Temporary Subsidies and the Adoption of Green Revolution Technologies by Mozambican Farmers and Their Social Networks

Michael Carter, Rachid Laajaj, Dean Yang

The "Green Revolution", which reshaped agriculture across Asia and Latin America during the last four decades of the 20th century, largely bypassed sub-Saharan Africa. Adoption of high-yielding seeds and chemical fertilizers led to rapid growth of agricultural yields in Asia and Latin America. In contrast, in sub-Saharan Africa, the modest growth in agricultural production that did occur was driven by land expansion, with little technological change, nor yield growth (Evenson and Gollin, 2003). While Green Revolution technological change allowed the rest of the developing world to take-off economically, sub-Saharan Africa has become the repository of an ever-larger share of the world's severely poor people. Twenty-five years ago, 17% of the world's absolutely poor lived in sub-Saharan Africa. Since that time, that figure has risen to 51% (World Bank, 2018).

In response to the Green Revolution that wasn't, African nations signed the Maputo Declaration in 2003, pledging to invest 10% of their national budgets in agriculture in order to achieve a 6% annual rate of agricultural growth. The aptly named Alliance for a Green Revolution in Africa (AGRA) was launched in 2006, led by former UN Secretary-General Kofi Annan. A number of countries subsequently introduced (or revived) input subsidy programs to prompt the adoption of the Green Revolution technologies that drove the economic take-off of other regions. These second-generation input subsidy programs were supposed to be "smart" in the sense that they did not (i) inhibit the development of private input markets; (ii) did not simply replace fertilizer that farmers were going to purchase without subsidies; and, (iii) be temporary. Input subsidy programs are now consuming substantial resources across the continent. While not all African nations have reached the Maputo Declaration budget targets, 20-25% of public spending on agriculture (nearly US$1 billion annually) seems permanently devoted to input subsidy programs.[1]

The magnitude and opportunity cost of these expenditures raises questions about the economic wisdom of these programs: Why subsidize a putatively profitable private investment good in the first place? What market failures, if any, are subsidies helping to address?

This latter question on market failures is of particular importance, as the answer suggests what the optimal policy response might be. For some market failures, subsidies are not the obvious policy response. For example, if poor farmers are unable to either finance the purchase of the technology or bear the additional risk technology adoption implies, then perhaps policy should facilitate markets for financial services (*e.g.*, credit, insurance, or savings) rather than providing subsidies.[2] On the other hand, an informational market failure (say, imperfect information on the returns to the technology) can be addressed by subsidies that overcome individuals' reluctance to risk their own money to generate the public good of information about the local profitability of new technologies. Note, however, that this information market failure argument only justifies temporary subsidies that can be removed once induced adopters learn the true returns to the technology. On the other hand, if technology adoption is inhibited by

[1] Jayne et al., 2018.

[2] Formation of rural financial markets is not easy, and subsidies for a short period of time that allow farmers to earn (and save) the full gross returns to technology could help farmers escape the kind of low technology poverty trap described by Dorward *et al.* (2008).

persistent behavioral biases such as present-bias or procrastination, permanent subsidies may be called for.

We present results from a randomized controlled trial in Mozambique designed to determine if temporary input subsidies can spur learning and lasting adoption of improved technologies, not only by direct subsidy recipients, but also by their neighbors. This study is among only a few other randomized studies of a production technology subsidy (Duflo et al. 2011). In this context, ours is the first randomized study designed to directly measure participants' estimates of the technology's productive impacts, and to assess spillovers in the social network of subsidy beneficiaries. Also distinctive, relative to most of the existing literature, is our examination of persistence of technology adoption beyond the subsidized season, when farmers would have to pay full price for the inputs.

We report the results of a randomized controlled trial we conducted in collaboration with the government of Mozambique and the International Fertilizer Development Center. We randomly assigned individual farmers vouchers for a generous subsidy for fertilizer and improved maize seeds. With the aim of determining the feasibility of a national agricultural input subsidy program, the government of Mozambique had embarked on a donor-funded pilot input subsidy program across 25,000 farmers in five provinces. To properly study impacts and social network spillovers, the government agreed to collaborate with us to randomly assign vouchers to maize farmers in one province, Manica. Governmental agencies distributed the vouchers. Our (the research team's) responsibility was to randomly assign vouchers to farmers from a larger list of eligible farmers provided by the government's extension services, to supervise the distribution to ensure compliance with randomization, and to collect survey data on outcomes. This study thus also has the merit of reflecting the impacts of a program as it was actually implemented by local authorities (specifically, the government's agricultural extension agency), rather than one implemented by researchers that may not be reflective of how programs are normally implemented in the local context.

