reports the

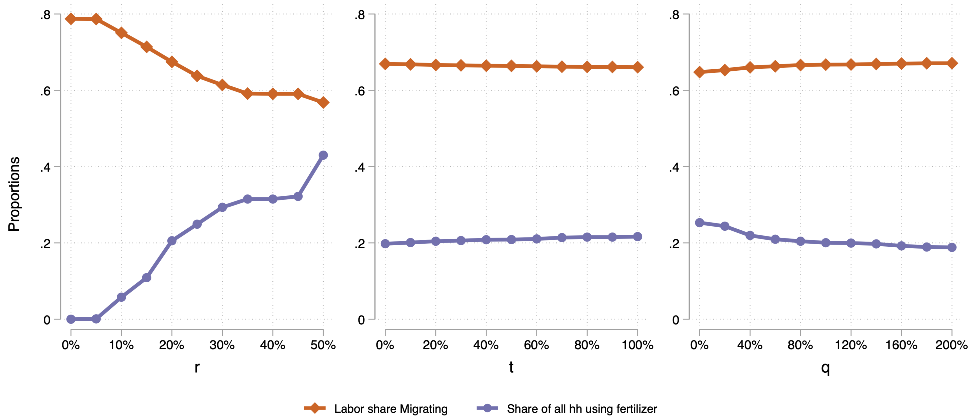


Figure 29: Simulations of labor allocation as a function of ρ, transfer and resale prices

allocation decision of one household with a particular comparative advantage. The first column shows a household that has a comparative advantage in the fertilizer agriculture, and does well in migrating. This household reacts to both an increase of the share of households using the fertilizer and an increase in the subsidy by allocating more members to the fertilizer agriculture and away from migration. Columns 2, 3 and 4 respectively have a comparative advantage in the fertilizer agriculture, the traditional agriculture and migration. When the comparative advantage of the household is in migrating, or in the traditional agriculture, the allocation in those two activities increases with the resale price of the fertilizer in parallel markets (see Columns 3 and 4). Universally, an increase in the share of farmers adopting the fertilizer increases the labor share allocated to the fertilizer agriculture in farming households.

As expected, changes in resale prices change the allocation of labor away from the fertilizer agriculture and the comparative statics plots 28, 27, and 26 are replicated in the last row of of Figure 30 in column 1, 3 and 4 respectively.

Marginal fertilizer CA* | Fertilizer CA | Traditional CA | Migration CA

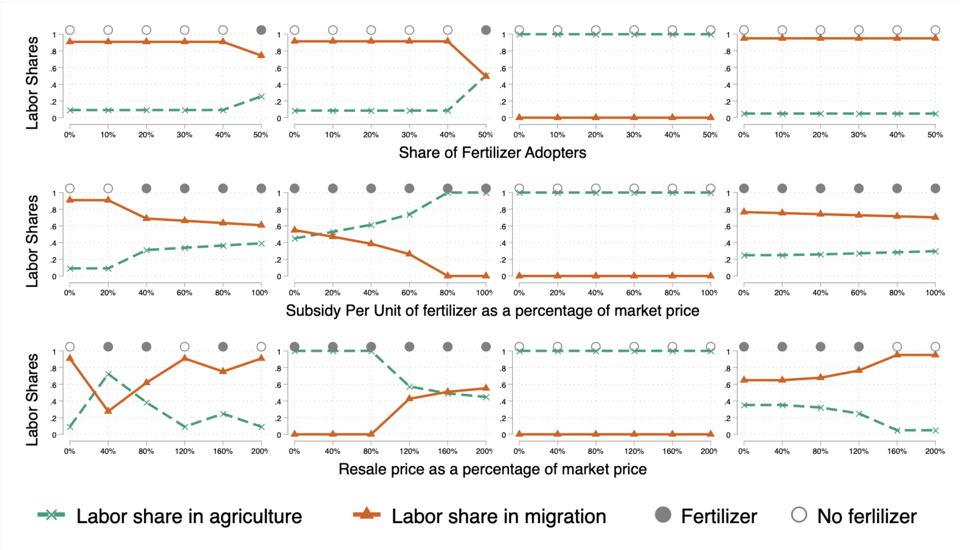


Figure 30: Four households with different comparative advantages

* CA: Comparative Advantage.
Figure generated using artificial data in order to show the heterogeneity of households decisions over labor allocation

Table 26: Values used in the simulations for the variables of the model

	Variables Plotted			Fert. quantity	Ag. costs			Mig. costs		Agricultural technologies				
Simulations	ρ	t^*	q^*	$\bar{f}$	b	a	w	m	c	x	y	z	α	β
ρ (fig. 29, left)	-	40%	100%	2	5	5	.5	1	.5	.5	.75	.5	1	1.5
t (fig. 29, center)	.3	-	100%	2	5	5	.5	1	.5	.5	.75	.5	1	1.5
q (fig. 29, right)	.3	40%	-	2	5	5	.5	1	.5	.5	.75	.5	1	1.5

* Percent of original unsubsidized price b.
Notes: The optimization are made over the values l_N, l_M, l_F, and $\tilde{f}$, which total quantity of fertilizer . The land endowment for the 100 households follows a normal distribution of mean 3 and variance 2. The migrant productivity is follows a normal distribution of mean 9 and variance of 5. When the values are negative, the endowment is equal to its absolute value. The household size is a normal distribution, with an absolute value transformation to avoid negative household sizes.