Estimating the Enduring Effects of Fertiliser Subsidies on Commercial Fertiliser Demand and Maize Production: Panel Data Evidence from Malawi

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(Original submitted September 2015, revision received February 2016, accepted March 2016.)

Abstract

Most studies of input subsidy programmes confine their analyses to measuring programme effects over a one-year period. This article estimates the potential longer-run or enduring effects of fertiliser subsidy programmes on smallholder farm households’ demand for commercial fertiliser and maize production over time. We use four waves of panel data on 462 farm households in Malawi for whom fertiliser use can be tracked for eight consecutive seasons between 2003/2004 and 2010/2011. Panel estimation methods are used to control for potential endogeneity of subsidised fertiliser acquisition. Results indicate that farmers acquiring subsidised fertiliser in three consecutive prior years are found to purchase slightly more commercial fertiliser in the next year. This suggests a small amount of crowding in of commercial fertiliser from the receipt of subsidised fertiliser in prior years. In addition, acquiring subsidised fertiliser in a given year has a modest positive impact on increasing maize output in that same year. However, acquiring subsidised fertiliser in multiple prior years generates no statistically significant effect on maize output in the current year. These findings indicate that potential enduring effects of the Malawi fertiliser subsidy programme on maize production are limited. Additional interventions that increase soil fertility can make using inorganic fertiliser...
more profitable and sustainable for smallholders in sub-Saharan Africa and thereby increase the cost-effectiveness of input subsidy programmes.

Keywords: Enduring effects; fertilisers; input subsidies; maize; Malawi; sub-Saharan Africa.

JEL classifications: Q12, Q18.

1. Introduction

Input subsidy programmes have re-emerged in recent years as major components of agricultural development and food security strategies in many sub-Saharan African (SSA) countries. An important rationale for the revival of subsidies for inorganic fertiliser and improved seeds is that they can help poor smallholder farm households break out of a low input/low output poverty trap (Dorward et al., 2004; Denning et al., 2009; Sachs, 2012). This literature argues that subsidising fertiliser for farmers over time can kick start growth processes that sustainably raise incomes and food security. However, to our knowledge this argument has yet to be fully tested or verified empirically.

We address whether or not the benefits of receiving subsidised fertiliser last only one season or whether they are of a more enduring nature. If the benefits of fertiliser subsidies are found to be one-off, lasting only one season, such programmes may still be useful and financially sustainable if the contemporaneous benefits outweigh the costs. However, if the benefits last only one season, then the assertion that subsidising farmers’ fertiliser use over time will put them on a trajectory of sustained production growth and wealth accumulation would not be supported. Conversely, if receipt of subsidised inputs in prior years has enduring longer-run impacts on households’ staple crop production, then this would give greater support for the argument that subsidies can launch sustained and enduring growth processes.

We use four rounds of household-level panel data from Malawi collected between 2003/2004 and 2010/2011 to estimate the enduring or longer-run impacts of input subsidies on commercial fertiliser demand and maize production. In doing so, two key hypotheses can be tested surrounding input subsidies in SSA that have not been fully addressed by the growing literature on the topic. Hypothesis 1 is that households who acquire subsidised fertiliser in consecutive prior years do not purchase significantly more fertiliser on the commercial market in the future than they would otherwise. Hypothesis 2 is that households who acquire subsidised fertiliser in consecutive prior years do not produce significantly more maize in the future than they would otherwise.

These hypotheses are interrelated because if input subsidy programmes are going to help households sustainably break out of a cycle of poverty then recipient households must use fertiliser more effectively to build up nutrients in the soil, and they must obtain the resources to purchase fertiliser at commercial prices in subsequent years. Hypothesis 1 directly tests how subsidised fertiliser crowds out or crowds in commercial fertiliser use over time. Previous studies investigating crowding out/in of

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2 Crowding out occurs when households that acquire subsidised fertiliser use it in place of commercial purchases that they otherwise would have made. Crowding in occurs when households that acquire subsidised fertiliser purchase additional commercial fertiliser.

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commercial input demand from input subsidy programmes have examined the issue as a static, current year phenomenon (see Xu et al., 2009; Ricker-Gilbert et al., 2011; Mason and Jayne, 2013; Liverpool-Tasie, 2014; and Takeshima and Nkonya, 2014; for fertiliser crowding out/in, and Mason and Ricker-Gilbert, 2013 for seed crowding out/in). All of these studies find significant crowding out of commercial inputs from subsidy programmes in the current year. The exception is Liverpool-Tasie who finds some evidence of crowding in of commercial fertiliser during a pilot subsidy programme in Nigeria. However, the present article is the first to investigate this issue in a longer-run framework to determine whether households that acquired subsidised fertiliser in the past purchase more or less commercial fertiliser in subsequent years.

Hypotheses 2 is tested by adapting a conceptual framework from the job-loss, and job-training literature. We follow Ashenfelter (1978) and Jacobson et al. (1993) to estimate a distributed lag model where current year and past year quantities of fertiliser enter as covariates in a model of maize production. Most previous studies estimate only the current year impact of subsidised fertiliser on maize production (Holden and Lunduka, 2010; Chibwana et al., 2014; Mason et al., 2015). The general finding from empirical studies that use recently collected household-level data in SSA is that input subsidies make a statistically significant, but relatively modest contribution to maize production in the current year. To our knowledge the only other study to investigate the enduring effect of input subsidies in SSA is by Carter et al. (2014) in Mozambique. Households in that study are randomly given vouchers allowing them to purchase subsidised fertiliser and seed at a reduced price in 1 year. The authors find that receiving the voucher contributes to household maize production and income in the current year, and for two additional years.

We extend the literature on input subsidies in several main ways. First, as mentioned we estimate longer-run crowding in/crowding out of commercial fertiliser by the subsidy. Second, we use four waves of panel data with 8 years of information on fertiliser use to investigate the channels through which input subsidies can affect maize production over a relatively long period of time. Third, we measure the effect of acquiring subsidised fertiliser in multiple prior years. This is an important contribution because most input subsidy programmes in SSA almost always last for multiple years, so participant households often acquire the benefit more than once.

Malawi is an important case study of input subsidy programme impacts because since 2005/2006 the country has scaled up a large targeted subsidy programme where the government distributes vouchers to selected farmers who meet certain criteria. Under this programme, the targeted farmers can then redeem the vouchers in exchange for fertiliser and improved maize seed at a reduced price. The programme received popular acclaim in a front-page New York Times article (Dugger, 2007) and is widely perceived as a litmus test for other countries in SSA. However, between 5% and 16% of government spending in Malawi since 2005/2006 has gone to funding input subsidies. Given the major cost and opportunity cost involved, policy-makers need to understand the potential enduring effects of fertiliser subsidy programmes on the lives of recipients.

When evaluating the impacts of fertiliser subsidies, it is essential to understand that they are not distributed randomly, so dealing with this issue is a major part of our modelling effort. We use panel estimators to deal with potential endogeneity that could be caused by omitted variable bias.

The rest of the article is organised as follows: A brief background on input subsidies in Malawi is provided in the next section, followed by discussion of data and survey
design. We then present the conceptual framework, empirical methods and identification strategy. Subsequent sections present the results and conclusions.

2. Input Subsidies in Malawi

Input subsidy programmes have existed in almost every agricultural year for decades in Malawi. Prior to 2005/2006 a relatively small subsidy programme called Starter Pack and then called the Targeted Input Subsidy Programme (TIP) were in place. After experiencing a drought-affected poor harvest in 2004/2005, the Government of Malawi decided to greatly expand the scale of its targeted fertiliser subsidy programme in 2005/2006 to promote maize and tobacco production. The programme was originally named the Agricultural Input Subsidy Programme (AISP) and later the Farm Input Subsidy Programme (FISP). Table 1 presents the quantity of subsidised fertiliser and maize seed along with programme costs for every year between 2002/2003 to 2010/2011, the years that pertain to the data used in the present study. Row 1 of the table shows how the quantity of subsidised fertiliser and seed distributed to smallholders in Malawi increased dramatically in 2005/2006 and continued to climb to 202,000 metric tons in 2008/2009 before declining to 161,000 metric tons in 2009/2010 and 2010/2011.

Farmers were allowed to acquire subsidised fertiliser from private sector retailers during the 2006/2007 and 2007/2008 growing season. Six private firms won the right to procure and distribute subsidised fertiliser through their retail networks. Row 2 of Table 1 shows the amount of subsidised fertiliser sold by the private sector over the nine relevant seasons. Farmers who received coupons could redeem them at participating retail stores along with their required contribution to obtain their fertiliser. Retailers would then submit the coupon and receipt to the government for payment. The private sector has been excluded from distributing subsidised fertiliser since 2008/2009, but has been involved in the distribution and retailing of subsidised maize seed. Row 3 of Table 1 shows the quantity of maize seed that was included as part of the subsidy programme from 2006/2007 onwards. Farmers could choose between hybrid and open pollinated varieties (OPV) of improved maize seed.