The technology package was designed for maize production. The subsidy was for a 73% discount on an input package composed of 100 kg of chemical fertilizer and 12.5 kg of improved maize seeds, and was valid for only one use in the 2010-11 agricultural season. The sample consists of 514 farmers; 247 were randomly selected to receive a voucher and 267 were in the control group. We tracked study participants' use of fertilizer and seeds in the subsidized season, and for two annual agricultural years afterwards (2011-12 and 2012-13). We also collected data on social network connections (by asking each participant whether they discussed agriculture during the season that preceded the intervention, with each other study participant in their village).[3] The subsidy was assigned randomly, so holding constant the size of one's social network, the extent to which members of one's social network received the subsidy was also random. We are therefore able to establish the causal impact of the subsidies on a beneficiary's own technology adoption over time, and on adoption by the social network contacts of subsidy beneficiaries. Importantly, we also examine impacts on study participants' agricultural production, consumption and knowledge related to the return of the subsidized package.

To estimate these direct and spillover effects of the voucher coupons, we estimate the following regression model:

[3] This methodology follows Conley and Udry (2010).

$$y_{ict} = [\alpha_d V_{ic} T_d + \alpha_a V_{ic} T_a] + [\sigma_d^n S_{ic} T_d + \sigma_a^n S_{ic} T_a] + [\sigma_d^b S_{ic} T_d + \sigma_a^b S_{ic} T_a] \quad (1)$$
$$+ X_{ict}\gamma + \alpha_c + \varepsilon_{ict}$$

where y_{ict} is an outcome variable for household *i* in community *c* in time period *t*, V_{ic} is a binary indicator variable that takes the value of 1 for households randomly assigned to receive voucher coupons, T_d is a binary variable that takes the value 1 for observations during the voucher period, T_a is the same for the observations for the two post-subsidy time periods and S_{ic} is a binary variable indicating households who have two or more baseline information neighbors who received vouchers (a baseline information neighbor is an individual with whom the respondent reported regularly discussing agricultural issues prior to the intervention). The terms on second line of equation (1) are control variables[4] and error components. The α_t parameters in the first square brackets capture the direct effects of voucher on recipient behavior. The σ_t^n parameters in the second set of brackets are the spillover impacts on non-recipients who are socially connected to voucher recipients, while the σ_t^b parameters in the third brackets are network-mediated spillover impacts from one voucher recipient to another.

Table 1 presents the estimated impact coefficients from regression (1) for a variety of variables.[5] Figure 1 graphically presents a restricted version of those results in which the two sets of spillover coefficients (the σ_t^n and σ_t^b) are restricted to be the same. The first column of graphs displays the during and after direct ITT treatment effects on voucher recipients, while the second displays average spillover effects for individuals' with two or more information neighbors who received vouchers. As can be seen, during the voucher period, vouchers directly induced substantial experimentation with green revolution inputs of improved maize seeds and fertilizers, with use of those inputs rising by approximately 37% and 83%, respectively. Immediate yield impacts are statistically insignificant, at least for socially disconnected voucher recipients who lacked information neighbors who also received voucher coupons.

While experimentation with highly subsidized inputs is perhaps not surprising, the more interesting question is what happened in subsequent seasons in which farmers had to pay full market price for the green revolution technology. As can be seen in Table 1 and Figure 1, direct impacts continued in the two seasons after the voucher subsidy crop year. Fertilizer and seed use rates drop compared to the subsidy period, but yield impacts become significant. Voucher farmers also experienced a statistically significant 7% increase in living standards as measured by a standard consumption expenditure questionnaire module. This continued use of inputs despite their price increase compared to the subsidy period can be explained by the fact that voucher recipients report increased subjective returns to green revolution technology following the subsidy year of experimentation.

Information about the returns to improved seeds and fertilizer is not a rival good and we naturally ask whether the subsidized learning by voucher recipients spilled over and influenced neighboring farmers. Spillovers are often thought of as impacts that affect individuals who did not receive the direct treatment. The middle panel of Table 1 displays these impacts.

[4] X_{vit} is a set of dummies for each possible combination of year and size of the network (pooling together respondents with 5 or more persons in social network). They are included in order to control for an effect of the network size which can vary over time.
[5] Say something about robustness of findings to dummy variable and level estimates

Unsurprisingly, there are no spillover impacts from voucher recipients to non-recipients during the subsidy season. However, in the two subsequent seasons we find that non-recipients who had two agricultural information neighbors that received vouchers substantially altered their behavior, with large increases in use of fertilizer, improved seeds (not statistically significant), maize yields and total agricultural production. For these farmers, expected returns to the green revolution package rose by 44% compared to socially disconnected non-voucher farmers.

In addition to these spillovers to non-voucher recipients, we also estimate substantial spillovers between voucher recipients. The spillover impacts on voucher recipients are shown in the bottom panel of Table 1. Supplementary Table XX shows that the combined direct and spillover effects for socially connected voucher recipients are larger during the voucher period (with fertilizer use rising by more than 100%, seed use by 85% and yields increasing by 48%, all statistically significant). These contemporaneous effects suggest that farmers helped each other experiment more effectively with the novel technologies, a perhaps not surprising result given that the voucher program was not supported by strong agricultural extension information. More impressively, the after-year impacts for socially connected voucher recipients are strong and statistically significant compared to socially disconnected control group members (100% increase in fertilizer use, 50% increase in use of improved seeds, 60% yield increases, 60% increase in expected returns to the technology and a 23% increase in consumption). While these numbers are large, they are in line with the experience of the green revolution elsewhere and are in fact somewhat modest relative to the program implementers who felt farmers should be able to triple their yields with the correct technology.[6]

The magnitude and nature of these direct and spillover impacts suggest that this kind of temporary voucher program can spur learning and be a cost-effective intervention in areas like Mozambique where the typical smallholder farmer has little experience with modern agricultural inputs. Using our estimates in Table 1, we can decompose both the direct and spillover benefits that occurred in voucher and post-voucher agricultural seasons.[7] Specifically, we calculate the present value of benefits, *B*, using the estimated coefficients reported in Table 1 as:

$$B = \left[\hat{\alpha}_1 + \sum_{t=1}^{2} \beta^t \, \hat{\alpha}_2 \right] + \lambda^n [\hat{\sigma}_1^n + \sum_{t=1}^{2} \beta^t \, \hat{\sigma}_2^n] + \lambda^b [\hat{\sigma}_1^b + \sum_{t=1}^{2} \beta^t \, \hat{\sigma}_2^b] \qquad (2)$$

where β is the discount factor and $\lambda^n = 0.78$ is the number of non-beneficiary households per-voucher household who have two or more social links to voucher households. The term $\lambda^b = 0.78$ is the same statistics for beneficiary households.

The top panel of Table 2 displays the decomposition of benefits. As can be seen, 73% of the total benefits occur through spillover impacts, with most of those occurring in the two post-voucher seasons. In other words, estimated gains are more than four-times larger when considering social network spillovers than when focusing only on direct beneficiaries. All told, 76% of benefits occur in the years after the subsidy ended.

[6] Converting our ITT to TOT estimates moves us in the direction of the more general green revolution expectations.
[7] We set coefficients that are statistically insignificant to zero. Impacts are counted as the impact on total agricultural production. When those impacts were statistically insignificant, we used estimated impacts on maize production, if that estimate was significant.

The bottom panel of Table 2 normalizes these benefits by the total direct cost of the voucher program. Cost estimates incorporate the cost of the subsidies, beneficiary co-pay amounts, and the cost of subsidy voucher distribution. See Supplementary Materials for further details. While these benefit-cost ratios are large, it is important to note that the vouchers allowed farmers to learn about and benefit from two prior investments, the costs of which we do not include in the Table 2 benefit-cost ratios. The first of these investments is simply the creation and adaptation of improved maize seed varieties appropriate for Mozambique. The second is a program that built up a network of agro-input dealers, making the technology more accessible to the farmers.[8]

In sum, we find evidence that the subsidy alleviates two kinds of market failures related to information. First, the subsidy alleviates *imperfect information* on the part of farmers receiving the technology – they raise their assessments of the technologies' productive impacts, such that they continue to show increased usage in two subsequent years (when no subsidy was provided).[9] In addition, we find evidence of an *information externality*: information spills over from subsidy beneficiaries to their social network contacts, leading these contacts to themselves raise their use of the technologies, and also report higher estimates of the technologies' productive benefits.