Row 4 of Table 1 also illustrates how the level of required beneficiary contribution to the FISP declined from 36% of the total cost in 2005/2006 to 7% in 2010/2011. Subsidised maize seed has always been available free of charge to participating farmers other than in 2005/2006, when maize seed was not part of the programme. Row 5 of the table also shows how the total cost of FISP increased between 2005/2006 and 2008/2009. Costs reached a high of USS 241 million (row 5) and 16.2% of the national budget in 2008/2009 (row 6), as global fossil fuel prices (which are used to make inorganic fertiliser) skyrocketed. Programme costs declined in subsequent years as fossil fuel prices retreated towards earlier levels. Most of the bill for the subsidy programme was paid by the Malawian government, with direct budget support from donors, while the rest was paid directly by the UK’s Department for International Development (DFID). (For more background information on Malawi’s FISP, see Chirwa and Dorward (2013) and Lunduka et al. (2013)).

Officially each household who participates in FISP is eligible to receive two coupons, each good for one 50-kg bag of fertiliser at a discounted price, and a coupon that can be redeemed for between 5 and 10 kg of improved maize seed. In reality, the actual amount of subsidised fertiliser acquired by households varied greatly. Key informants and anecdotal evidence in Malawi indicate that fertiliser retailers may...
Table 1
Subsidised input supply and cost by year in Malawi (2002/2003–2010/2011)

| Year       | 2002/03 | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 | 2008/09 | 2009/10 | 2010/11 |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1) Total new subsidised fertiliser supplied (’000 metric tons)* | 35      | 22      | 54      | 131     | 175     | 217     | 202     | 161     | 161     |
| 2) Subsidised fertiliser sold at private retailers (’000 metric tons)* | 0.00    | 0.00    | 0.00    | 0.00    | 17.43   | 24.53   | 0.00    | 0.00    | 0.00    |
| 3) Subsidised maize seed supplied (’000 metric tons)* | 4.0     | 3.4     | 10.0    | 0.00    | 4.5     | 5.5     | 5.4     | 8.7     | 10.7    |
| 4) Percentage of total fertiliser cost paid by farmers* | 0.00    | 0.00    | 0.00    | 36      | 28      | 21      | 9       | 12      | 7       |
| 5) Total recorded program costs in ’000,000 USD (less farmer redemption)† | N/A     | N/A     | N/A     | 32.00   | 73.90   | 107.26  | 241.68  | 108.49  | 143.57  |
| 6) Program cost as percentage of national budget† | N/A     | N/A     | N/A     | N/A     | 6.8%    | 8.2%    | 16.2%   | 6.5%    | 8.0%    |

Notes: *From Mason and Ricker-Gilbert (2013, p. 78).
†From Chirwa and Dorward (2013, pp. 122–123).
sometimes break up the bags and sell fertiliser in smaller quantities. Also Holden and Lunduka (2010) note that due to egalitarian and other cultural sentiments in rural Malawian communities, there is evidence of households sharing bags of subsidised fertiliser with their neighbours. Figure 1 shows the percentage of households in our sample participating in the subsidy programme, while Figure 2 shows the amount of subsidised and commercial fertiliser that the average household in our sample acquired.

Throughout the subsidy programme’s implementation, the process of determining who receives coupons has been subject to a number of idiosyncrasies. Coupons, fertiliser and seed are officially allocated to regions and districts based on area cultivated and number of farm households. At the community-level, subsidy programme com-

![Figure 1](image1.png)
**Figure 1.** Percentage of households using fertiliser by year and source

![Figure 2](image2.png)
**Figure 2.** Average kilograms of fertiliser used by households, by year and source

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mittees and village heads are supposed to determine who is eligible. In recent years open community forums have been held in some villages where community members could decide for themselves who the recipients should be. Originally the general programme eligibility criterion was that beneficiaries should be ‘full-time smallholder farmers who cannot afford to purchase one or two bags of fertiliser at prevailing commercial prices as determined by local leaders in their areas’ (Dorward et al., 2008). From about 2008 onward ‘vulnerable households’ were officially supposed to be targeted with priority given to resource-poor households, including disabled, elderly, female and child-headed households. Prior studies have shown that other factors were significantly associated with voucher allocation, such as a household’s relationship to village leaders, length of residence, and social and/or financial standing of the household in the village (Chibwana et al., 2011; Ricker-Gilbert et al., 2011; Kilic et al., 2015). It is also possible that factors which are unobservable to researchers, such as risk aversion or farm management ability may affect how much subsidised fertiliser a household receives. As a result, we need to consider that subsidised fertiliser may be endogeneous in our empirical models.

3. Data and Survey Design

Our data come from four surveys of rural farm households in Malawi. The first wave of data come from the Second Integrated Household Survey (IHS2), a nationally representative survey conducted during the 2002/2003 and 2003/2004 growing seasons. It covers 26 districts and 11,280 households in Malawi. The second wave comes from the 2007 Agricultural Inputs Support Survey (AISS1) conducted after the 2006/2007 growing season. The budget for AISS1 was much smaller than the budget for IHS2. Of the 11,280 households interviewed in IHS2, only 3,485 of them lived in enumeration areas that were re-sampled in 2007. Of these 3,485 households, 2,968 were re-interviewed in 2007, which gives us an attrition rate of 14.8%.

The third wave of data comes from the 2009 Agricultural Inputs Support Survey II (AISS2) conducted after the 2008/2009 growing season. The AISS2 survey had a smaller budget than the AISS1 survey in 2007. Of the 2,968 households first sampled in 2003 and again in 2007, 1,642 of them lived in enumeration areas that were revisited in 2009. Of the 1,642 households in revisited areas, 1,375 were found for re-interview in 2009, which gives us an attrition rate of 16.3% between 2007 and 2009.

The fourth wave of data comes from the 2011 Agricultural Inputs Support Survey IV (AISS4) collected by Wadonda Consulting after the 2010/2011 growing season. The budget was again smaller than in previous rounds and of the 1,375 households that were surveyed in each of the first 3 rounds, 515 of them lived in enumeration areas that were revisited in 2011. Of the 515 households in revisited areas, 462 of them were found for re-interview in 2011, which gives us an attrition rate of 10.3% between 2009 and 2011. Since we are interested in measuring the potential enduring impacts of input subsidies over time, we need to confine our analysis to households interviewed in all four rounds between 2002/2003 and 2010/2011. Therefore we use the balanced panel of 462 households that were surveyed in each of the four survey waves conducted over 8 years. The sample is no longer nationally representative when the

3The first wave of data used in this analysis as part of the IHS2 was collected over two agricultural years, 2002/2003 and 2003/2004.

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AISS4 data are included, but it covers eight districts across all three regions of Malawi, and represents eight major maize growing livelihood zones, and 77% of Malawi’s rural households (Wadonda Consulting, 2011).

Data collection followed standard protocols for interviewing households in multiple waves. Respondent households are identified by region, district, traditional authority and enumeration area. They are also given a unique identifier that is carried across survey rounds. In addition, GPS estimates of the household’s physical location are taken so that the enumerators are able to return to the same spot in subsequent rounds.

In each survey wave, respondents are asked a full set of demographic, production, income and asset questions that pertain to the years in which the survey takes place. Respondents are asked recall questions about the quantities of subsidised and commercial inputs they acquired in the years prior to the survey waves. For example, households are surveyed in 2006/2007 and 2008/2009, and during the 2008/2009 survey a household is asked a recall questions about fertiliser acquisition in 2007/2008, which is a year in which the survey did not occur. In total, this dataset provides us with the ability to track fertiliser use and other activities for the same households over 8 years, which is a longer period of time than any other dataset in Malawi to our knowledge.

4. Conceptual Framework

Our conceptual framework to understand the impact of fertiliser subsidies on commercial fertiliser use and maize production over time is adapted from the job training and job loss literature. In that literature the event or treatment of interest is the year when an individual participates in a job training Ashenfelter (1978) or when the individual loses employment (Jacobson et al., 1993). This framework has been applied to the development literature to measure the impact of adult mortality due to HIV/AIDS on household income and well-being (Beegle, 2005; Chapoto and Jayne, 2008; Kirimi, 2008). Our context is similar to the aforementioned literature because recipients of subsidised fertiliser receive a positive shock in the year when they participate in the subsidy programme. However, the measurement of impacts over time in our study is slightly more complicated than in earlier studies that use the same basic framework. For example, in Malawi the input subsidy programme has occurred over multiple years, so a household can receive the treatment in more than one time period. Although households participating in the subsidy are officially supposed to receive 100 kg of fertiliser at a reduced price, the actual amount of subsidised fertiliser acquired varies from household to household and year to year. Therefore, we have to account for the fact that programme participation occurs over time, and should be modelled as a continuous variable rather than a binary treatment as in Ashenfelter (1978) and Jacobson et al. (1993).

We conceptualise two main ways in which acquiring subsidised fertiliser in the past could affect maize output in the current year. First, there could be a learning effect where households who acquire inorganic fertiliser at a reduced price are able to experiment and learn from using the fertiliser over time. The learning effect could enable farmers to improve their fertiliser management and obtain higher response rates to fertiliser in the future. The other potential benefit from using subsidised fertiliser over time could come from a soil fertility effect, because when inorganic fertiliser is applied
to the soil some of the nitrogen and phosphorus from the input may remain there from one year to the next.