This study was done in a particular context and time period, and, as with all empirical work, additional studies should be done in different contexts to determine the external validity of the findings. But as it stands, our study highlights previously-underemphasized benefits of subsidy programs. We provide the first evidence based on a randomized controlled trial that the vast majority of gains from subsidies for Green Revolution technologies actually derive from social network learning spillovers (positive information externalities). Direct benefits for subsidy winners themselves account for just a minority of gains. A further key result it that the vast majority of gains accrue in years after the subsidy has ended, due to learning that persists after the subsidized period. These results suggest that the gains from Green Revolution subsidy programs that are widespread and expanding in Sub-Saharan Africa are perhaps actually underestimated, to the extent that they focus only on the direct benefits for subsidy recipients in the periods they are receiving subsidies, and ignore social network informational spillovers and persistent benefits in future unsubsidized years.

Finally, there is much yet to be learned about how to best design temporary voucher subsidy programs. Actual redemption of the vouchers was a bit less than 50%, with the vast majority of those who did not redeem the vouchers reporting that they lacked the cash to make the co-payment for the voucher. Better understanding these constraints is important not only to enhancing the efficacy of the program, but also to avoid perpetuating initial disadvantage. For example, we know that agricultural learning networks are often gender-specific (Beaman and Dillon, 2018). If women farmers tend to be more cash constrained than men, then an intervention that bypasses women as direct beneficiaries will also cut out women's social networks, effectively reserving the potentially large spillover benefits for men farmers alone. In

[8] Prior to the implementation of the agro-dealer development program, the average Mozambique maize farmer was 100 km away from an agro-dealer. In our study area, this program substantially reduced this distance (get more detail from IFDC).

[9] Similar results were found in the health literature by Dupas (2014)

the spirit of BenYishay and Mobarak (2018), there is also much to be learned about how to best target vouchers so as to maximize social spillover effects.

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Table 1: Estimated Impacts of Voucher Coupons on Input Use, Production & Consumption

Outcome Variables (In Logs)		*Green Revolution Input Use & Expected Returns*				*Production & Consumption*		
		Fertilizer on Maize	Fertilizer on All Crops	Improved Seeds	Expected Yield with Technology	Maize Yield	Production of All Crops	Consumption
Direct Impacts on Voucher Recipients	During, α_d	0.83*** [0.24]	0.69*** [0.26]	0.37* [0.21]	0.11 [0.10]	0.11 [0.11]	-0.20** [0.097]	0.0028 [0.057]
	After, α_a	0.31* [0.16]	0.32* [0.17]	0.055 [0.15]	0.18** [0.086]	0.12 [0.082]	0.067 [0.081]	0.073* [0.039]
Spillover Impacts on Non-Voucher Recipients	During, σ_d^n	0.33 [0.31]	-0.051 [0.45]	0.16 [0.30]	-0.012 [0.18]	0.12 [0.17]	-0.090 [0.19]	0.14 [0.10]
	After, σ_a^n	0.75*** [0.24]	0.54 [0.34]	0.33 [0.25]	0.44** [0.17]	0.33* [0.17]	0.48*** [0.15]	0.11 [0.076]
Spillover Impacts on Other Voucher Recipients	During, σ_d^b	0.19 [0.35]	-0.34 [0.48]	0.47 [0.35]	0.11 [0.17]	0.37** [0.17]	0.37* [0.20]	0.17 [0.11]
	After, σ_a^b	0.72** [0.31]	0.54* [0.30]	0.44* [0.24]	0.40** [0.19]	0.47*** [0.18]	0.68*** [0.16]	0.16 [0.099]
Observations		1428	1413	1404	1273	1346	1357	1393

Notes: The control variables are village fixed effects and a set of dummies for each possible combination of year and size of the network (pooling together values of 5 or more persons in social network). Robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table 2: Direct and Spillover Impacts of the Voucher Program

	Subsidized Year	*2 years following subsidy*	*Totals*
Benefits			
Direct Benefits to Voucher Recipients	2,963	5,928	8,891
Total Spillover Benefits to Non-voucher and Voucher Recipient Households	4,775	18,854	23,629
Total Impacts	7,738	24,782	32,520
[% Due to Spillovers]	[62%]	[76%]	[73%]
Benefit-Cost Ratios			
Direct Impacts Only	1.6	3.2	4.9
Spillover Benefits Only	2.6	10.3	12.9
Total Benefits	4.2	13.5	17.8

Benefits are calculated using equation (2). The estimation of the costs sums (i) the cost per capita of the listing and distribution of vouchers; (ii) the costs of the voucher (net of what is disbursed to treatment group compared to control group); and, (iii) the additional contribution of the farmer to complete the 73% subsidy (also net of treatment versus control group).

Figure 1: Point and 95% Interval Estimates of Direct and Spillover Impacts of Vouchers

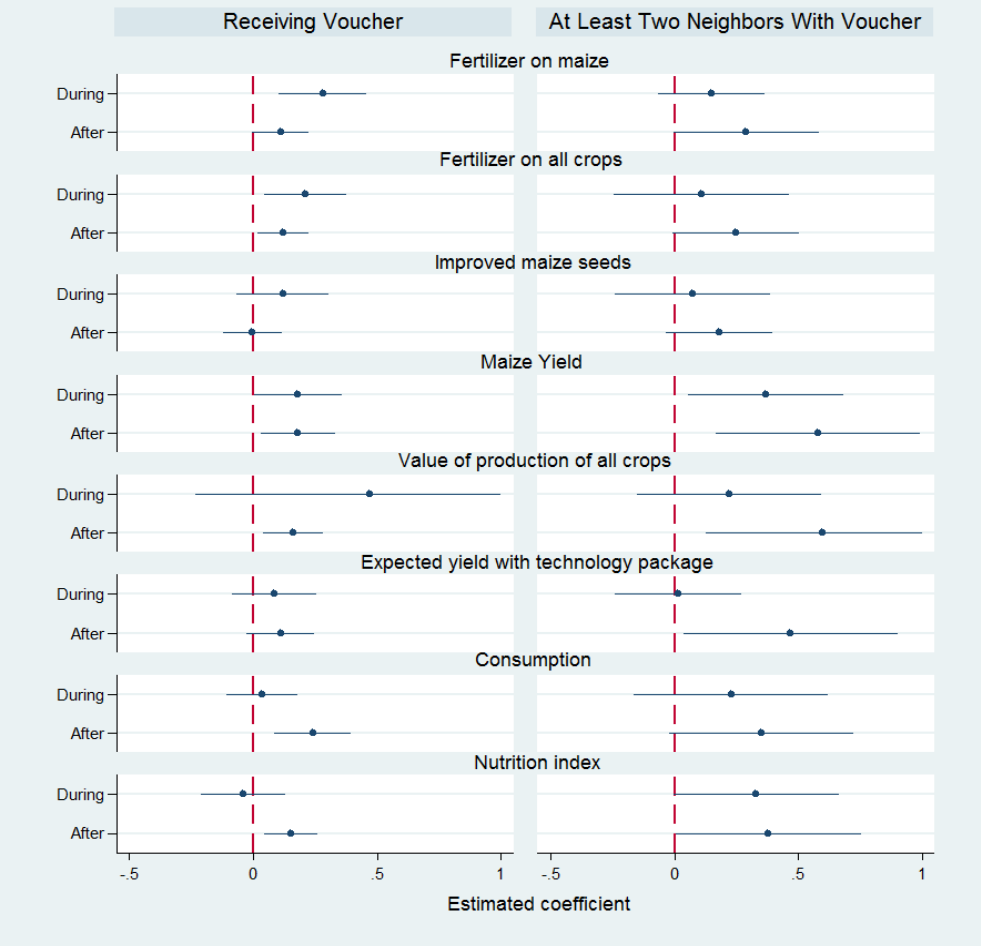


Figure 1 is based on a restricted version of equation (1) in which the spillover benefits to voucher and non-voucher recipient households are constrained to be the same.