Based on the majority of previous literature, we might expect that acquiring subsidised fertiliser in 1 year leads to the household purchasing less commercial fertiliser that year (Xu et al., 2009; Ricker-Gilbert et al., 2011; Mason and Jayne, 2013; Takashima and Nkonya, 2014). However, if acquiring subsidised fertiliser in 1 year enables the household to learn how to use fertiliser effectively, then it can potentially increase maize production and income in that year. This could in turn induce the household to purchase more fertiliser from commercial sources the following year(s). In addition, by lowering the price of fertiliser, acquiring subsidised fertiliser could help relieve the credit constraint for recipient households and enable them to purchase more fertiliser in the current year and in the future (Liverpool-Tasie, 2014). This wealth effect, and learning effect could possibly justify some crowding in of commercial fertiliser by subsidised fertiliser over time. However, whether or not this happens over time is an empirical question.

The crowding in/crowding out framework recognises that the total quantity of fertiliser obtained by the household, denoted by $F$, consists of two parts: (i) the quantity of subsidised fertiliser $S$ that a household acquires, and (ii) the quantity of commercial fertiliser $C$ that a household purchases, where $F = S + C$. Households that acquire some quantity of $S$ may or may not use it in place of some or all of their commercial purchases. Therefore, as originally shown in Xu et al. (2009) a subsidy programme’s impact on total fertiliser used by the household is a function of the following:

$$\frac{\partial F}{\partial S} = \frac{\partial S}{\partial S} + \frac{\partial C}{\partial S} = 1 + \frac{\partial C}{\partial S}$$

where the derivative $\frac{\partial C}{\partial S}$ represents the degree to which subsidised fertiliser affects commercial fertiliser use. If $\frac{\partial C}{\partial S} \leq 0$, subsidised fertiliser is said to ‘crowd out’ or displace a household’s commercial fertiliser purchases. Conversely, if $\frac{\partial C}{\partial S} \geq 0$ then subsidised fertiliser is said to ‘crowd in’ a household’s commercial fertiliser purchases. In addition, if $\frac{\partial C}{\partial S} = 0$, then subsidised fertiliser has no effect on a household’s commercial fertiliser purchases.

5. Methods

Equation (2) operationalises the model for testing potential crowding in or crowding out of commercial fertiliser by subsidised fertiliser in a longer-run framework. Consider commercial fertiliser purchases by household $i$ at time $t$ as a function of the following factors:

$$C_{it} = \gamma + \beta_0 S_{it} + S_{it-j} \beta_j + X_{it}\zeta + \xi_i\delta + b_i + \mu_{it}$$

where $S_{it}$ is the quantity of subsidised fertiliser that a household acquires at time $t$, and $\beta_0$ is the corresponding parameter. The possible enduring effect of acquiring subsidised fertiliser in multiple previous years on commercial fertiliser demand in the current year is represented by the sum of $S_{it-j}$ where $j = 1, 2, 3$. The statistical significance and magnitude of the coefficient estimates on $\beta_j$ tests the first hypothesis.

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4 Other reasons given for potential crowding in of commercial fertiliser by subsidised fertiliser include economies of scale developing as fertiliser suppliers expand activities into rural areas so that the cost of acquiring inputs is reduced for smallholders (Dorward, 2009).
in this article, about whether or not subsidised fertiliser has a longer-run crowding in or crowding out effect on commercial fertiliser purchases.\footnote{To our knowledge the most recently published area-specific fertiliser application recommenda-
tions are from Benson (1999). The study recommends that Malawian farmers apply between 100 and 250 kg of fertiliser per hectare depending upon local agro-ecology and fertiliser/maize prices. Since the FISP officially provides recipients with 100 kg of fertiliser, and the average area planted to maize is between 0.79 and 0.84 ha in our dataset there would be room for many smallholders to purchase additional commercial fertiliser based on the Benson (1999) recommendations.}

The price of other inputs including agricultural labour wage rate, and maize seed prices are denoted by the vector $X$, with corresponding parameter vector $\zeta$. The commercial price of NPK and urea in year $t$ is also included in $X$. In addition, the price of maize is included in $X$. In Malawi, maize price is lowest just after harvest during the months of May, June and July, but increases steadily after harvest to a high in the months of January, February and March when maize is scarce. Since most rural households in Malawi are net consumers of maize, most of them have run out of their own maize stocks by January, and the next harvest is still several months away (Alwang and Siegel, 1999; Dorward, 2006). Therefore, we use the retail price of maize during the hungry season to proxy for the naïve expectation for the retail maize price that maize deficit households would face as consumers in the coming year.

Household demographics and landholding are also included in $X$. Household landholding enters equation (2) as a quantity because it is regarded as quasi-fixed in this application given the under-developed state of land markets in Malawi. In addition, community factors such as whether or not the community has a farm credit organisation, distance in kilometres to the nearest road, and distance in kilometres to the main district market are included in $X$.

Unexpected, observable shocks, such as death of the household head or spouse over the previous 2 years are denoted by $\xi$. Also included in $\xi$ is a household’s naïve expectation of rainfall in the coming year, proxied by two variables: average cumulative rainfall over the past five growing seasons; and the coefficient of variation (CV) on rainfall over the past five growing seasons, which is included to control for expectations about rainfall risk. The corresponding parameter vector is denoted by $\sigma$.

The error term in equation (2) has two comments. First, $b_t$ represents the time-constant unobserved factors that affect household commercial fertiliser purchases in year $t$. These unobserved factors may include motivation and risk aversion of the household. Second, $\mu_t$ represents the time-varying shocks that affect $C_{it}$. These include factors such as conflicts among family members, or sickness of a family member that we cannot observe in our data (the error terms are given further treatment in the identification strategy section).

5.1. Estimating enduring effects of subsidised fertiliser on maize output

After estimating the possible enduring effects of subsidised fertiliser on commercial fertiliser use we estimate the effect of inorganic fertiliser and other factors on (i) area...
planted to maize, and (ii) maize production using a household-level production function as follows\(^6\):

\[
Y_{it} = a + \delta_0 F_{it} + \frac{F_{it-j}}{C_0} \delta_j + Z_{it} \alpha + e_i + v_{it}
\]

where \(Y\) represents hectares planted to maize in one specification and kilograms of maize produced by the household in another. In equation (3), \(F\) is decomposed into two parts. First, \(F_{it}\) represents the quantity of inorganic fertiliser that a household acquires in the current year, \(t\). The coefficient on the corresponding parameter \(\delta_0\) estimates the contemporaneous effect of an additional kilogram of fertiliser on maize area and maize production in that year. The second vector, \(\frac{F_{it-j}}{C_0}\), represents the quantity of fertiliser that a household acquires in past years, \(t-j\), where \(j = 1, 2, 3\).\(^7\) The sum of the individual coefficient estimates in the vector \(\delta_j\) provides an estimate of fertiliser’s enduring effect on maize production.\(^8\) By running separate models of maize area and maize output we can infer yield impacts from the subsidy programme. This is important because it provides evidence of whether or not increased maize production from subsidised fertiliser comes from increased area planted to maize (potentially at the expense of other crops), or through intensification by increasing yields.\(^9\)

The other covariates in the model estimated in equation (3) are denoted by the vector \(Z\). These variables are expected to impact maize area and maize production on household plots. We include a dummy variable for whether or not a household owns goats or cattle, as a proxy for whether or not they use organic manure. It is a good

\(^6\)Household input use and production on maize plots are aggregated into a household level production function. We do this because fertiliser acquisition in years where no survey occurred are recorded as recall transactions at the household-level. Therefore, there would be no way to differentiate lagged fertiliser effects at the plot-level to measure possible enduring benefits. The average household in our sample had 1.44 maize plots in the first wave (2002/2003) and 2.34 maize plots in 2010/2011. Results obtained when a plot-level analysis is conducted measuring only contemporaneous fertiliser use are similar to the results presented in this article.

\(^7\)We tested numerous lag structures for the fertiliser covariate, such as allowing \(j\) to vary from 1 to 5, and only including \(j = 2, 3\) in the model to account for longer than a 1 year enduring effect. None of these alternative specifications generated statistically significant coefficient estimates on the lagged fertiliser covariates, so we focus on the specification presented in equation (3). Results from the alternative lag structures are available from the authors upon request.

\(^8\)The model is estimated linearly because lowess smoothing functions suggest that the unconditional maize response to fertiliser is linear through the realistic range of the data used in this study. The lowess figures are not shown for space considerations but are available from the authors upon request.

\(^9\)Another reason that the dependent variables are estimated separately as maize area and maize output while the key covariate is total fertiliser use at the household-level is to avoid measurement error leading to attenuation bias in the results. If the dependent variable is maize yield (maize output/maize area) then the fertiliser variable needs to be fertiliser kilograms/maize area. The problem is that the fertiliser/maize area may be incorrectly measured because maize area is self-reported. Therefore, the coefficient on that variable could be biased downward, leading to under-estimates of maize-to-fertiliser response rates as in the classic error-in-variables problem. Attenuation bias is avoided when the model is estimated as maize output regressed on total fertiliser use and other factors. In addition, when the dependent variable is maize area, attenuation bias is unlikely because measurement error in the dependent variable does not cause bias if the measurement error is random (Wooldridge, 2010).
proxy variable for the quality of the soil on the household’s plots (Holden and Lunduka, 2012).\footnote{Additional heterogeneity in soil quality on household plots is controlled by estimating the production function via household-level first difference (FD). Doing so removes soil quality heterogeneity from the model to the extent that it is time constant at the household and plot level. FD estimation is discussed in detail in the identification strategy section.}

In addition we also include a binary variable $=1$ if the household plants improved hybrid or OPV of maize, as opposed to traditional varieties, in year $t$. This variable controls for the effect that improved seeds have on maize production, as households that use improved varieties would be expected to have higher output.\footnote{While improved seed is part of the FISP programme in Malawi, we focus our empirical estimation on fertiliser because it represents the vast majority of programme expenditure. The Malawian government spent US$ 600.47 million acquiring subsidised fertiliser between 2005/2006 and 2010/2011, compared to US$ 55.91 million spent acquiring maize seed over the same period (Chirwa and Dorward, 2013). Explicitly considering subsidised seed would complicate the analysis by introducing the need to deal with an additional potentially endogeneous variable. For these reasons we simply include the binary variable $=1$ if the household plants improved seed. From testing multiple specifications we find no evidence of a statistically significant interaction effect between hybrid seed and fertiliser.} We also include the amount of land in hectares that a household has cultivation rights to as a covariate in $Z$, to control for farm size.

We control for labour and plot management in several ways. First, the average number of weedings on all household maize plots is included as a covariate in $Z$ in the maize production equation.\footnote{Number of weedings is not included as a covariate in the maize area planted equation because weeding occurs after planting.} Empirical evidence from Malawi suggests that the weed *striga* is a major inhibitor of maize production, so more intensive weed management should facilitate higher maize output (Snapp et al., 2014). Second, the number of adult equivalents in the household is also included as a proxy for the amount of labour available. Third, we include a dummy variable $=1$ if the household is headed by a female, which controls for the possibility that female-headed households are more likely to be labour constrained and have lower access to inputs than male-headed households.

Observed shocks such as whether a household head or spouse has died in the past 2 years are also included in $Z$. In the maize production model we also include cumulative rainfall over the growing season to account for rainfall effects. In the maize area planted model, a household’s naïve expectation of rainfall in the coming year is proxied by the same variables as in equation (2): the average cumulative rainfall over the past five growing seasons, and the CV on rainfall over the past five growing seasons.

Similar to equation (2), the error term in equation (3) also has two components. The time constant unobserved factors that affect maize area and maize production are represented by $e_t$, while $v_{it}$ represents the time-varying shocks that affect these outcomes.

### 5.2. Obtaining estimates of subsidised fertiliser’s effect on maize area and maize production

We follow Mason and Smale (2013) to show that subsidised fertiliser affects maize production as follows:
\[ Y_{it} = \alpha + \delta_0 F(S_{it} + C_{it}) + F(S_{it-j} + C_{it-j}) \delta_j + Z_{it} \varepsilon_i + \varepsilon_{it} \] (4)

where the production of \( Y \) is a function of \( F \), which \( F = S + C \) by identity. Production of \( Y \) also depends on other factors, as explained in equation (3). Ignoring the time subscripts for simplicity, from equation (4) we can obtain the implicit effect of subsidised fertiliser, \( S \) on the production of \( Y \) through the following equation:

\[
\frac{\partial Y}{\partial S} = \frac{\partial Y}{\partial F} \times \frac{dF}{dS} = \frac{\partial Y}{\partial F} \times \left( \frac{\partial S}{\partial S} + \frac{\partial C}{\partial S} \right) = \frac{\partial Y}{\partial F} \times \left( 1 + \frac{\partial C}{\partial S} \right) = \delta \times \left( 1 + \frac{\partial C}{\partial S} \right) \] (5)

where the chain rule indicates that \( S \) affects \( Y \) through the effect of \( F \) on \( Y \). This is denoted by the coefficient estimate, \( \delta \) which is multiplied by \( 1 + \) the crowding in/crowding out estimate \( \frac{\partial C}{\partial S} \) obtained when equation (2) is estimated. The coefficient estimates are obtained in Stata, and valid standard errors for this multi-step estimation process are computed via bootstrapping.

5.3. Functional form

The commercial fertiliser demand (crowding in/crowding out) model presented in equation (2) is estimated as a corner solution model using a truncated normal hurdle (THN).\(^{13}\) Commercial fertiliser demand exhibits many observations with a zero value.\(^{14}\) However, for those households who purchase commercial fertiliser, the quantity that they buy varies. Following previous literature, the fertiliser purchase decision is estimated in two steps (Xu et al., 2009; Ricker-Gilbert et al., 2011; Mason and Jayne, 2013; Mason and Smale, 2013). In the first step a household makes the binary decision whether or not to purchase commercial fertiliser. In the second step the household decides how much commercial fertiliser to purchase. Step 1 includes fixed costs such as distance to market and number of fertiliser dealers in a village that must be factored into a household’s participation decision. Step 1 is estimated via a probit, while step 2 uses a truncated normal estimator.\(^{15}\)

6. Identification Strategy

The following sub-sections present our strategy for dealing with the non-random nature of how subsidised fertiliser is distributed to smallholder households in Malawi.

6.1. Controlling for unobserved time-constant heterogeneity

Estimating equations (2) and (3) via Pooled OLS will yield inconsistent coefficient estimates if the time constant error terms denoted by \( b_i \) in equation (2)
and \( e_i \) in equation (3) are correlated with the observed covariates in these models. For linear models such as those estimated in equation (3), potential correlation between \( e_i \) and the other covariates can be controlled by estimating the equations in first difference (FD) form. The FD estimator removes time-constant unobserved factors from the model. These include soil quality, risk aversion and motivation of the farmer. Estimating equation (3) via FD requires the assumption of strict exogeneity where the covariates must be uncorrelated with \( \Delta v_{it} \) in all time periods.\(^{16}\)

First difference regression is not an option when estimating commercial fertiliser demand in equation (2), because the model is non-linear, and there are many cross-sectional observations and few time periods. In this situation, FD is subject to the *incidental parameters* problem (Wooldridge, 2010). Fortunately, the Mundlak-Chamberlain (MC) approach is available to deal with unobserved heterogeneity in this context (Mundlak, 1978; Chamberlain, 1984).\(^{17}\) We implement this approach by including a vector of variables containing the means for household \( i \) of all time-varying covariates. The values of these variables are the same every year for a given household but vary across households (for more on the MC framework see Wooldridge, 2010).

### 6.2. Controlling for correlation between subsidised fertiliser and unobserved time-varying shocks

We also need to consider the fact that estimates of \( S_{it} \) commercial fertiliser purchases, maize area planted and maize production will still be inconsistent if changes in subsidised fertiliser acquisition are correlated with unobserved time-varying shocks.

Given the difficulty in finding an exogenous instrumental variable (IV) and the fact that using an endogeneous IV is likely worse than using no IV, especially if the IV is only weakly correlated with the potentially endogenous explanatory variable (Wooldridge, 2010, p. 108) we deal with any potential left-over endogeneity by including several observable shocks as covariates in the model. These are: (i) average cumulative growing season rainfall over the past 5 years, (ii) coefficient of variation on rainfall over the past 5 years, (iii) current season rainfall (in the maize production model),

\(^{16}\)We run the strict exogeneity test using FD suggested by Wooldridge (2010, p. 325) when \( T > 2 \). The strict exogeneity holds in all models estimated where maize output is the dependent variable, and shown in Table 6 (*P*-value on the level form of all covariates in FD estimation \( >0.10 \)). Strict exogeneity holds in three out of four models estimated where maize area is the dependent variable, and shown in Table 5. The *P*-value on the level form of all covariates is only \( <0.10 \) in the contemporaneous effects model presented in column (1) of Table 5. Given the results of the test, strict exogeneity is reasonably maintained in this application, as it is maintained in seven out of eight main models, and in all of the models with lagged fertiliser use on the RHS.

\(^{17}\)The Mundlak-Chamberlain approach is also referred to as correlated random effects (CRE).
and (iv) a dummy variable = 1 if the household head or spouse died in the past 2 years.\footnote{As a robustness check we tested an alternative specification where kilograms of subsidised fertiliser distributed to the district per rural household in year $t$ is used as an IV for kilograms of subsidised fertiliser that a household acquires in year $t$. The IV is likely to be correlated with subsidised fertiliser acquisition, and since the IV is administratively determined it is less likely to be correlated with unobservable household characteristics that change over time. This IV deals with contemporaneous correlation for the models shown in column (1) of Tables 4–6. We use the control function (CF) approach to test the validity of this IV and whether or not subsidised fertiliser is still endogenous after controlling for unobserved heterogeneity using FD and the MC device. Coefficient estimates on the IV suggest it is a strong instrument in the contemporaneous model of subsidised fertiliser acquisition (see column (1) of the table in Appendix S1a – supplementary materials to this paper available online). From there we derive the residuals from this model, and include them as a covariate in the main models estimated in the article. Results indicate that the residuals are not statistically significant in the commercial fertiliser demand models in Table 4 ($P > 0.10$), or in the maize production model in Table 6 ($P > 0.10$). The residuals are statistically significant in the maize area planted model in Table 5 ($P < 0.05$), but the coefficient estimates on total fertiliser use and subsidised fertiliser use in the maize area models remain the same to four decimal places compared with the main specifications. This suggests that the remaining endogeneity of subsidised fertiliser is not a practical concern in this application. The control function results are available from the authors upon request.}

6.3. Controlling for possible resale of subsidised fertiliser

Households that acquire vouchers for subsidised fertiliser can potentially sell the voucher or sell the fertiliser after they redeem the voucher. Both of these possibilities can affect how we define our treatment and control group, and the estimates of programme impacts. For this reason we compare the main results estimated in equation (3) where fertiliser acquisition in kilograms is the key programme variable of interest, with results where the key programme variable is defined as number of fertiliser vouchers that the household acquires (see Appendix S2a and S2b of the supplementary materials to this paper, available online).

The additional specification using number of fertiliser vouchers acquired by a household as the programme variable of interest provides an estimate of the ‘eligibility’ effect of receiving a voucher to participate in the FISP. The coefficient estimate is the intention to treat (ITT) effect, and the estimates generated by this specification will be unbiased only if (i) everyone who acquires a subsidised fertiliser voucher redeems it for the same amount of fertiliser (recall that 50 kg of fertiliser per voucher is the official amount), and (ii) if people not acquiring a fertiliser voucher do not obtain subsidised fertiliser through any other channel (Imbens and Angrist, 1994; Wooldridge, 2010). This may be a strong assumption given evidence from Malawi indicating that farmers do in fact acquire subsidised fertiliser through resale (Holden and Lunduka, 2010). However, we add this specification as a robustness check.

Table 2 shows that the correlation between the number of vouchers received and kilograms of subsidised fertiliser acquired by households ranged from 0.277 in the 2007/2008 season to 0.953 in the 2010/2011 season. Evidence that the correlation between voucher receipt and subsidised fertiliser acquisition is higher in recent years is consistent with reports that the Malawian government tightened up its voucher
distribution system. This was accomplished by forcing beneficiaries to register with the local extension staff, and tying beneficiaries’ voucher number identification to their voter identification. The results presented in Appendix S2a and S2b (available online) where the treatment variable is number of subsidised fertiliser vouchers acquired are largely consistent with the main results of this article where the treatment variable is kilograms of subsidised fertiliser acquired, lending robustness to our results.

6.4. Subsidised fertiliser applied to crops besides maize

It is possible that households apply subsidised fertiliser to crops other than maize. However, the data suggest that the vast majority of fertiliser in Malawi goes to maize production. First, NPK and urea are the main fertilisers distributed as part of FISP and they are blended for maize cultivation. In the early years of the FISP, tobacco fertiliser called CAN was included, but due to low tobacco prices at that time, some farmers applied tobacco fertiliser to maize. Second, the 2010/2011 data used in this study indicate that of the 2,405 plots managed by households in the survey, 1,726 (72%) were fertilised. Of these 1,726 fertilised plots, 87% of them grew mono-cropped maize or maize intercropped with another crop. Conversely, only 13% of fertilised plots grew mono-cropped tobacco or intercropped tobacco, and <1% of fertilised plots (13 plots total) grew crops other than maize or tobacco. Considering the fact that maize is by far both the most widely grown crop and the most fertilised crop in Malawi, it makes sense to focus our analysis on how FISP impacts maize production.

6.5. Controlling for potential attrition bias

As mentioned in the data section, the rate of attrition across the four waves of the sample is between 10.3% and 16.3% for households living in enumeration areas that were re-surveyed after the first round of data collection. This can potentially lead to biased coefficient estimates caused by households leaving the sample for non-random reasons. If households drop out of the sample for reasons that are time-constant and unobserved, then using a FD estimator removes this problem. However, attrition may still be correlated with time-varying errors. Fortunately we have four waves of data, which allows for a formal test of attrition bias, so the maize production model is estimated via a FD using the attrition bias test proposed in Wooldridge (2010, pp. 837–838).

Results of the test indicate that when all households surveyed in at least two waves are included, there is no statistically significant evidence of attrition bias ($P$-value on the selection indicator >0.10). When we only include households in the enumeration

| Year    | 2005/06 | 2006/07 | 2007/08 | 2008/09 | 2009/10 | 2010/11 | Six-year average |
|---------|---------|---------|---------|---------|---------|---------|-----------------|
| Correlation | 0.572 | 0.515 | 0.277 | 0.860 | 0.599 | 0.953 | 0.629 |

Note: $N = 462$.  

Table 2

Correlation between number of vouchers and kilograms of subsidised fertiliser acquired (by year)
areas sampled in all four waves, then we find marginal evidence of attrition bias (P-value on the selection indicator between 0.05 and 0.10). Therefore, for robustness purposes we estimate the linear maize area planted and maize production models using Inverse Probability Weights (IPW) and compare those results to results where IPW is not used. Unfortunately IPW is not valid in non-linear models. However, observing the differences in linear models when IPW is used and when it is not provides a useful test for how attrition may affect coefficient estimates. Results indicate that the coefficient estimates on the maize area planted and maize production models do not vary in any meaningful way between when IPW are included and when they are not. However to improve robustness, the linear maize production models are estimated with IPW included.

7. Results

Table 3 presents the data means and medians for variables used in this analysis by survey wave. The descriptive statistics are displayed for survey wave 1 collected during 2002/2003 and 2003/2004 (IHS2); wave 2 collected during 2006/2007 (AISS1); wave 3 collected during 2008/2009 (AISS2); and wave 4 collected during 2010/2011 (AISS 4). The descriptive statistics are based on the 462 households for whom we have information in all four survey waves.

In total, Figures 1 and 2 provide *prima facia* evidence that household demand for commercial fertiliser has rebounded to pre-FISP levels in 2003/2004, even as the FISP remains in effect. This would suggest that crowding out of commercial fertiliser may have been reduced in recent years, in contrast to findings from studies that analysed the programme in earlier years (Ricker-Gilbert et al., 2011).

7.1. Crowding out/in of commercial fertiliser by subsidised fertiliser

Table 4 presents the model results from equation (2) for factors affecting commercial fertiliser demand, estimated via double hurdle following the MC approach. The key treatment variables of interest are the kilograms of subsidised fertiliser that a household acquires in year \( t - j \). Column (1) presents the model results when \( j = 0 \), and the coefficient estimates on the subsidised fertiliser variable represent the average partial effect for contemporaneous crowding in or crowding out. This specification is the same as previous studies that estimate crowding in/out of commercial fertiliser by the

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19The IPW technique involves three steps: (i) use probit to measure whether observable factors in one wave affect whether a household is re-interviewed in the next wave; (ii) obtain the predicted probabilities \( (P_{ri}) \) of being re-interviewed in the following wave; (iii) compute the IPW = \( (1/P_{ri}) \) and apply it to all models estimated. For households originally sampled in the first survey (IHS2), the IPW for household \( i \) in the second survey (AISS1) = \( 1/P_{riAISS1} \). The IPW for being interviewed in the third survey (AISS2) = \( 1/(P_{riAISS1} \times P_{riAISS2}) \), while the IPW for being interviewed in the fourth survey (AISS4) = \( 1/(P_{riAISS1} \times P_{riAISS2} \times P_{riAISS4}) \). (For more information on IPW, see Wooldridge (2010)). The IPW is multiplied by the sampling weights to account for the probability that a household is randomly selected for interview from the population in the first survey wave.

20Because we lack data on lagged quantities of fertiliser before the first survey wave, the econometric analysis measuring the enduring effect of fertiliser on maize production in this article uses data from waves 2, 3 and 4 only.

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### Table 3
Descriptive statistics (by survey wave)

| Variables                                                                 | Wave 1 2002/03 & 2003/04 | Wave 2 2006/07 | Wave 3 2008/09 | Wave 4 2010/11 |
|--------------------------------------------------------------------------|--------------------------|----------------|----------------|----------------|
| Maize production in kg                                                  | 605 (327)                | 647 (373)      | 716 (467)      | 818 (525)      |
| Tobacco production in kg                                                | 15 (0)                   | 58 (0)         | 106 (0)        | 97 (0)         |
| Maize area in hectares                                                  | 0.77 (0.61)              | 0.84 (0.61)    | 0.79 (0.61)    | 0.79 (0.61)    |
| Kilograms of commercial fertiliser in year $t$ (unconditional)          | 77 (0.00)                | 18 (0.00)      | 60 (0.00)      | 74 (15)        |
| Kilograms of subsidised fertiliser in year $t$ (unconditional)          | 19 (0.00)                | 76 (50)        | 66 (50)        | 54 (50)        |
| Kilograms of commercial fertiliser in year $t$ (conditional)            | 160 (70)                 | 139 (50)       | 166 (50)       | 131 (60)       |
| Kilograms of subsidised fertiliser in year $t$ (conditional)            | 48 (10)                  | 103 (100)      | 79 (50)        | 70 (50)        |
| Number of subsidised fertiliser vouchers in year $t$                    | 0.40 (0.00)              | 1.28 (1)       | 1.28 (1)       | 1.06 (1)       |
| Household owns cattle or goats*                                          | 0.31                     | 0.29           | 0.35           | 0.35           |
| Average number of weedicings on maize plots                            | 1.97 (2.00)              | 1.67 (2.00)    | 1.74 (2.00)    |                |
| Farm credit in village*†                                                 | 0.33                     | 0.33           | 0.32           | 0.27           |
| Distance to paved road in kilometres†                                    | 16.63 (10.00)            | 17.07 (12.00)  | 16.92 (12.00)  | 16.43 (10.00)  |
| Distance to main district market in kilometres†                          | 39.13 (30.00)            | 39.06 (30.00)  | 39.53 (32.00)  | 38.71 (30.00)  |
| Household plants improved maize seed in year $t$                         | 0.53 (0.58)              | 0.69           | 0.80           |                |
| Household landholding in hectares                                       | 1.07 (0.81)              | 0.98 (0.81)    | 1.12 (0.81)    | 1.17 (0.81)    |
| Age of household head, first wave†                                      | 46.30 (44.00)            | 45.53 (43.00)  | 44.78 (42.00)  | 44.24 (41.00)  |
| Household head attended school, first wave*†                             | 0.73 (1.00)              | 0.73 (1.00)    | 0.73 (1.00)    | 0.85 (1.00)    |
| Household head is female*                                               | 0.27 (0.00)              | 0.30 (0.00)    | 0.32 (0.00)    | 0.31 (0.00)    |
| Adult equivalents in household                                          | 3.68 (3.52)              | 3.95 (3.72)    | 4.16 (3.92)    | 4.17 (4.08)    |
| House or spouse died in past 2 years*                                    | 0.02 (0.00)              | 0.04 (0.00)    | 0.03 (0.00)    | 0.05 (0.00)    |
| Retail maize price, last harvest, kwacha/kilogram, real                  | 23 (23)                  | 26 (27)        | 45 (44)        | 32 (32)        |
| Retail maize price, last hungry season, kwacha/kg, real                  | 46 (49)                  | 56 (55)        | 44 (45)        | 44 (43)        |
| Retail NPK and Urea price, kwacha/kg, real                              | 73 (72)                  | 93 (91)        | 160 (153)      | 97 (100)       |
| Agricultural labour wage rate, kwacha/day, real                          | 173 (194)                | 164 (159)      | 331 (284)      | 243 (214)      |
| Variables                                                                 | Wave 1 2002/03 & 2003/04 | Wave 2 2006/07 | Wave 3 2008/09 | Wave 4 2010/11 |
|--------------------------------------------------------------------------|--------------------------|---------------|---------------|---------------|
| Commercial price of NPK & Urea, kwacha/kg, real                          | Mean 118                | Mean 198      | Mean 40       |
|                                                                          | Median 108              | Median 192    | Median 40     |
| Cumulative rainfall during growing season, in mm                         | Mean 798                | Mean 830      | Mean 770      |
|                                                                          | Median 758              | Median 815    | Median 756    |
| Average growing season rainfall past 5 years, in mm                      | Mean 856                | Mean 821      | Mean 823      |
|                                                                          | Median 856              | Median 816    | Median 820    |
| Coefficient of variation on average growing season rainfall past 5 years, | Mean 0.14               | Mean 0.12     | Mean 0.11     |
|                                                                              | Median 0.14             | Median 0.12   | Median 0.99   |
| IV: kilograms of subsidised fertiliser distributed to                     |                          |               |               |
| district/per rural household (Appendix S1a)                              | Mean 5.40               | Mean 69.35    | Mean 100.29   |
|                                                                          | Median 5.18             | Median 65.40  | Median 102.29 |
|                                                                          |                          |               |               |

Notes: N = 1,848 (462 observations per wave, balanced).
*Indicates that variable is binary (0,1); †Indicates that variable is time-constant. real values are in 2011 Malawi Kwacha; US$ 1.00 = 151.55 Malawi Kwacha during 2010/11 (Chirwa and Dorward, 2013).
## Table 4
Factors affecting commercial fertiliser demand (crowding in/crowding out)

| Covariates | Contemporaneous | Year $t - 1$ | Year $t - 2$ | Year $t - 3$ |
|------------|-----------------|--------------|--------------|--------------|
|            | Coeff. | $P$  | Coeff. | $P$  | Coeff. | $P$  | Coeff. | $P$  |
| Kilograms of subsidised fertiliser acquired in year $t$ | -0.286* (0.059) |          | -0.149 (0.283) |          | -0.158 (0.146) |          | -0.073 (0.456) |          |
| Kilograms of subsidised fertiliser acquired in year $t-1$ | 0.038 (0.245) |          | -0.021 (0.770) |          |          |          |          |          |
| Joint effect: (Kilograms of subsidised fertiliser acquired in year $t-1 + t-2$)§ |          |          | 0.200** (0.041) |          |          |          |          |          |
| Household landholding in hectares | 9.591*** (0.016) |          | 2.371 (0.714) |          | 5.233 (0.452) |          | 4.905 (0.460) |          |
| Household head is female ‡ | -17.629 (0.442) |          | -35.253 (0.257) |          | -34.373 (0.270) |          | -41.201 (0.175) |          |
| Adult equivalents in household | 16.747** (0.026) |          | 6.109 (0.149) |          | 6.300 (0.157) |          | 8.152* (0.068) |          |
| Head or spouse died in past 2 years † | -32.674 (0.416) |          | 41.909 (0.221) |          | 38.960 (0.315) |          | 62.392* (0.060) |          |
| Farm credit in village§ | 0.300 (0.921) |          | -0.382 (0.906) |          | 0.165 (0.959) |          | -0.551 (0.843) |          |
| Distance to paved road in kilometres | -0.110 (0.419) |          | -0.019 (0.887) |          | -0.016 (0.897) |          | -0.022 (0.841) |          |
| Distance to main district market in kilometres¶ | 0.005 (0.945) |          | 0.001 (0.984) |          | -0.004 (0.955) |          | -0.023 (0.666) |          |
| Retail maize price, last hungry season, kwacha/kilogram, real | 3.331* (0.052) |          | -1.228 (0.596) |          | -1.079 (0.652) |          | -1.399 (0.530) |          |
| Agricultural labour wage rate, kwacha/day, real | 0.030 (0.160) |          | 0.010 (0.655) |          | 0.013 (0.652) |          | 0.004 (0.868) |          |
| Commercial price of NPK & urea, kwacha/kilogram, real | 0.259 (0.249) |          | 0.161 (0.392) |          | 0.135 (0.493) |          | 0.281 (0.140) |          |
| Commercial seed price, kwacha/kilogram, real | 0.270** (0.039) |          | 0.269** (0.043) |          | 0.201* (0.072) |          |          |          |
| Average growing season rainfall, past 5 years in mm | -0.246 (0.468) |          | 0.335 (0.509) |          | 0.179 (0.677) |          | -0.340 (0.442) |          |
| Coefficient of variation on average growing season rainfall, past 5 years in mm | 213.043 (0.577) |          | -479.128 (0.343) |          | -423.093 (0.447) |          | -332.853 (0.475) |          |
| $N$ | 1,848 | 1,386 | 1,386 | 1,386 |
| $R^2$ (correlation squared) | 0.537 | 0.619 | 0.624 | 0.810 |

**Notes:** Models estimated via truncated normal hurdle, with Mundlak-Chamberlain device that includes time-averages of all time-varying covariates (coefficient estimates are not shown); coefficient estimates are average partial effects (APE).

***, **, *Denotes that the corresponding coefficients are significant at 1%, 5% and 10% level respectively.

†Indicates that variable is time-constant.

‡Indicates that variable is binary (0,1); 20 observations drop when calculating APE’s in column (2); four observations drop when calculating APE in column (3).

§Indicates that standard errors obtained via bootstrapping at 500 repetitions.
fertiliser subsidy programme. The results indicate that the crowding out rate of the contemporaneous model is \(-0.286\) on average \((P = 0.059)\). As such, an additional 100 kg of subsidised fertiliser will add 71.4 kg of new fertiliser to total fertiliser use. This estimate is in line, but slightly higher than earlier estimates of crowding out by Ricker-Gilbert et al. (2011) at \(-0.22\), Jayne et al. (2013) at \(-0.18\), and Chirwa and Dorward (2013) who give a crowding out range of \(-0.15\) to \(-0.21\).

Columns (2), (3) and (4) of Table 4 present the longer-run crowding in/out effects when subsidised fertiliser is lagged by year \(j\), where \(j = 1, 2\) and 3 respectively. The statistical significance of these coefficients directly test Hypothesis 1. Interestingly, in columns (2) and column (3) the \(t - 1\) lagged effect and the \(t - 1 + t - 2\) joint lagged effect from subsidised fertiliser are not statistically significant. However, in column (4) the cumulative lagged subsidised fertiliser effect from \(t - 1 + t - 2 + t - 3\) suggests that an additional kilogram of subsidised fertiliser acquired in each of the previous 3 years leads the average household to purchase 0.20 kg more commercial fertiliser in the current year \((P = 0.041)\). This is a relatively small magnitude of crowding in but it suggests that the clear contemporaneous crowding out effect from subsidised fertiliser on commercial fertiliser appears to be partly mitigated by some crowding in of commercial fertiliser in the longer term. In doing so it provides some evidence in support of rejecting hypothesis 1, that acquiring subsidized fertiliser has no longer-run effect on a recipient’s commercial fertiliser purchases.

7.2. Impact of subsidised fertiliser on incremental maize area planted and maize production

Table 5 presents the regression results from equation (3) which show the impact of inorganic fertiliser on area planted to maize. Column (1) shows the contemporaneous effect of an additional kilogram of total fertiliser (kilograms of subsidised fertiliser + kilograms of commercial fertiliser) on maize area planted. Columns (2), (3) and (4) show the lagged effects. Estimates across the columns indicate that total fertiliser acquisition does not have a statistically significant effect on the area of maize that a household plants in the current year. Even in the specifications where the \(P\)-values approach statistical significance, the magnitude of the effect is very small. An additional 100 kg of subsidised fertiliser acquired in the current year causes the average household to plant between just 0.02 and 0.03 ha more maize. Considering that the average area planted to maize in any year of the sample is at most 0.84, and average landholding is at most 1.17 ha, acquiring 100 kg of additional fertiliser increases maize area planted by <5%. As seen across the columns in Table 5, the enduring effects of prior fertiliser acquisition on maize area planted in the current year is found to be statistically insignificant.

The bottom of each column in Table 5 presents the indirect effect that subsidised fertiliser has on area planted to maize, after accounting for crowding in/crowding out as shown in equations (4) and (5).\(^{21}\) The subsidised fertiliser coefficient is not statistically significant in the current year or in previous years in any of the models. This indicates that subsidised fertiliser does not have a meaningful enduring or contemporaneous effect on area planted to maize. Our results are somewhat different from

\(^{21}\)Recall from equation (5) that the impact of subsidised fertiliser on maize production is obtained by multiplying \(\delta' (1 + \frac{\partial C}{\partial S})\) or each observation.
Table 5
Factors affecting area planted to maize

| Covariates | Year \( t \) | Year \( t - 1 \) | Year \( t - 2 \) | Year \( t - 3 \) |
|------------|-------------|----------------|----------------|----------------|
| Hectares   | 0.02        | 0.03           | 0.03           | 0.03           |
|\( \times 100 \) | (0.231)     | (0.104)        | (0.178)        | (0.183)        |
| Kilograms of total fertiliser acquired in year \( t \) | 0.002 | (0.760) |          |               |
| Kilograms of total fertiliser acquired in year \( t - 1 \) \( \times 100 \) | 0.01 | (0.795) |          |               |
| Kilograms of total fertiliser acquired in year \( t - 2 \) \( \times 100 \) | 0.002 | (0.322) |          |               |
| Kilograms of total fertiliser acquired in year \( t - 3 \) \( \times 100 \) | 0.003 | (0.326) |          |               |
| Household owns cattle or goats \( \dagger \) | 0.0237 | (0.557) | 0.0480 | (0.315) |
| Household plants improved maize seed in year \( t \) \( \dagger \) | 0.0944*** | (0.007) | 0.0679* | (0.059) |
| Average number of weedings on maize plots | 0.3138*** | (0.001) | 0.2384** | (0.011) |
| Household landholding in hectares | 0.0023 | (0.958) | 0.0150 | (0.767) |
| Household head is female \( \dagger \) | 0.0209 | (0.131) | 0.0316* | (0.065) |
| Adult equivalents in household | -0.0205 | (0.771) | -0.0772 | (0.398) |
| Cumulative current growing season rainfall in mm | 0.2340 | (0.766) | -0.3361 | (0.796) |
| Subsidised fertiliser indirect partial effect \( \ddagger \) | 0.01 | (0.374) | 0.002 | (0.224) |
| Subsidised fertiliser indirect partial effect \( \ddagger \) | 0.003 | (0.875) | 0.003 | (0.276) |
| Subsidised fertiliser indirect partial effect \( \ddagger \) | 0.01 | (0.840) | 0.01 | (0.771) |
| Observations | 1,386 | 924 | 924 | 924 |
|\( R^2 \) | 0.287 | (0.000) | 0.212 | (0.582) |
| Strict exogeneity test \( \S \) | 0.212 | (0.582) | 0.212 | (0.501) |

Notes: Null hypothesis for the test is that strict exogeneity is maintained, and \( R^2 \)-values of the test are shown in parentheses.

***, **, * Denotes that coefficients are significant at 1\%, 5\% and 10\% level, respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown;

\( \dagger \) Indicates that variable is binary (0,1);

\( \ddagger \) Indicates that standard errors obtained via bootstrapping at 500 repetitions;

\( \S \) Strict exogeneity test for fully specified models follows Wooldridge (2010, p. 325).
Chibwana et al. (2011) who find an increase in the share of maize area due to Malawi’s subsidy programme. However, Holden and Lunduka (2010) find that households that acquire subsidised fertiliser plant a smaller total area to maize, suggesting some intensification.

Table 6 presents the regression results for factors affecting incremental maize production, estimated via FD. Column (1) of Table 6 shows the contemporaneous effect of an additional kilogram of total fertiliser (kilograms of subsidised fertiliser + kilograms of commercial fertiliser) on maize production, while columns (2), (3) and (4) show the lagged effects. The statistical significance and magnitude of the estimates on the lagged effects answers Hypothesis 2 about whether or not subsidised fertiliser has an enduring effect on maize production. The coefficient estimates from the contemporaneous model in column (1) indicate that an additional kilogram of fertiliser adds 1.40 kg to maize production on average ($P < 0.01$). After accounting for crowding in/out of commercial fertiliser, we find that the effect of subsidised fertiliser on maize production shows that an additional kilogram of subsidised fertiliser leads to an additional 1.00 kg of maize production on average ($P < 0.01$).

Column (2) of Table 6 presents the specification where fertiliser use from the previous season ($t/C0q$) is added to the model. In this specification, the coefficient estimate on the contemporaneous effect of fertiliser indicates that an additional kilogram of fertiliser boosts maize production by 1.25 kg on average ($P < 0.01$). Subsidised fertiliser’s effect on maize production is 1.07 on average after crowding out is accounted for ($P < 0.01$). The 1 year lagged effect of fertiliser, both total and subsidised are found to be statistically insignificant.

Column (3) presents the results where kilograms of fertiliser is lagged up to 2 years, while column (3) presents results where kilograms of fertiliser is lagged up to 3 years. The results for both models are very similar for contemporaneous impacts, as an additional kilogram of fertiliser is found to increase maize output by 1.55 kg on average in column (3) and by 1.58 kg on average in column (4), (in both models $P < 0.01$). Subsidised fertiliser’s current year effect on maize production is found to be 1.31 in column (3), and 1.46 in column (4) (in both models $P < 0.01$). The 2-year lagged effect of fertiliser is found to be statistically insignificant in column (3), and the 3-year lagged effect is also found to be statistically insignificant in column (4). Therefore, the results from Table 6 provide evidence in favour of Hypothesis 2, that subsidising fertiliser over 1, 2 or 3 previous years has no statistically significant enduring effect on maize production in the current year.

The other main factors that affect maize production have the expected sign. Households that plant improved maize seed (either hybrid or OPV varieties), produce significantly more maize than other households that do not (results are marginally significant in column (1) and approach statistical significance in other columns). Households with more land produce significantly more than other households in the contemporaneous model in column (1). More rainfall during the growing season has a positive effect on maize output with results approaching statistical significance in columns (2) and (3).

8. Conclusions

This study is motivated by the need to better understand the potential enduring or longer-run effects of fertiliser subsidy programmes, which have been reinstated in many African countries as a means to increase fertiliser use and boost food...
### Table 6
Factors affecting maize production

| Covariates                                                                 | Contemporaneous Year $t$ | Year $t-1$ | Year $t-2$ | Year $t-3$ |
|----------------------------------------------------------------------------|--------------------------|------------|------------|------------|
| Kilograms of total fertiliser acquired in year $t$                        | 1.40***                  | 1.25***    | 1.55***    | 1.58***    |
|                                                                             | (0.000)                  | (0.003)    | (0.000)    | (0.001)    |
| Kilograms of total fertiliser acquired in year $t-1$                      | -0.37                    |            |            |            |
|                                                                             | (0.187)                  |            |            |            |
| Kilograms of total fertiliser acquired in year $(t-1 + t-2)$†               | 0.34                     |            |            |            |
|                                                                             | (0.414)                  |            |            |            |
| Kilograms of total fertiliser acquired in year $(t-1 + t-2 + t-3)$‡         | 0.24                     |            |            |            |
|                                                                             | (0.600)                  |            |            |            |
| Household owns cattle or goats †                                         | 62.35                    | 83.90      | 70.74      | 72.03      |
|                                                                             | (0.197)                  | (0.143)    | (0.218)    | (0.213)    |
| Household plants improved maize seed in year $t$†                          | 119.99*                  | 114.78     | 109.00     | 106.06     |
|                                                                             | (0.061)                  | (0.127)    | (0.145)    | (0.164)    |
| Average number of weedings on maize plots                                 | 43.56                    | 45.06      | 44.15      |            |
|                                                                             | (0.233)                  | (0.218)    | (0.222)    |            |
| Household landholding in hectares                                        | 86.43**                  | 58.02      | 60.90      | 60.30      |
|                                                                             | (0.049)                  | (0.272)    | (0.204)    | (0.214)    |
| Household head is female †                                                | -10.93                   | 18.23      | 20.86      | 20.47      |
|                                                                             | (0.844)                  | (0.753)    | (0.723)    | (0.727)    |
| Adult equivalents in household                                            | 20.81                    | 19.72      | 14.17      | 15.03      |
|                                                                             | (0.220)                  | (0.373)    | (0.512)    | (0.491)    |
| Head or spouse died in past 2 years‡                                      | 40.54                    | 110.39     | 115.91     | 118.86     |
|                                                                             | (0.791)                  | (0.422)    | (0.405)    | (0.391)    |
| Cumulative current growing season rainfall in mm                          | 0.13                     | 0.54       | 0.72       | 0.72       |
|                                                                             | (0.725)                  | (0.263)    | (0.116)    | (0.116)    |
| Subsidised fertiliser indirect partial effect‡                             | 1.00***                  | 1.07**     | 1.31***    | 1.46***    |
| Kilograms of subsidised fertiliser acquired in year $t$                    | (0.009)                  | (0.029)    | (0.009)    | (0.007)    |
| Kilograms of subsidised fertiliser acquired in year $t-1$                  | -0.38                    |            |            |            |
|                                                                             | (0.386)                  |            |            |            |
| Kilograms of subsidised fertiliser acquired in year $(t-1 + t-2)$‡         | 0.31                     |            |            |            |
|                                                                             | (0.550)                  |            |            |            |
| Kilograms of subsidised fertiliser acquired in year $(t-1 + t-2 + t-3)$‡   | 0.17                     |            |            |            |
|                                                                             | (0.780)                  |            |            |            |
| Observations                                                              | 1,386                    | 924        | 924        | 924        |
| $R^2$                                                                     | 0.141                    | 0.085      | 0.106      | 0.107      |
| Strict-exogeneity test§                                                    | (0.254)                  | (0.268)    | (0.237)    | (0.254)    |

**Notes:** The null hypothesis for the test is that strict exogeneity is maintained, and $P$-values of the test are shown in parentheses.

***, **, * Denotes that the corresponding coefficients are significant at 1%, 5% and 10% level, respectively; standard errors clustered at household level; all specifications include year dummies and a constant that are not shown; standard errors are clustered at household level.

† Indicates that variable is binary (0,1); number of weeding on maize plots was not asked in first survey so the variable is not included in the model shown in column (1).

‡ Indicates that standard errors obtained via bootstrapping at 500 repetitions.

§ Strict exogeneity test for fully specified models follows Wooldridge (2010, p. 325).
production. Our analytical framework distinguishes between current year and longer-run measures of commercial fertiliser crowding in or crowding out, and maize production effects of input subsidy programmes. Nearly all existing analyses of subsidy programme impacts to date are based on static, or contemporaneous effects. Ultimately the persistence of enduring effects is an empirical question.

We use four waves of panel data from Malawi that track respondents’ fertiliser use patterns for the previous 8 years going back from the 2010/2011 season. We test two main hypotheses surrounding input subsidies that remain largely unanswered to date. The first is that households who acquire subsidised fertiliser in consecutive prior years do not purchase significantly more fertiliser on the commercial market in the future than do other households. This hypothesis is tested using a truncated normal hurdle model to measure how acquiring subsidised fertiliser in the current year and previous years affects commercial fertiliser demand in the current year. Our results reject Hypothesis 1, as the receipt of subsidised fertiliser in multiple prior years significantly increases a household’s commercial fertiliser purchases in the current year. However the magnitude of the effect is small, as an additional kilogram of subsidised fertiliser acquired in each of the previous 3 years causes the household to purchase 0.2 kg more commercial fertiliser in the current year, equivalent to an average annual crowding in rate of 0.067. Consistent with previous studies, we find evidence of statistically significant contemporaneous crowding out of commercial fertiliser from subsidised fertiliser in the same year of −0.286 on average. We find that over the 4-year period in question, the receipt of 100 kg of subsidised fertiliser in each of the prior 3 years results in a cumulative reduction in commercial fertiliser purchases of between 25 and 70 kg.22

The second null hypotheses that households who acquire subsidised fertiliser in consecutive prior years do not produce significantly more maize in the future than do other households, is largely upheld by this analysis. We find very little evidence to support the contention that Malawi’s fertiliser subsidy programme has had meaningful enduring effects on smallholders’ maize production for the population sampled in our survey. These findings call into question whether receiving subsidised fertiliser over time generates major learning effects or soil fertility effects that can lead to higher maize-to-fertiliser response rates for subsidy recipients in the future.

Potential reasons for limited enduring effects of subsidised fertiliser on maize production are (i) because fertiliser has been used extensively in Malawi for decades, hence it is unlikely that many smallholder households are unfamiliar with its use. Thus learning effects about fertiliser from a subsidy programme are likely to be limited. This is in contrast to other areas in the region where fertiliser use has been historically very limited; (ii) the soil fertility effects from subsidised inorganic fertiliser may be small because other soil quality features may pose binding constraints that limit the contribution of nitrogen-based fertilisers to maize production (Snapp et al., 2014). These contextual differences may explain why our results suggest limited enduring impacts from subsidised fertiliser in Malawi, while Carter et al. (2014) find evidence of higher response rates and enduring benefits from subsidised fertiliser in Mozambique, a country where inorganic fertiliser is much less commonly used.

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22 The lower bound estimate assumes a contemporaneous crowding out rate of −0.15, 
(−0.15 × 3 + 0.2) = −0.25; while the upper bound estimate assumes a contemporaneous 
crowding out rate of −0.30, (−0.30 × 3 + 0.2) = −0.70.
While the enduring effects of subsidised fertiliser on maize production appear to be limited, we do find a statistically significant and small contemporaneous effect. Acquiring a kilogram of subsidised fertiliser in a particular year generates an increase in maize production between 1.00 and 1.46 kg in that year after accounting for contemporaneous crowding out of commercial fertiliser. Our use of observational data with panel estimators may raise the question of omitted variable bias affecting our results. Since we might expect that left-over unobservable factors such as higher ability, motivation and intelligence are positively correlated with subsidised and commercial fertiliser acquisition, the fertiliser coefficient estimates derived in this study could be thought of as upper bound estimates of FISP impacts on commercial fertiliser demand and maize production.

Furthermore, our finding of statistically significant, and low contemporaneous returns to inorganic fertiliser is entirely consistent with other empirical studies from Malawi that measure the returns to the FISP in terms of maize output per kilograms of fertiliser (Holden and Lunduka, 2010; Chibwana et al., 2014). Our results suggest that the contemporaneous benefits from subsidised fertiliser on maize production work through intensification (increasing yields), as we find that the subsidy programme has no significant effect on the area planted to maize. This result makes sense as there is little unused fertile land to be brought into cultivation in many parts of Malawi, so any increase in output would have to come at the intensive margin.

Relatively low rates of return from subsidised fertiliser on maize production indicate that there is very little possibility that the benefits of these programmes in terms of maize output can cover their full implementation costs. Low benefit/cost ratios limit programme sustainability, and raise the need for interventions that complement subsidies for inorganic fertiliser. For example, promoting practices such as maize rotation with legumes, conservation agriculture, organic manure and other soil fertility management strategies can help make soils more responsive to inorganic fertiliser over time (Giller and Cadisch, 1995; Snapp et al., 2014). Combining input subsidies with such practices, perhaps by making participation in the FISP conditional on using one or more soil fertility management techniques, could be part of a holistic strategy that would raise the contribution of input subsidy programmes to agricultural productivity and food security in Malawi and elsewhere in sub-Saharan Africa.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1a. Factors affecting subsidised fertiliser acquisition.

Appendix S2a. Factors affecting area planted to maize (subsidy treatment measured as number of fertiliser vouchers acquired).

Appendix S2b. Factors affecting maize production (subsidy treatment measured as number of fertiliser vouchers acquired).

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